SUSTAINABLE AND RESILIENT SYSTEM DEVELOPMENT IN A VUCA-WORLD: AN EMPIRICAL STUDY TO DEVELOP A PROCESS ORIENTATED METHOD OF RISK AND TECHNICAL CHANGE MANAGEMENT IN AUTOMOTIVE INDUSTRY

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ABSTRACT

Revolutionary changes of a VUCA-world are effecting more and more industries. Focusing the automotive industry, this is caused by several new trends in technology or market. This situation is requiring high flexibility and is questioning for sustainability as well as resilience in system development projects.

This publication represents results out of a survey, part of a wider research. The objective is the development of a process orientated method for risk and technical change management. The survey is conducted by participants of transdisciplinary system development in automotive industry. Topics questioned are VUCA, complexity, (re-)action, quality and module interfaces of Generic Systems Engineering. The results demonstrate the participants' experience and demands for sustainable and resilient system development projects. In conclusion, this report provides information on the considering elements to develop a process orientated method for risk and technical change management in automotive industry.

Keywords: Case study, Complexity, Integrated product development, Process modelling, Project management

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1 INTRODUCTION

The automotive sector is in a disruptive change caused by new technologies and upcoming market trends such as e-mobility, autonomous driving or community owned cars. (Muenzel et al., 2017.) Moreover, the automotive domain is affected by VUCA (volatility, uncertainty, complexity, ambiguity) surrounding. This situation restricts taking strategic decisions on past experiences or knowledge. (Lennartsson/Sadia, 2020.) Additionally, in the year 2020, COVID19 consequences impressively proved the rapidness and dimensions of changing economic conditions. (Bundtzen/Hinrichs, 2021.) The setting just described causes the challenge to acquire adequate flexible management, organisation, innovative leadership, and being able to adapt the business to the VUCA world. (Meri M., 2021) Moreover, this dramatically shows up the importance of integrating engineering change management, steering complex and dynamic changes (product or value chain process related), especially for complex engineered products in order to ensure efficiency and profitability. (Storbjerg et al., 2019., p. 150)

That is why sophisticated transdisciplinary development projects demand for flexible process orientated methods, constituting sustainable and resilient project work.

This paper considers state of the art literature about the segments VUCA, technical change management, Systems Engineering (SE) and project management (PM). The literature base is used for a survey exploring optimisation potential for steering and managing complex development projects in a VUCA world. The investigation is accomplished for electronic control units (ECUs) in autonomous mobility systems, involving interdisciplinary participants. The empirical study underlines and confirms the literature result: Significant VUCA- and complexity-driven influences or rather changes in system development are existing. This confirmation is the baseline focussing on a sustainable as well as resilient risk and technical change management in automotive specific projects.

2 STATE OF THE ART

The system development of the 21st century is influenced by increasing volatility, uncertainty, complexity and ambiguity (VUCA). VUCA is an acronym established by American military. (Mack/Khare, 2016., p. 5, Fridgeirsson et al., 2021., p. 41) It is a strategic method investigating into levels of prediction and levels of information quality / content of events or situations. (Bennett/ Lemoine, 2014.) That is why this paper especially focuses the optimisation potentials of steering and managing projects using dedicated and helpful results out of an empiric study.

Technical change management is a formal discipline, allowing complex products to be designed and produced concurrently by several involved parties, along the product life cycle. (Clarkson et al., 2005., p. 265). In a system development, a product / engineering change (EC) is an alteration to already released parts, drawings or software, which can be of any scale or type involving an arbitrary number of persons and can demand various timing for realisation. (Jarratt et al., 2003.) Summarizing, ECs are modifications to a product's design, documentation, or method of manufacturing, rising from several reasons like design enhancements, manufacturing process evolutions, material advancements or documentation errors. (Antonaras/Deasley, 1999.) Reasons for technical changes can originate from internal influences, or external sources. (PMBOK, 2021., p. 58) The investigation concentrates on technical changes of inner factors like expansions / optimisations for product functionalities, capabilities, and general product optimisation. (PMBOK, 2021., p. 59) The considered external factors are addressed to market, law, regulation and stakeholders. (PMBOK, 2021., p. 59)

Enhancing management of technical changes, literature more often recommends agile methods. Albeit originally agile methods like Agile Manifesto (Beck et al., 2001.) or SCRUM (Schwaber/Sutherland, 2020.) are developed for software projects. (Beck et al., 2001., Hohl et al., 2018.) In addition, there are no scientific agile approaches available for transdisciplinary system projects. (Conboy/Fitzgerald, 2004.)

SE is '… a transdisciplinary and integrative approach to enable the successful realisation, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods.' (INCOSE, 2022.) In other words, SE develops frameworks and methodologies for designing, acquiring and fielding multi-purpose systems. (Tolk et al., 2011., p. 8) Moreover, it is the sum of applying systems thinking and best practices of engineering, realizing systems successful. (Bajzek et al., 2021., p. 165) Basically, SE is influenced by System Thinking and its laws (Chechile, 2021., p. 12) which enables the observation and illustration of system models

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avoiding neglection or disregarding of information. (Haberfellner et al., 2019., p. 23) Primary objective of SE is the definition and characterisation of complex systems. (Dekkers, 2017., p. 270)
PM is the application of knowledge, skills, tools and techniques achieving project requirements, using a broad range of approaches. (PMBOK, 2021., p. 4) Moreover, PM simplifies and encourages direct, interdisciplinary cooperation. (Kuster et al., 2015., p. 4) The systematic approach and usage of an integrated project management are crucial success factors achieving the common project objective. (Kuster et al., 2015., p. 4 13)
Currently there is no existing approach identified combining the range of topics (SE, PM and VUCA) into a comprehensive method for product development - from start to release of product development. Integrating VUCA-strategies into a pro-active and acting project management supports target-orientated realisation, despite continual new challenges.

3 RESEARCH APPROACH

3.1 Research design

The research is based on latest state of the art and scientific knowledge, using the Information Systems Research Framework (ISRF), and Design Science Research Approach by (Hevner et al., 2004.), as well as the Design Science Sequence (Awareness of problem, suggestion, development, evaluation, conclusion) according to (Kuechler/Vaishnavi, 2008.). Furthermore, empirical results out of a survey in automotive industry are under consideration defining a process orientated proving model.

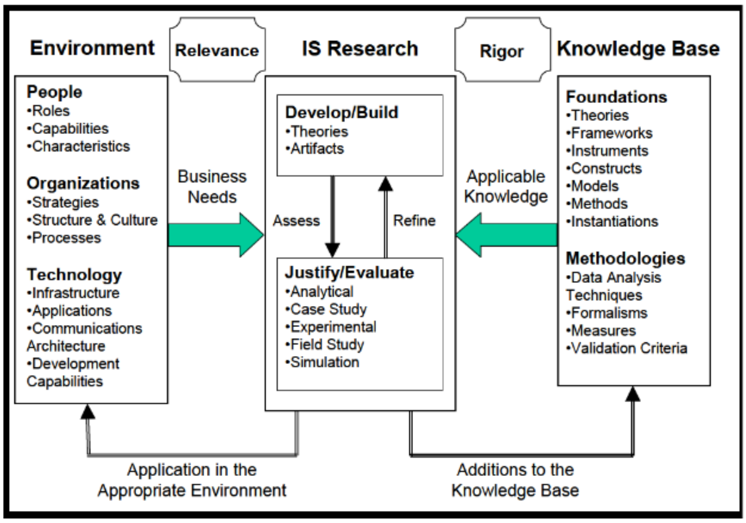

Figure 1: ISRF (Hevner et al., 2004.)

Figure 1 presents the ISRF which is a conceptual framework for comprehension, implementation and evaluation of behavioural science and design science paradigms (Hevner et al., 2004.), serving as a scientific base and evaluation model, which is iterative renewable. ISRF consists of three areas: environment, artifacts and knowledge. These areas are linked by relevance cycle (continuous check of environmental needs and research-relevance), rigor cycle (check of existing scientific literature of identified problem formulation), and design cycle (artefact out of relevance and rigor cycle, evaluating solution and enables feedback and reporting of results). The environment contains information on system/system boundaries/parameters (employees, organisation, technologies) defining needs/challenges of business. (Hevner et al., 2004.)

3.2 Data collection

3.2.1 Literature

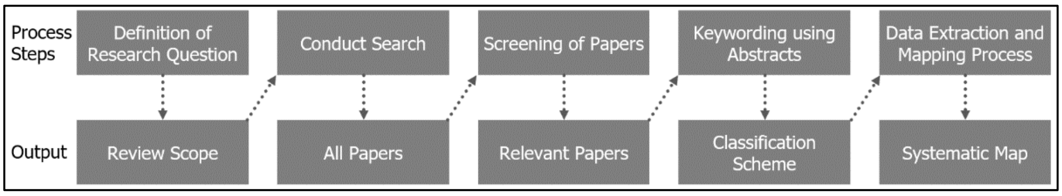

Figure 2: Systematic literature analysis according (Petersen et al., 208., p. 2)

The used literature is selected through research process by (Petersen et al., 2008.). This systematic process enables a wide science base and identification of gaps in observed topics. First, establishing the base for literature research (conduct search). Screening of researched papers will reveal relevant ones, which will subsequently receive keywords, in order to build a classification scheme. Finally, the data will be extracted and mapped, receiving a complete

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literature overview. (Petersen et al., 2008., p. 2) The whole process is illustrated in Figure 2. The Following data bases were selected for the mapping study: Springer Professional, Hanser elibrary, Wiley Online Library, ResearchGate and Google Scholar. The researched literature period spans from 2001 until today. This is based on publication of 'Agile Manifesto' in 2001, the increase of VUCA factors since the economic crises in 2008 and further forced by the COVID-pandemic. The literature is used as base knowledge, creating the survey's questions to identify actual demands in system development projects. Counter-checking existing practical challenges with potential scientific approaches and strategies supports the optimisation of projects and business.

3.2.2 Survey

The survey is conducted online, anonymously, voluntarily and is based on participants' experiences in automotive business. It includes five categories: VUCA (e.g. Which factor is confronting you most / is most challenging?), complexity (e.g. What are the prevailing complexity characteristics in your projects?), (re-)action (e.g. Which (re-)actions can you recognise from system towards your discipline?), quality (e.g. Which is most important measurement ensuring quality requirements?) and module interfaces of Generic Systems Engineering (GSE) (e.g. Which requirements do you identify for optimising risk management out of the perspective of your discipline?). The study investigates prevailing VUCA factors to analyse existing handling deficits for system development of ECUs in the automotive industry, explicitly for autonomous mobility systems. Furthermore, this study is used to evaluate optimisation potentials for risk and technical change management, in relation to complex transdisciplinary systems inside the VUCA world. The quality aspects support the empowerment of product innovation and quality. The section of GSE serves to ensure optimised model interfaces according to defined approach by (Winzer, 2016.). The survey structure enables a precise analysis per category, creating a target-oriented process model. All questions are based on latest state of science of each category. The questions are asked and answered in German language. Aggregated results are ensuring anonymity and are input parameters to develop a model based, iterative concept to steer technical changes in transdisciplinary, complex development projects including consideration of VUCA factors. Definitions of specific topics, like VUCA and GSE, have been shared prior initiating the survey, ensuring comprehension and accomplishment.
Furthermore, the deep analysis, reflection and optimisation is based on precising the field of management disciplines: A successful requirement elicitation of risks and technical change management during the project's realisation phase. Involved system disciplines are Hardware, Mechanics, Software, Cyber Security, System Test and Quality. Each participant is working in one of the defined development disciplines. These participants represent the users and sub-disciplines of analysed system development. This approach serves as an optimal source evaluating status quo, as well as identifying requirements for the developing meta / process model. The participation quota is 90 percent (18/20 persons).

3.2.3 Research questions

This paper, or rather the research questions (RQ) concentrate onto the survey's results. According to participants' feedback on the presence of VUCA, and high degree of complexity in current system development, these topics are prioritised in focus. The focussed topics are the first potential factors optimising risk and technical change management for system development projects.
Enabling a consistent and resilient system development by a process model is the targeted investigation. This target should be achieved for system development projects, while operating with changes influencing the system development, as well as managing most recent (VUCA) risks. This is why the following research questions support the design for developing a process model for complex system development projects:
RQ1: Which VUCA factors are most likely influencing the system development?
Identifying most critical and present VUCA factors is the baseline for establishing prioritised measurements and actions for demanded categories. The research for appropriate and prioritised measurements and actions can be initiated.
RQ2: Which project phase (definition, planning, realisation, closure) is most likely influenced by VUCA?
Moreover, recognising most likely influenced project phase is another source for enhancing existing processes with an optimised process approach.

RQ3: Which target dimension (scope, cost, time, quality) of your project is most critical due to VUCA factors?
Identifying most critical target dimension enables improvement of process and work instruction in existing risk and technical change management. This result does not only indicate the limits of existing approaches, also the participants' feedback supports the improvement of existing state of the art in developing projects.
RQ4: Which complexity factors are prevailing system development projects?
Identifying the complexity factors enables guidance to generalise the factor identification and establishing a guideline how to handle complexity factors to minimize or avoid their impacts.
RQ5: Which tools are preferred for complexity accomplishment in current development projects?
Identified preferred tools can be checked for effectiveness. Furthermore, the identification presents an acceptance level by users. This supports the improvement to accomplish complexity by all users.

4 FINDINGS

4.1 Research Question 1 - VUCA relations to SE

Based on the literature, several challenges are identified to be caused by VUCA. These challenges can be categorized into (1) known factors (e.g., material shortages, resource shortages, cost increases, …) (Alam/Guehl, 2022., VIII, p. 6) and (2) unknown factors (e.g., property crises, economic crises, pandemics, …) (Nangia/Mohsin, 2020., Abidi/Joshi, 2015.), as well as into the subjects of (3) technologically driven (Krishnan/Bhattacharya, 2002., Schmidt et al., 2016.), or (4) economically driven (Bennett, 2003., Schmidt et al., 2016.) global competition. Subsequently the project and business success are risked by uncertainty (Abidi/Joshi, 2015.).

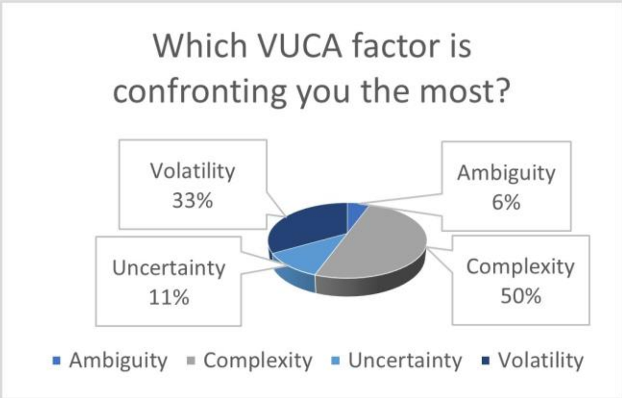

Figure 3: Results of most confronting VUCA factors

The survey confirms the existence of VUCA factors in daily business with 100 percent. The results about the occurrence are fluctuating between permanent, very often, and often. These results are indicating a clear demand for action. A concise summary about the biggest challenges dealing with VUCA are the impacts of the factor complexity and volatility. Those characteristics are most recent and express the major challenges in system development projects, expressed in detail in Figure 3 and in Figure 4: Most confronting VUCA factors are complexity (50 percent), volatility (33 percent), uncertainty (11 percent) and ambiguity (6 percent). Greatest challenges caused by VUCA factors are driven by complexity and volatility (each 39 percent), followed by ambiguity and uncertainty (each 11 percent).

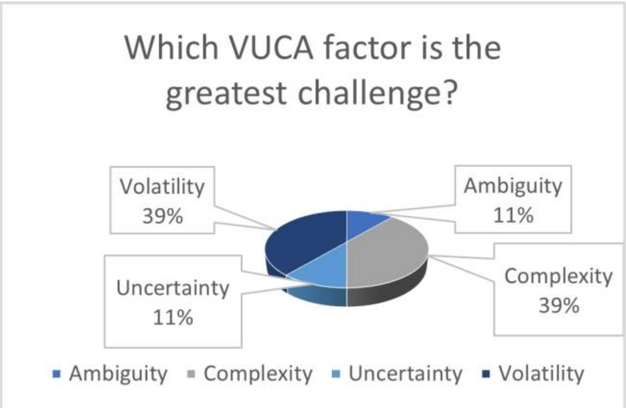

Figure 4: Result of greatest challenge by VUCA factor

4.2 Research Question 2 - VUCA relations to PM

Observing the impacts at assigned project phases (definition, planning, realisation, closure), impacts are already significant during definition phase (22 percent). Slightly higher results are achieved for the realisation phase (28 percent) and no VUCA-impacts during closure phase. This result is visualised in Figure 5. Indeed, the planning phase (50 percent) is the most affected project phase by VUCA-factors.

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Another survey question already focuses whether there is demand for actions, dealing with VUCA factors as well as asking what kind of support is requested. The survey results show up massive demand handling VUCA factors in risk management (13 of 18 participants) and technical change management (15 of 18 participants). More precise, specific measurements and strategies are requested. Furthermore, a missing experience in handling VUCA factors has been identified.

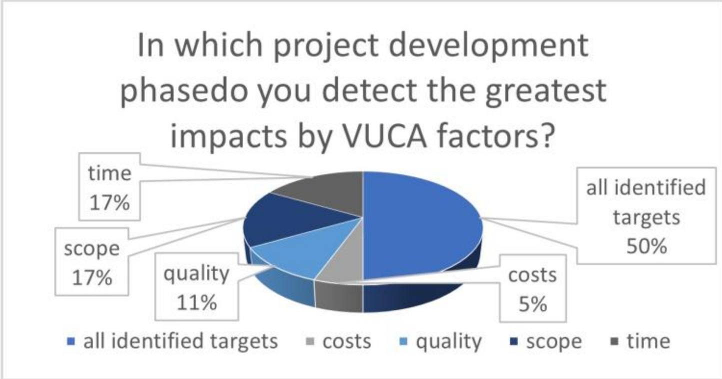

Figure 5: Result of impacted project phases

4.3 Research Question 3 - VUCA influenced critical target dimension

Focusing the project target dimensions (scope, cost, time, quality) for system developments, the participants' feedback is distinctive, see Figure 6. The participants acknowledge all project target dimensions (50 percent) of their recent project are preserved critically due to VUCA influences. In regards of single dimension, following order of criticality is identified: scope (17 percent), time (17 percent), quality (11 percent) and costs (5 percent).

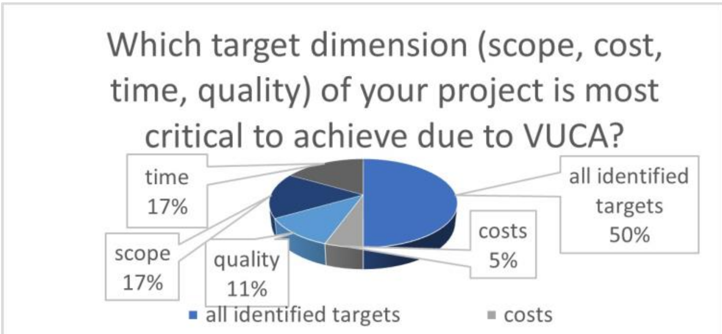

Figure 6: Results of target dimension criticality

Widening the perspective and concentrating on product quality and power of innovation, the study figures out that impacts of VUCA are rated on average as 4= 'strong' (out of rating categories:1 = 'very low', 2 = 'low', 3 = 'neutral', 4 = 'strong', 5= 'very strong'). This rating is underlined by various reasons which are aggregated as:

- VUCA prolongs the developmental period. Due to defined project time the product quality is suffering, which might cause a project stop.
- Missing or outdated requirements causing deviations or incontrollable complexity.
- VUCA aggravates planning, focussing and continuity (e.g., increasing maturity, testing) while targeting product quality and innovation power.
- VUCA demands short-term (re-)actions which can lead to quality impacts due to unachievable targeted quality measurements. In addition, inconsiderate actions are forced in case of reaction to occurrence of parallel unforeseen situations.
- Focus regarding VUCA factors must be pre-defined by each company/industry. What is the preferred focus: market entry (innovation power, i.e. TESLA delivers products requiring bug fixes in operation) or quality? A'VUCA market' forces its participants to bring up innovation power otherwise they cannot persist.
- Mastering VUCA is an essential condition managing and steering product development.

4.4 Research Question 4 - Prevailing complexity factors in SE projects

Evaluating the level of complexity in current system development projects is resulting in an averaged severity of 4.56 out of maximum 5 points (1 = 'very low', 5 = 'very high'). A more intense analysis is based on the complexity characteristics: transparency, connectivity of requirements/variables, vague targets, multiple/succeeding targets, (own) dynamics, and quantity of variables. (Clarkson et al., 2005., p. 176 ff., Kreimeyer/Lindemann, 2011., p. 41 ff., Lindemann et al., 2009., p. 29, Doerner, 2008., p. 286, Funke, 2012., PMI, 2014., p. 11 ff.) Table 1 presents the emergence of each complexity attribute, ranked by selected categories: 'very low', 'low', 'neutral', 'high' and 'very high'. The most appearing

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characteristic classification is 'high' (43 points), followed by 'very high' (32 points) and 'neutral' (27 points).

Table 1: Emergence of complexity attributes

Character-istics / Emergence	Lack of transpar-ency	Connectivity of requirements/ variables	vague targets	multiple/ sequential targets	(Own) Dynamics	Quantity of variables	Sum
Very high	3	5	7	9	4	4	32
high	8	8	7	7	7	6	43
neutral	6	4	3	1	6	7	27
low	1	0	1	1	1	1	5
Very low	0	1	0	0	0	0	1
Sum	18	18	18	18	18	18	108

- Ranking category 'very high' is initiated by multiple/sequential targets, followed by vague targets and connectivity of requirements/variables. (Own) dynamics and quantity of variables are on same level, ending up with the attribute of lack of transparency.
- Category 'high' differs only slightly from 'very high'. It starts with same level of lack of transparency and connectivity of requirements/variables, followed by equal grading for vague targets, multiple/sequential targets and (own) dynamics, ended up by quantity of variables.
- 'Neutral' characteristics are attributed by the quantity of variables, the equalling selection of lack of transparency and (own) dynamics, followed by connectivity of requirements/variables, vague targets and closes up with multiple targets.
- Rating categories 'low' and 'very low' are not further analysed due to minor ratings, nevertheless they can be reviewed in Table 1.

4.5 Research Question 5 - preferred tools for complexity accomplishment

The literature analysis presents complexity attributes which need to be handled or even avoided. Now tools for complexity accomplishment need to be identified. The survey evaluates following tooling: higher information density, system decomposition and analysis, model design/simulation, system value analysis as well as target definition and balancing.
In the next step all identified recommended tooling is analysed in the empirical study, receiving users' feedback about acceptance and effectiveness.
The participants prefer the following tool sequencing for complexity mastering: Target definition and balancing, system decomposition and analysis, followed by higher information density. Model design/simulation and system value analysis were only of interest to a few. Table 2 contains evaluation results in perspective of tool selection priorities, or rather the acceptance by users.

Table 2: Ranking of complexity tooling

Tooling / Priority	Higher information density	System decomposition and analysis	Model design/simulation	system value analysis	Target definition and balancing	Sum
Prio 1	3	5	1	0	10	19
Prio 2	10	4	1	4	3	22
Prio 3	1	6	6	5	1	19
Prio 4	1	1	6	4	2	14
Prio 5	3	2	4	5	2	16
Sum	18	18	18	18	18	90

Table 2 reflects results per priority. Target definition and balancing are highest selected tools of 'priority 1'. 'Priority 2' is demanding a higher information density, followed by system decomposition and analysis, as well as a system value analysis. While 'priority 3' focusses on the system decomposition and

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analysis, the model design/simulation as well as system worth analysis. 'Priority 4', determined by model design/simulation, system worth analysis and higher information density. 'Priority 5' is led by system value analysis and model design/simulation, which reflect sequence of tool selection.

5 DISCUSSION, CONLUSION AND FUTURE WORK

This publication presents challenges for the risk and technical change management in automotive industry, designated for system developments of ECUs. Challenges are identified in a literature review and are investigated through an empirical study. A major confirmation of the study is the significant prevalence of VUCA, mainly the VUCA factors complexity and volatility. Furthermore, participants confirm the project planning phase along with the project target dimensions of scope and time are most influenced by VUCA factors. In addition, dependencies of VUCA towards innovation power and product quality must be considered. The dependencies need to be carefully managed assuring project as well as business success.

The particular topic focus provides information on identification and management of complexity. Further, an establishment of guidelines accomplishing complexity can be initiated considering preferred and effective tools with high acceptance by users.

Advantages out of the empiric study are feedback on existing challenges as well as demand enhancing present processes and tools. These identified challenges and demands are the base for a particular process model in automotive industry:

- VUCA relations to SE: Complexity is major problem
- VUCA relations to PM: Planning phase
- VUCA influenced critical target dimensions: Scope and time
- Prevailing complexity factor (very high emergent): Multiple and vague targets
- Preferred tooling for complexity accomplishment: Target definition and balancing

The findings in chapter 4 lead to certain questions to analyse and understand nowadays situation more precise:

- **RQ1**: Why do the participants see handling deficits? Does not the existing process already consider VUCA-impacts like '(un)known', 'technical' or 'economical' topics. This causes the question: What is the real gap in risk and technical change management perceived by the participants?
- **RQ2**: Is planning still that important or are nowadays projects realised with constant re-plannings?
- **RQ3**: Is there a methodology change? Is the standardised approach of defining, planning, realising, and closing projects still valid? Or is there a general change towards a flexible and iterative project set-up and project re-organisation/-planning serving customer demands? Could this be improved by minor customer acceptance/release milestones than by large-scaled project targets? Are the minor milestones not even a part of innovation power and quality assurance? Is mastering this mystery possible by cutting the big scenario into small portions (work packages) and iterative circles?
- **RQ4** indicates a high emergence of vague and multiple/sequential targets. Is it a deficit by management or a VUCA-situation? Does a clear and fixed guidance by customer or management already solve a big portion of existing complexity characteristics?
- **RQ5**: The ranking surprises with demanding higher information density: Is higher information density a blessing or curse?

For future work, we aim transferring obtained results and guiding questions to create an automotive specific proving model. The model will consider identified issues influencing system development projects as well as effective measurements for avoidance or management of impacts. Target is the development of an iterative process model, steering and managing risks and technical changes in transdisciplinary complex development projects influenced by VUCA factors. Figure 7 is a first draft showing up the interferences caused by changes in all levels:

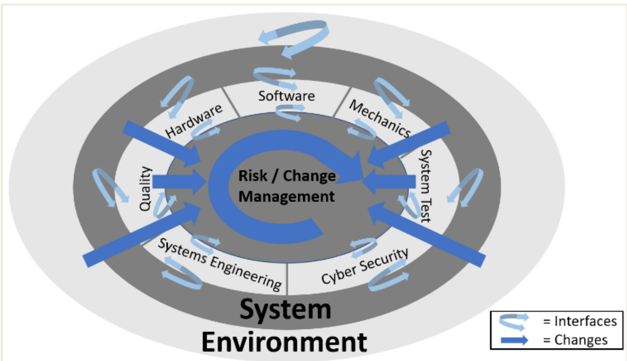

Figure 7: Iterative process model

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environment, system and system-disciplines. Iterative interactions via system-disciplines and level interfaces needs to be established for a powerful risk and technical change management. In the next step, the process model will be evaluated in dedicated system development projects for ECUs in autonomous mobility system's segment.

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