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Aligning Requirements with Verification & Validation for Software Engineering Process
Improvement

Durga Poudel

College of Computer and Information Sciences

Regis University

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Thesis Advisor: Dr. Mohammad Abu-Matar

Abstract

Coordination between different phases of the Software Development Life Cycle is critical for success of any development projects. Particularly, effective alignment of requirements with verification and validation process helps to provide building blocks to the process that produce a quality product that meets customer expectations. Modern software development process strives to be more responsive by promoting tight collaboration between different people and teams. It is therefore, more important than ever to realize the importance of coordinated functioning requirements and testing phases. Lack of alignment between different phases can lead to wasted efforts in building right software that meets customer needs.

This thesis highlights the current challenges in requirements engineering and testing processes and recommends measures for better alignment of requirements analysis with verification and validation. The paper underscores the findings of research that involved different data sources from the industry and academia. The research is derived from the study of data collected from 9 interviews of active software development practitioners, 7 white papers published by large scale software technology organizations, and 7 academic journals available on the research topic. Ambiguous and incomplete requirements were found to be the major problems in software development projects while effective collaboration and cooperation between teams were found to be the most important aspects in improving alignment between requirements and testing. The findings provide insights to common challenges in establishing strong link between different phases of software development process and how these challenges can be overcome for process improvement.

Keywords: Software engineering, requirements engineering, validation and verification, testing, alignment, SDLC, process improvement.

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Introduction

Software Engineering is a successful coordination of different activities in a deliberate, structured and methodological process of building a software system. Different phases of the Software Engineering model are team efforts that provide building blocks to the process. Hence, coordination between these units is essential to produce a quality product. The requirements are the starting point for developing any system, so they are critical for the success of any development projects (Medeiros, Alves, Vasconcelos & Wanderly, 2015). Effective requirements engineering guides development projects towards building software that meets customer agreements. When developing software, coordination between different organizational units is essential in order to develop a good quality product, on time, within budget (Sabaliauskaite et al. 2010). Modern software development strives to be more responsive to changes by integrating requirements, design implementation and testing process (Bjarnason, Unterkalmsteiner, Borg & Engstrom, 2016). In addition, requirements tend to change overtime, and in many cases the requirements specifications are not updated during development of the product making it hard to use them as solid base (Sabaliauskaite et al., 2010) for later phases of the development cycle. Misunderstanding between analyst and the customer, and ambiguity in the documentation can also lead to delays in production and problems with the overall functionality of the product. It is therefore important to set in motion steps that will minimize errors, detect and correct them as soon as possible (Maalem, 2016). This thesis investigates two important phases of the software development process that benefit particularly from coordinated functioning (Unterkalmsteiner et al., 2013): *requirements engineering* and *testing (verification and validation)*. These are two essential steps common to all software development projects, regardless of size or complexity (Royce, 1987). Requirements Engineering (RE) is a process that

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specifies expectations on a software system and verification and Validation should ensure these expectations are met (Barmi et al., 2011). Requirements are used to communicate with stakeholders to drive design and testing (Bjarnason et al., 2016). From the project management perspective, linking requirements and testing would help to reach a more accurate testing plan, that would improve project and estimation (Barmi et al., 2011) and serve as a reference for project managers and in the evolution of the system (Bjarnason et al., 2016). Hence, due to the central role of Requirements Engineering in coordinating different phases of software development, a significant number of studies have been done on improving requirement documentations and testing activities with varying degrees of formality.

The purpose of this study is to analyze the detailed description and understanding of the problems of requirements and verification alignment and develop prescriptive solutions for process improvement. A strong link between requirements engineering and testing would help to reach more accurate testing plan, which in turn would improve the outcome of the software development process. This research is, thus, a part of a typical action research effort between practice and research, where problem understanding is informed by practice, while this understanding also changes the attitude toward the problem in practice (Runeson, Host, Rainer, & Regnell, 2012).

Background

The alignment of Requirements Engineering and Validation and Verification plays a vital role in quality assurance process that aims to ensure that software product is built up to the specification and meets stakeholders' needs. Weak coordination of requirements with development and testing tasks can lead to inefficient development, delays and problems with the

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functionality and the quality of the software (Bjarnason et al., 2013). In real-world scenarios, if requirements changes are agreed without involving testers and without properly documenting and communicating the changes, the changes will likely go under-tested, leading to a higher risk of producing software that does not meet the customer requirements. In small systems, with just a few requirements it could still be possible to handle changes, but it gets extremely hard in complex systems. A lack of alignment between requirements and testing cannot only lead to wasted efforts but also to defective software (Unterkalmsteiner, Gorschek, Feld & Klotins, 2015). Hence, there is a need for a mechanism to align and manage coordination between the requirements and testing processes (Sabaliauskaite et al., 2010). Therefore, requirement engineering and software testing that includes verification and validation are crucial aspects of process to deliver right product that is built correctly to the stakeholders' specifications and needs.

Rationale

This study was undertaken to understand current challenges in requirements engineering as well as testing activities during software development projects in different industries. The research was carried out primarily to identify common problems that affect alignment of requirements engineering and testing and provide recommendations for the improvement measures, by taking into accounts the data from personal interviews, industry white papers, and academic literature reviews in this discipline.

Objectives

The objective of this research is to understand the current challenges in requirements engineering and testing processes and identify measures for alignment of requirements analysis with testing (verification and validation) for software development process improvement.

Related Work

With the ever-growing market for high quality software, there have been many studies investigating different fields in Software Engineering. Requirements Engineering and testing are not new topics as well. Requirements Engineering and software testing have mainly been explored with a focus on one or the other, though there are some studies investigating the alignments between the two (Bjarnason et al., 2013).

Barmi et al. (2011) presents a systematic mapping of the alignment of specification and testing of functional or non-functional requirements in order to identify useful approaches and need for future research. The study found that most studies in this area focused on Model-based approaches, and traceability studies (Barmi et al., 2011). Requirement traceability ensures that all requirements defined for a system are tested in the test protocol. Although there is a need to establish a strong link between requirements and testing, the study finds a significant gap between these areas (Barmi et al., 2011). In particular, the current approaches to alignment have paid little attention to non-functional, quality requirements even though they play a critical role in achieving successful software systems (Barmi et al., 2011). And hence, Barmi et al. (2011) concludes the need and high potential for further research in establishing methods and processes to aligning requirements and testing to improve efficiency of the process.

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The study by Sabaliauskaite et al. (2010) includes a range of challenges faced by the studied organizations in alignment of requirements and verification. The results of the study summarize numerous challenges related to requirement processes that affect alignment with testing (Sabaliauskaite et al., 2010). As per authors, there are numerous challenges faced such as organization and process related issues; people related issues; software tools; requirements process related issues; testing process related issues; change management issues; traceability issues; and measurability issues in measuring the alignment metrics (Sabaliauskaite et al., 2010). Frequent process change is one of the greatest challenges that negatively influence alignment, as it takes time for people to learn and use new process and tool, while sometimes, people are reluctant to use a process knowing it will change soon (Sabaliauskaite et al., 2010). The study presents the most salient challenges in managing large scale of requirements and test information, and hence can inspire further research in alignment improvement efforts.

A multi-case study of agile requirements engineering by Bjarnason et al. (2016) investigates the agile practices of using test cases as requirements to understand how test cases can support main requirements activities, validation and verification. The study provides an empirical insight into how development projects manage and communicate requirements in any software development project. Coordinating and aligning business need with efficient product is a challenge (Bjarnason et al., 2016). The detailed requirements are often documented as test cases rather than in a separate requirements specification, thereby reducing the effort required to keep two separate artifacts updated and aligned (Bjarnason et al., 2016). In addition, the study suggests, using test case as requirements encourage direct and frequent communication, which supports eliciting, validation and managing customer needs clearly. Furthermore, specifying requirements as acceptance test cases allows the requirement to become a living document that

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supports verifying and tracing requirements through the software development life cycle (Bjarnason et al., 2016). The result clearly provides empirically-based outcomes that can aid in better alignment between requirements engineering and testing. The authors also present future research direction to investigate factors, relationships and limits at play when introducing requirements as a test case.

Challenges and practices in aligning requirements with verification and validation was investigated by Bjarnason et al. (2013) through a case study of six companies. The study results provide a strategic roadmap for practitioner's improvement works to address requirements and testing alignment challenges. The study found, although important, the alignment of Requirements Engineering with testing was deemed challenging and was seen to affect the whole project life cycle (Bjarnason et al. 2013). Defining requirements of good quality is found to be central to enabling good alignment and coordination with other development activities including testing (Bjarnason et al., 2013). In addition, the quality characteristics of requirements like being clear, complete, verifiable, at a suitable level of abstraction and up-to-date are also important to build a strong alignment between requirements and testing (Bjarnason et al., 2013). The authors provide categorized lists of industrial alignment challenges and industrial practices for improving alignment and mapping between challenges and practices (Bjarnason et al., 2013).

Research Questions

The following research questions were selected for gaining deeper understanding of the software engineering process in large-scale organizations.

1. What are the challenges in current requirements engineering process?
2. What are the challenges in current verification and validation process?

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3. How can the current alignment be improved?
4. What are the benefits of an improved requirements-testing alignment?
5. What are the common problems that have been encountered with Requirements Engineering and Validation and Verification?

Methods of Data Collection

The research was set with an aim to study the challenges in aligning requirements engineering and testing processes by examining research topics from multiple data sources. It is important to choose the realistic and reliable data sources for analysis. Hence, three different data sources from distinct industries were analyzed for answers to the research questions.

Interviews

The main source of information in this research is the interviews performed with software engineering professionals in different large-scale organizations. The method was applied using semi structured interview strategy, which supports combination of exploratory and explanatory interview process (Runeson et al., 2012). Semi Structured interview is the interview process where questions are planned, but they are not necessarily asked in the same order as they are listed, and development of the conversation can influence the order in which different questions are presented to the interviewee (Runeson et al., 2012). Additionally, semi structured interviews allow for improvisation and exploration of the issues raised in the interview process (Runeson et al., 2012). Hence, it was determined to be the best fit for this research study. The interviews were conducted with people actively involved in software development and testing practices, and ensured all important topics are covered. Nine software engineering professionals with different roles (3 Lead Developers/Architects, 4 Senior Developers, 1 Requirement Analyst, and 1 Lead

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Testing Analyst) were interviewed for data collection. The main form of interview documentation was the transcript of the answers in the questionnaire.

Whitepapers

The secondary data source in this research was the exploratory understanding of research theme from the software industry. White papers published by seven large-scale software technology organizations were reviewed and analyzed based on relevant research questions. This method of data collection does not offer the same control over the quality of data as interviews, because the data was extracted from the sources recorded for another purpose, i.e. that of the research study (Runeson et al., 2012). However, whitepapers are an excellent way to address common industry problems and best practices to resolve them. Hence, the whitepapers published in research theme were analyzed for answers to the research questions.

Academic Papers

Finally, data from interviews and industry white papers were complemented by literature reviews of academic journals available on the research topic. Systematic academic paper reviews help in synthesizing the empirical evidence related to specific research questions (Runeson et al., 2012). Seven different journal articles were identified and analyzed to answer relevant research questions. The empirical papers related to challenges in alignment of requirements and testing were included and detailed information about the research outcome were analyzed as per the research questions. The main objective of including literature reviews on this research paper was to compare, contrast and correlate scholarly research works that have been done in the past that are directly related to the research theme of this study.

Data Analysis

The basic objective of data analysis is to derive conclusion from the data while keeping clear the chain of evidence (Runeson et al., 2012). During the course of analysis, the information obtained from different sources take several forms. The subjects of data collection including interviews and whitepapers observe area of research in context of their organization. These observations are transcribed as quotes; grouped together and coded to identify individual results in order to facilitate the analysis. Interview, white paper, and academic paper transcriptions were analyzed using similar process, guidelines, strategy and tools. The codes corresponded directly to the research questions, i.e. Requirement Challenges, Testing Challenges, Common problems, Measures to Improvement, and Benefits of improved alignment.

Tools and instruments

The qualitative analysis conducted in this research project comprised of a large extent of working with text in different forms like, interview transcript, whitepapers and literature reviews. Hence, some kind of a tool specializing in qualitative data coding, annotation, sort, organize and query support was deemed necessary. It is possible to use standard text editors to accomplish such requirements. However, Atlas.ti (Atlasti, 2018) was chosen for this research, because the tool could provide support for qualitative analysis based on quotes extracted from transcripts.

Coding

Coding scheme was developed focusing solely on the research questions. Coding for white papers and academic papers observation was different from that implemented to interview transcripts. Two different set of codes were employed in the research as depicted in Table 1.

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Classification	Description	comments
High level codes	Codes directly based on answers to interview questions	Employed for interviews
Low level codes	Codes that are interpretation of the text narrowed down to research questions	Employed for whitepaper and academic paper analysis

Table 1. Coding Classification

The coding of interview transcripts was straightforward in most cases, as the quotes attained from a research question were recorded into corresponding coding schema. However, quotes recorded from white papers and academic papers required more analysis and coder's interpretation of the section involving the context of research. At times, the summary of the information described in the section were also interpreted to record into the coding schema.

Generalization

The goal of most qualitative studies is to provide a rich, contextualized understanding of human experience through the intensive study of particular cases (Polit and Beck, 2010). In the empirical practice environment of current industry, the applicability of research findings beyond the group of people who took part in a study is very important to ensure that those understandings are documented as an important source of evidence for practice. Explorative studies do not generalize well but develop general statements, which can be tested for generality in following studies (Mayring, 2007). This research has tried to generalize not just the results, but the procedures to come to the results. Given the nature of three distinct data sources to analyze, the study tried to generalize the process, tools and guidelines to draw the conclusion that could be used to solve similar problems in future.

Threats to validity

The validity of a study denotes the trustworthiness of the results, and to what extent the results are not biased by the researcher's point of view (Runeson et al., 2012). Identification of possible threats to validity will help to qualify the results and highlight the issues associated with the study (Sabaliauskaite et al., 2010). If a study cannot consistently produce valid results, then policies, programs, or predictions based on these studies cannot be relied on (Maxwell, 1992). Due to the nature of the study, threats to external validity and reliability is discussed below.

External validity:

External validity is concerned with the extent of possibility to generalize the finding, and to what extent the findings are of relevance to other people outside the study (Runeson et al., 2012). The primary purpose of the study was to explore common challenges, problems and methods to improve requirements and testing alignment in the context of companies researched. Hence, the results of this study can be generalized to the companies of similar size and domain.

Reliability:

Reliability is concerned with to what extent the data and the analysis are dependent on the specific researchers (Runeson, 2012). Hypothetically, if this study was to be done a second time, it should yield the same results. The investigation procedures are systematic for all data sources and documented with the clear chain of evidence. However, the observation reflects the subjective views of the participants that was transcribed. The coding could contain errors due to misinterpretation in case of analyzing white papers and academic papers, where the clear answer to research question or the

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whole context was not readily apparent. Another threat to reliability of the data collected can be the fact that the number of interviewed professionals might not have been sufficient to draw conclusion about the practices in software engineering industry. However, the interviews were conducted with people actively involved in software development and testing processes covering different roles (architect, developers, requirement analyst, and test analyst). Hence, we believe the sample was sufficient to capture the consensus of requirements and testing alignment challenges among the software development practitioners.

Reporting and Dissemination

The result of this study includes a variety of challenges faced by the professionals involved in the study in the field of requirements engineering, testing, and software development process improvement. In addition, the whitepapers and academic research analysis highlight the summary of challenges faced in the studied organizations. All findings are rooted in the transcriptions that were further broken down into quotes and codes for analysis.

Requirements Related Challenges

This section summarizes the challenges related to the requirement process that was found to be prominent across studied domains. Figure 2 presents the network of quotes and responses from the interviews. From the analysis of interview transcriptions, Scope Creep and Communication Gaps were identified as the greatest challenges in requirements engineering. Requirements are often not given enough attention by other organizational units. Product owners not being able to clearly identify what's needed for the customers leads to unclear, ambiguous and vague requirements.

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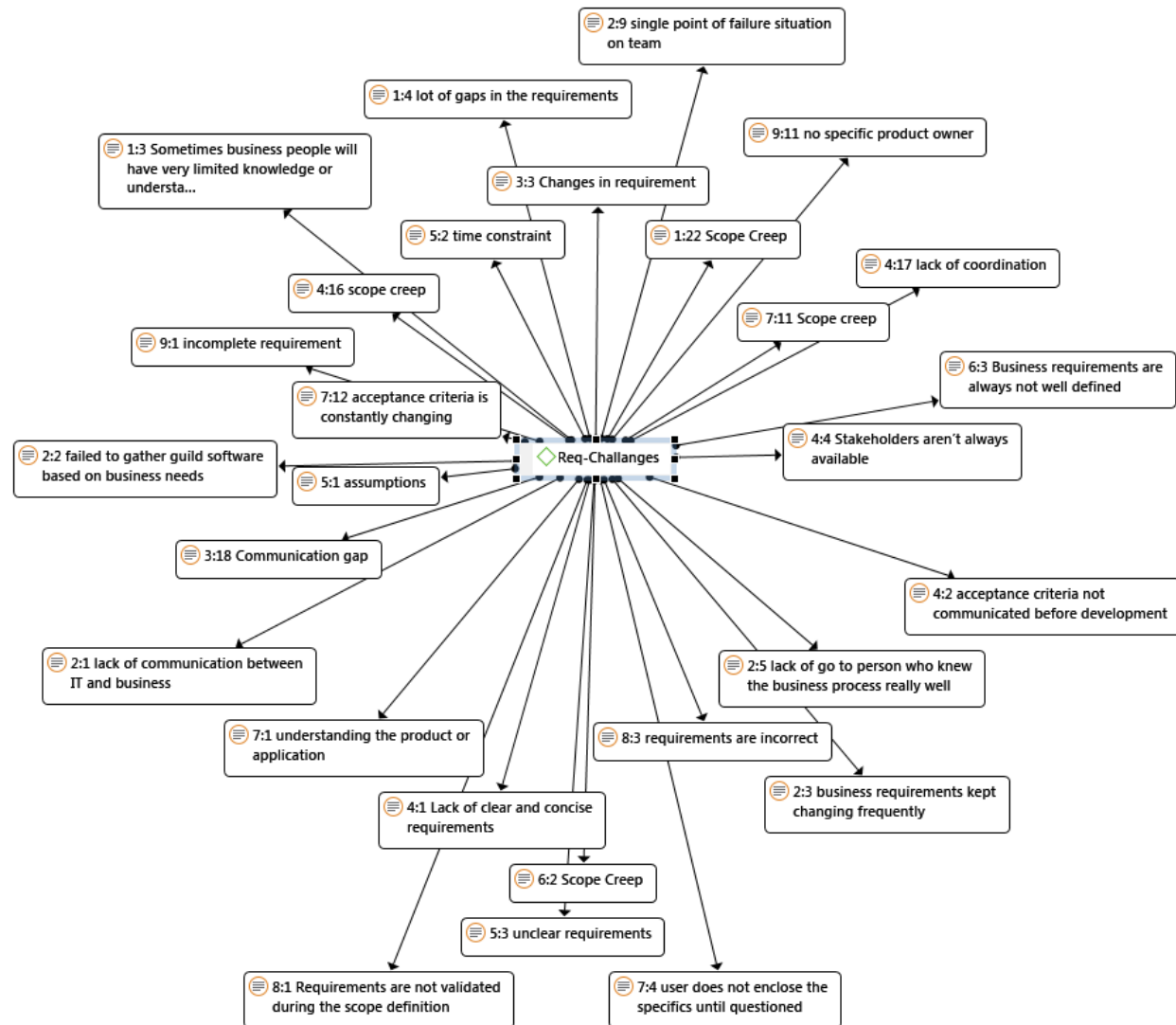


Figure2. Requirement related challenges – interview network

Based on the interview data analysis (Figure 3), lack of cross training and lack of competent product owners, makes the requirements gathering more difficult by posing a risk of single-point-of failure in teams. In addition, different stakeholders have different needs and those needs must be managed during requirements gathering. Incorrect identification of requirements and assumptions made by different stakeholders also posed challenges in accurate elicitation of requirements.

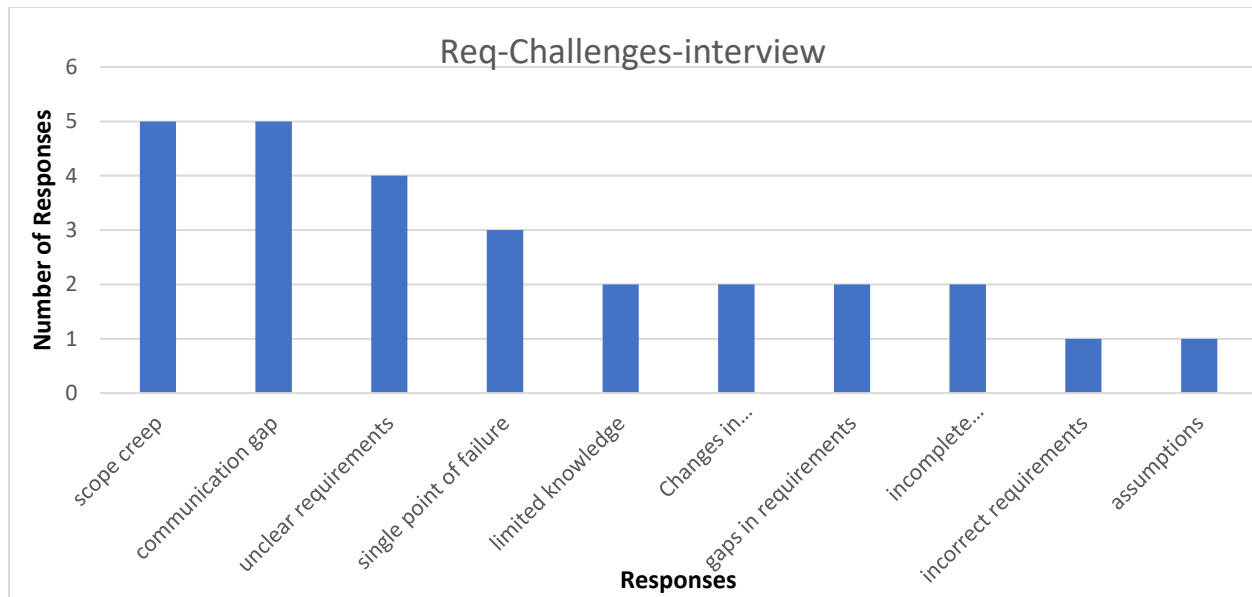


Figure 3. Number of responses by requirements related challenges interview data.

Similarly, Figure 4 depicts the network diagram based on the Responses derived from industry white papers in software development domain. Figure 5 represents graphical representation of challenges during requirements engineering analyzed from industry white papers. Based on the analysis, gaps in requirements and ambiguous requirements are the top most challenges in managing requirements in larger scale. Stakeholders not knowing what they want and getting conflicting requirements are huge challenges to any requirements analysts and project manager. Apart from those, miscommunication and lack of coordination and collaboration were also identified as major challenges in the industry. It gets harder to manage requirements when the organization is continuously piloting new technology and tools for the project team. In addition, complexity of the software, demanding customers, and poor information referenceability also add burden to already challenging requirements management process.

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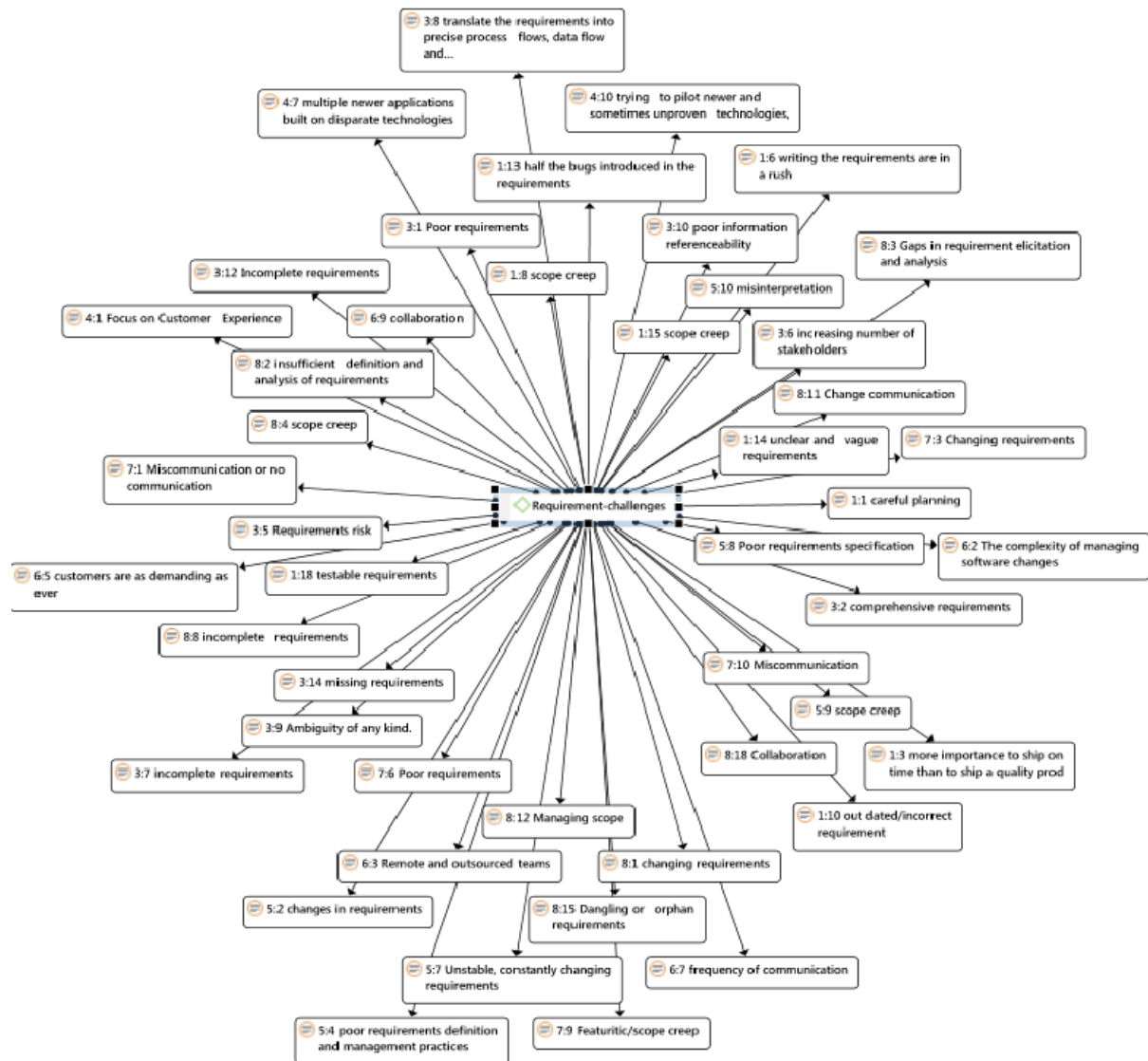


Figure 4. Requirements related challenges -whitepaper network

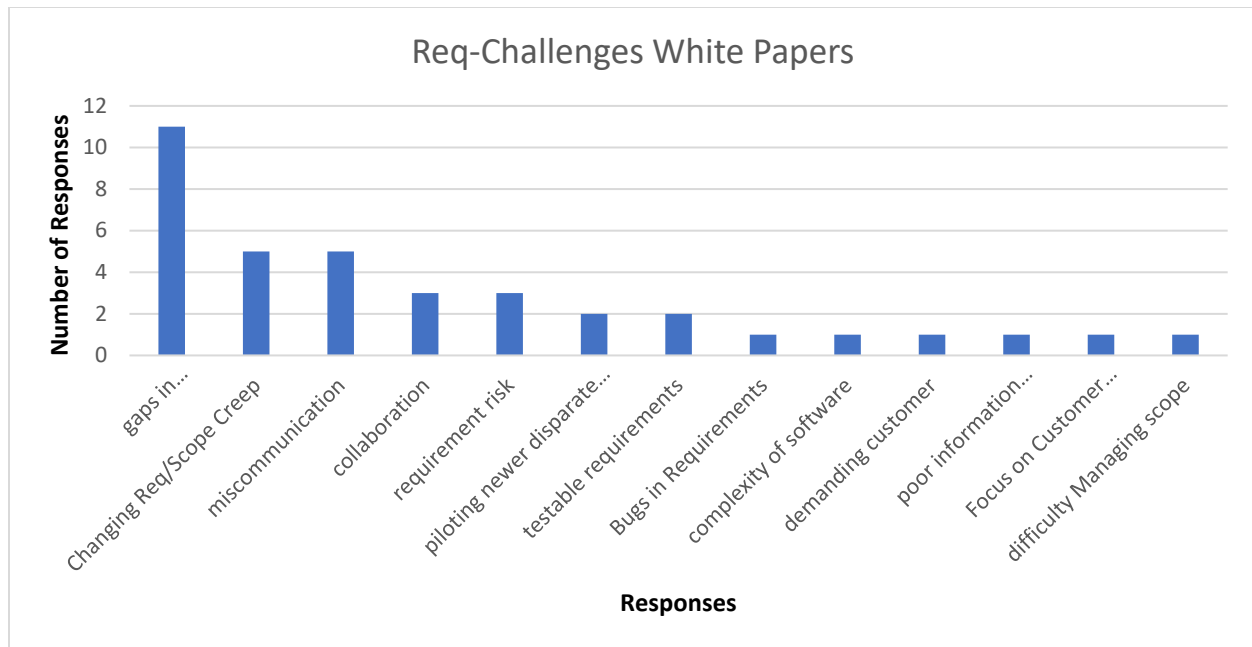


Figure 5. Number of responses by requirements related challenges whitepaper data

Analysis of requirements related challenges from academic journal papers are represented in figures 6 and 7. Communication and interaction was found to be the most prominent challenge in requirement engineering process. It is difficult to manage requirements in an organization working with large set of requirements if there is lack of requirements modelling tools available for analysts. In addition, similar to whitepaper and interview responses, coordination and cooperation between teams was also found to be as a significant challenge in managing requirements.

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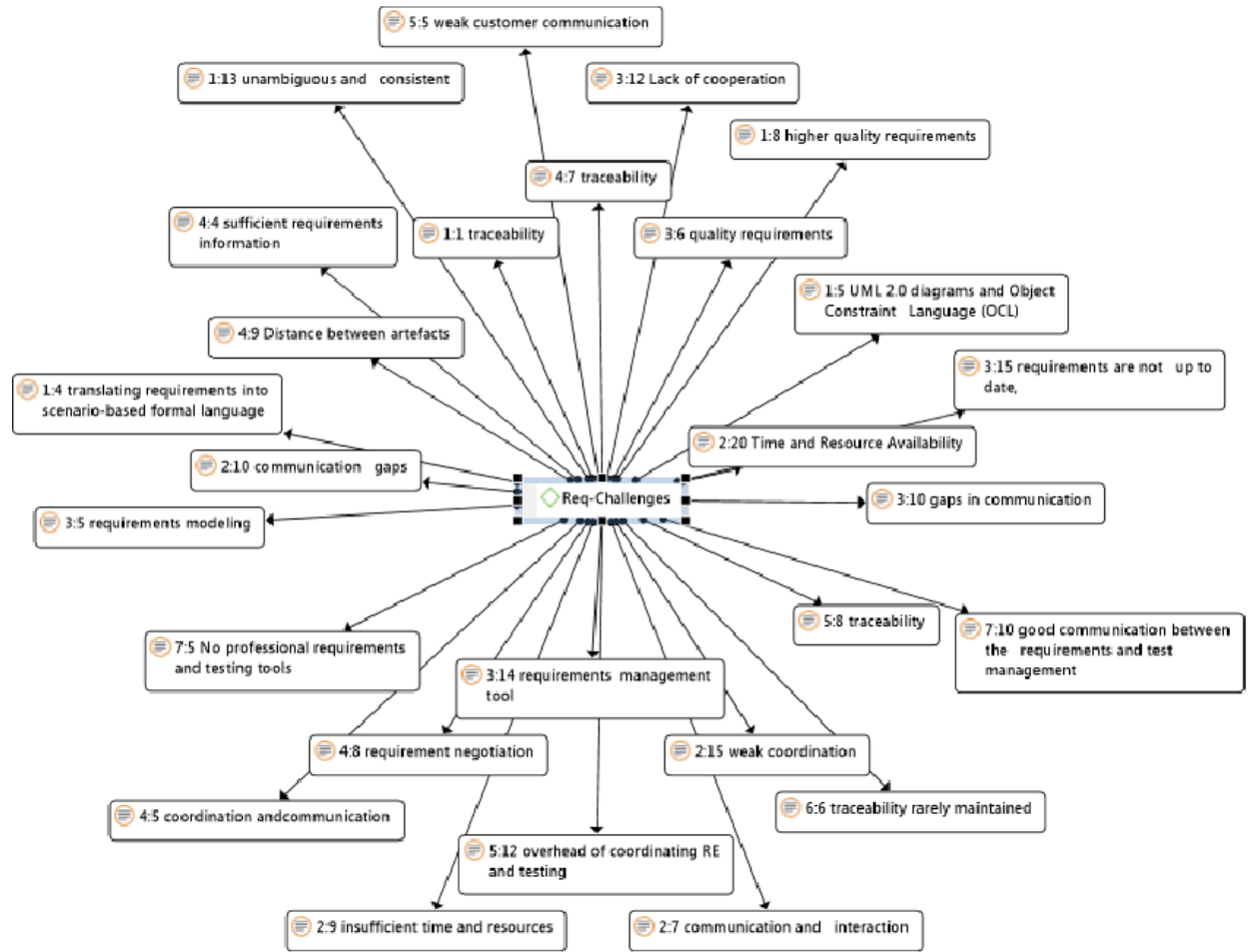


Figure 6. Requirements related challenges – academic paper network

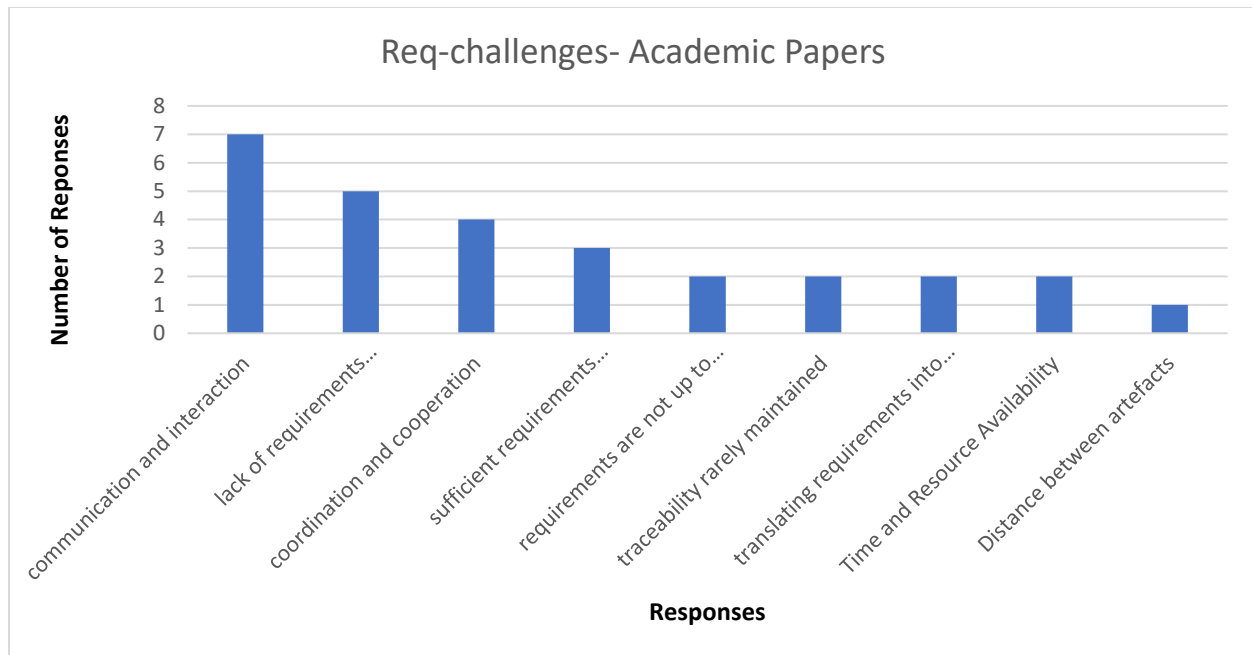


Figure 7. Number of responses by requirements related challenges – academic paper data

Other challenges relating to requirements are insufficient available requirements information, outdated information, traceability and time and resource constraints. Furthermore, distance between artefacts and skills needed in translating requirements into scenario-based formal language, was also identified as a noticeable challenge in requirements engineering process.

Testing Related Challenges

This section presents challenges that are related to the testing process across all data sources. Figure 8 presents network diagram depicting challenges related to validation and verification process in large-scale organizations.

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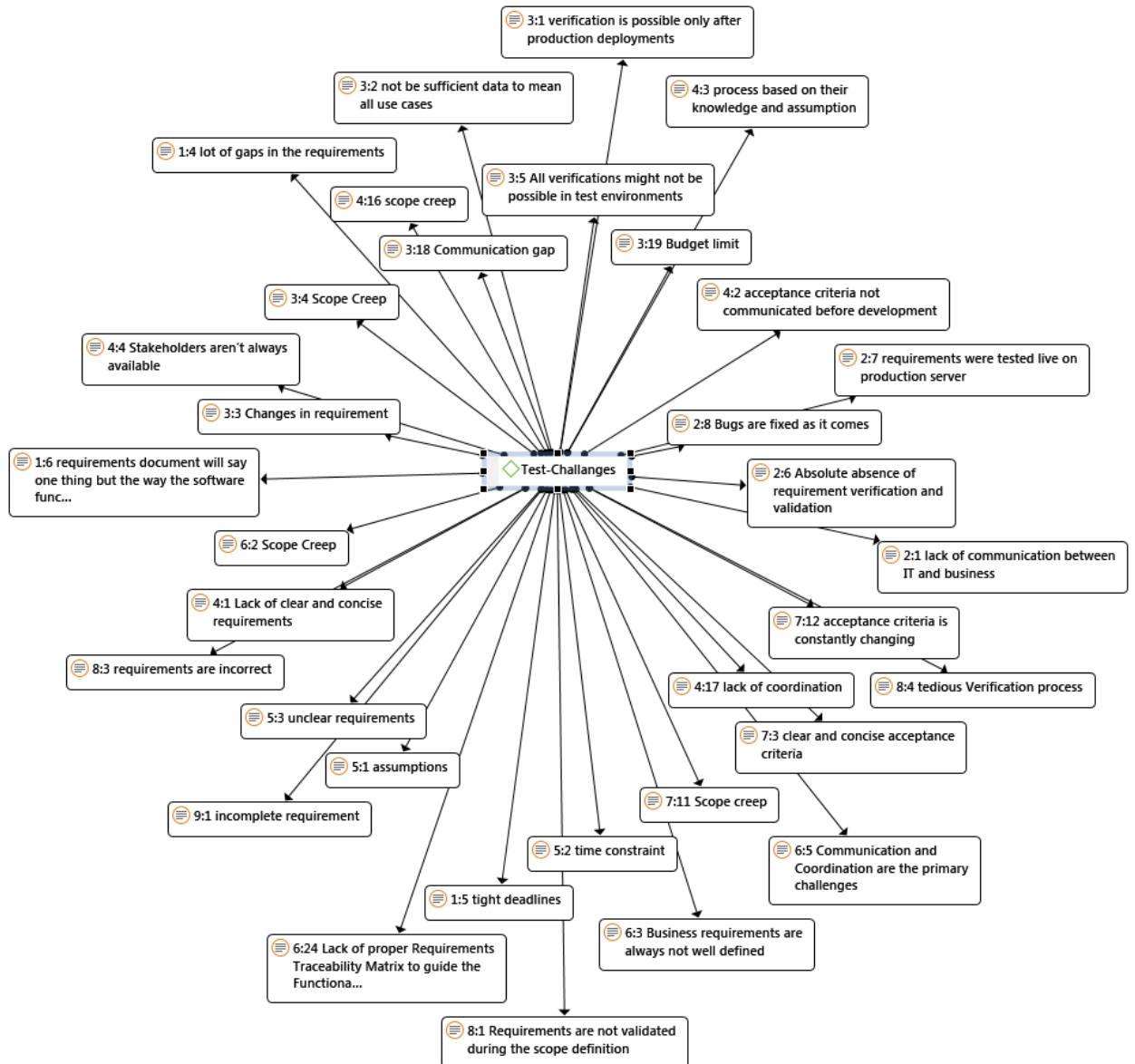


Figure 8 Testing related challenges – interview network

The quality of requirements directly affects the testing efforts in any development project. As depicted in Figure 9, gaps in requirements were found to be the top challenge in testing efforts among the software development professionals. Several organizational units are involved in the software development process including stakeholders, requirements analysts, developers, testers and business unit. Therefore, it is crucial to have clear communication and

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coordination. From the interviews analysis, it was found that keeping a clear communication was the second most challenging task in the testing process. Lack of separate environments for test and production makes it harder for testing professionals to conduct verification and validation if a single environment is used to host test and live environments.

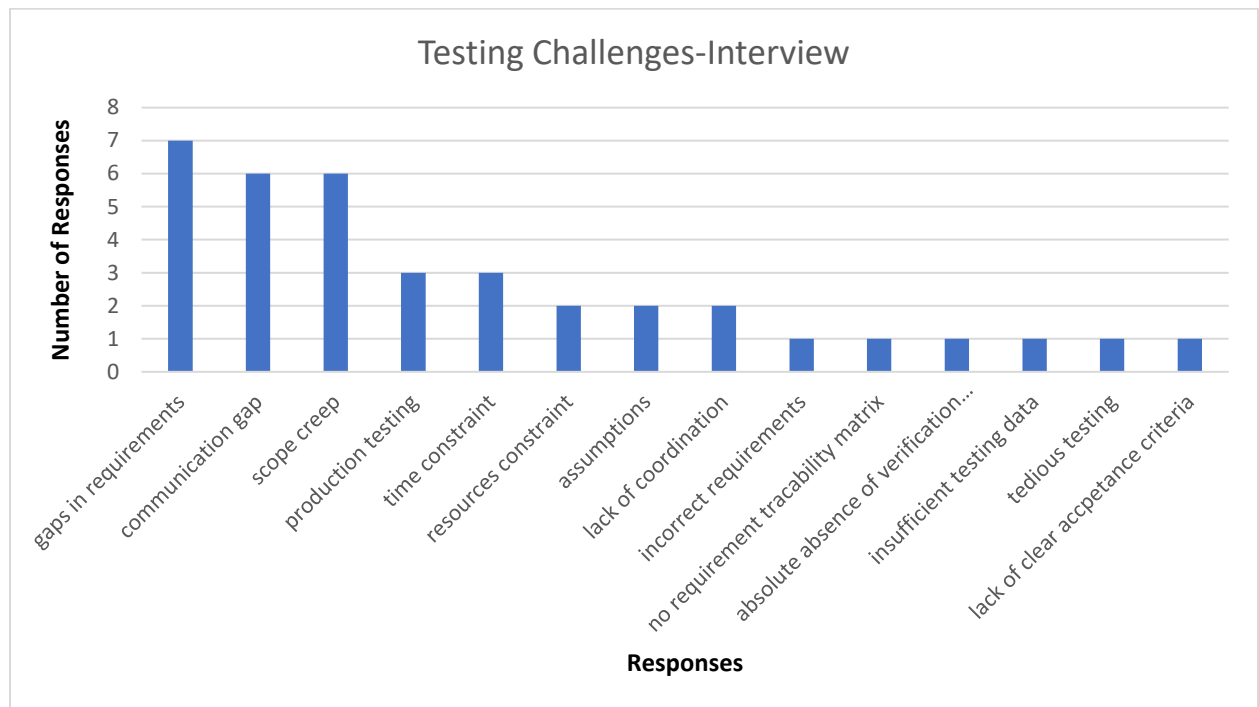


Figure 9. Number of responses by testing related challenges – interview data

Lack of time and resources also adds hurdle to the testing process. With the increase in agility of the development teams, there is an increased pressure on QA teams to reduce the turnaround time and deliver code to production (Infosys, 2017). Moreover, assumption-based requirements, incorrect information on requirements, insufficient testing data and lack of clear acceptance criteria are some of other testing related challenges.

Unrealistic testing schedule and communication gaps were found to be the top most challenges in testing practices in the software development industry. If too much work is

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crammed into little time, problems are inevitable (Pointe Technology group, 2005). In the industry of large-scale organizations, lack of automation tools sets massive load on QA for manual testing which is resource intensive and error prone. Moreover, unavailability of business flow and use cases documented adds burden to testing teams to “figure out on their own”.

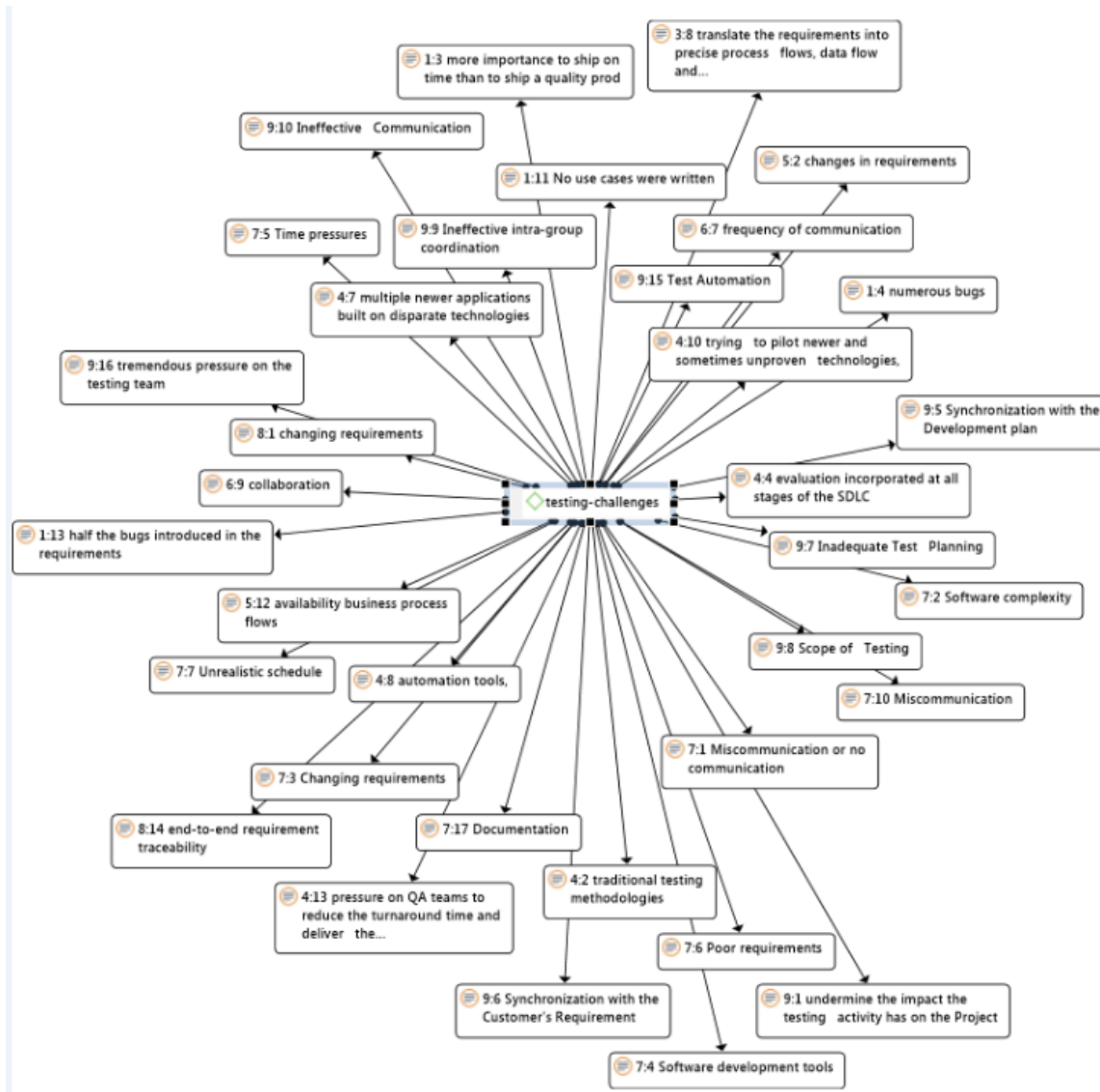


Figure 10. Testing related challenges – whitepaper network

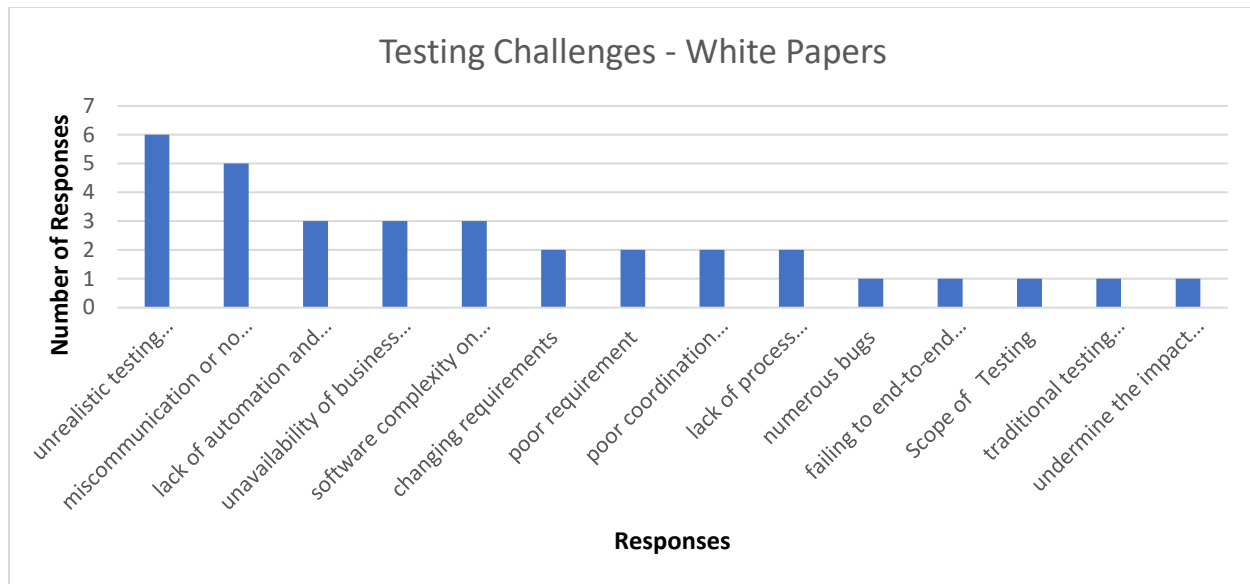


Figure 11. Number of responses by testing related challenges – whitepaper data

Business process flows, and documentation should be available to QA personnel, so they are not guessing or duplicating efforts in running the application (Micro Focus, 2011). In addition, software complexity, changing requirements, ambiguous requirements and poor communications and coordination between teams are few of other eminent challenges related to testing in large scale. Figure 11 represents the graphical presentation of industry white paper analysis in respect to challenges relating to the testing process.

Similarly, illustration of academic data network is depicted in Figure 12, while Figure 13 presents a graphical representation of academic paper analysis. The biggest challenges based on academic research papers, were unclear requirements, quality of available requirements and the coordination between project teams. As portrayed earlier by interviews and whitepaper analysis, communication gaps and weak traceability were also found to be significant hurdles in the testing process from academic reviews. In addition, ever changing requirements, unavailability of test coverage metrics and automated acceptance tests also account for significant challenge in

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testing software products. Insufficient time and resources dedicated to testing efforts contributes to inefficient tests. Lack of professional tools, adequacy of black box testing, and lack of early tester involvement also leads to problems relating to efficient testing that are presented on the academic research papers.

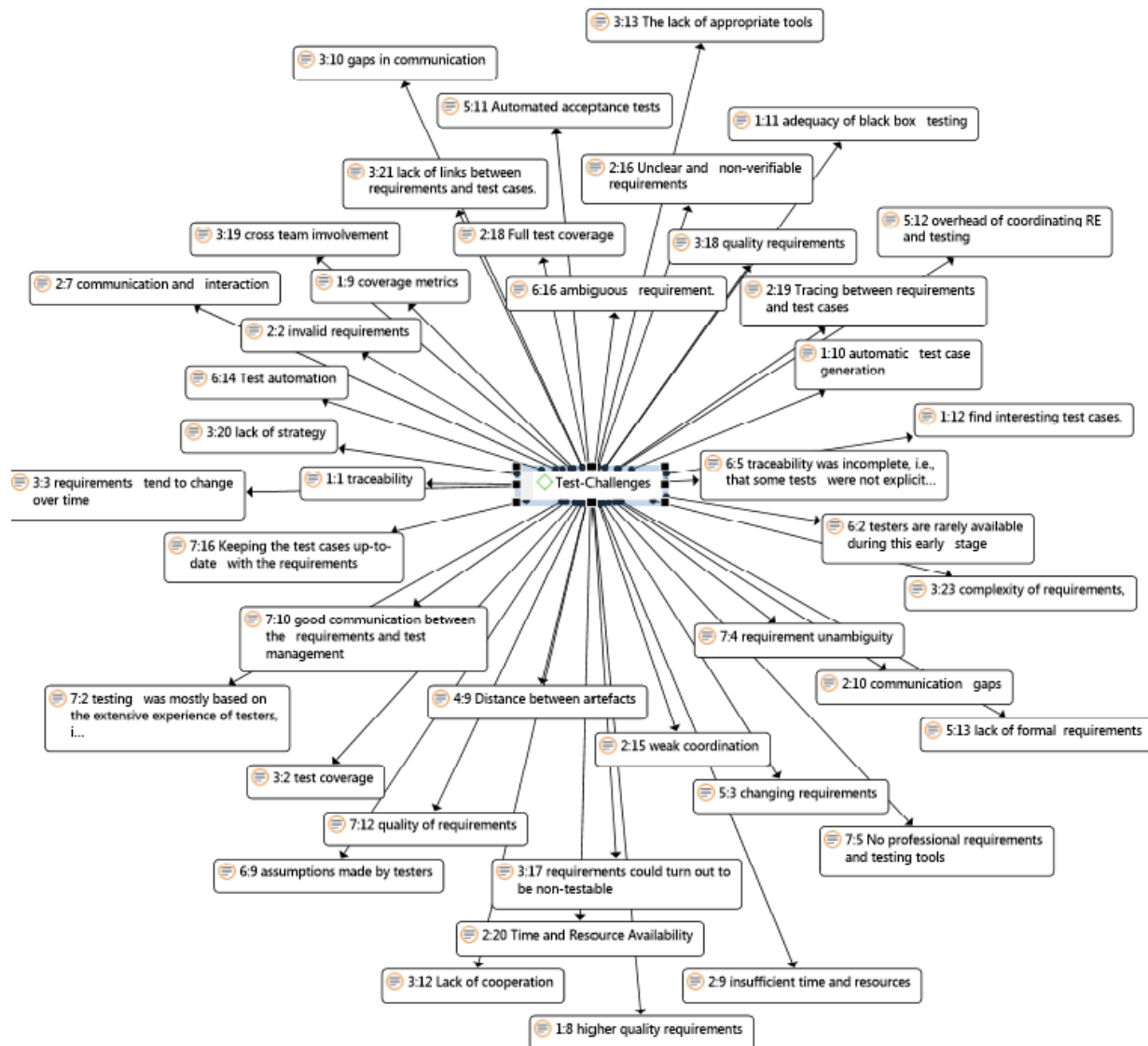


Figure 12. Testing related challenges – academic papers network

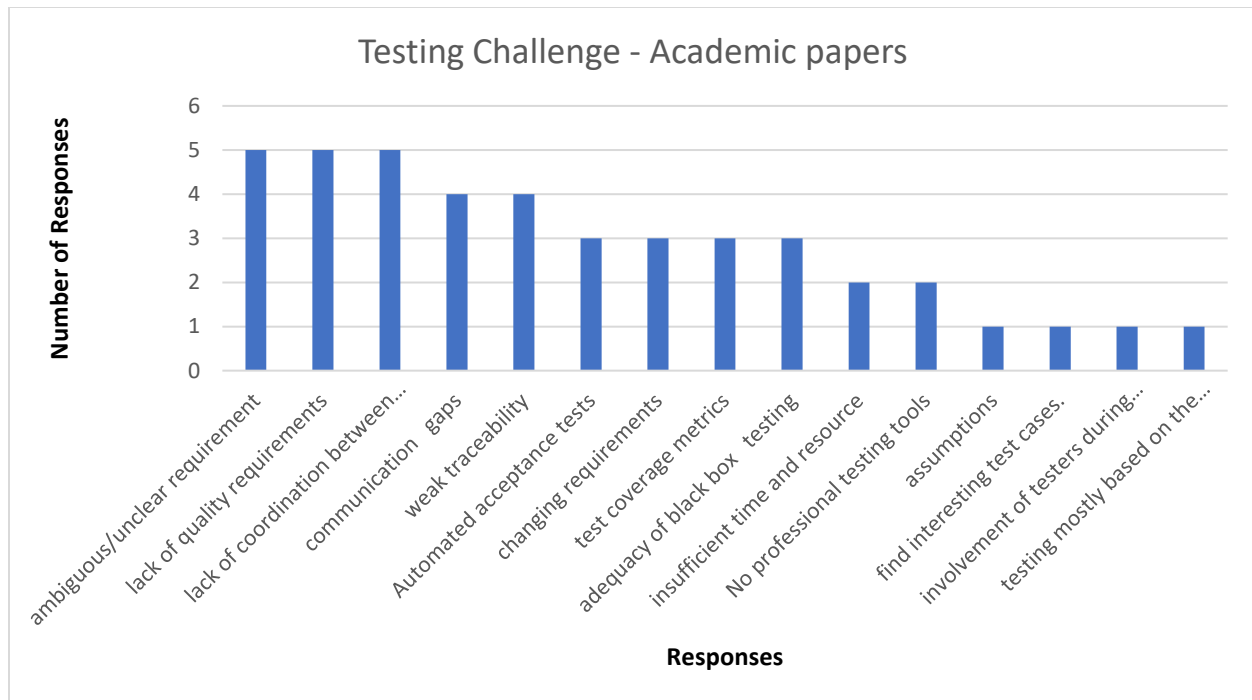


Figure 13. Number of responses by testing related challenges – academic papers data

Discussion

This section evaluates the results of the study and identify common problems associated with the alignment of requirements and testing in the software development process. Weak coordination of requirements with development and testing tasks can lead to inefficient development, delays, and problems with the functionality and the quality of the software (Bjarnason et al., 2013).

Discussion about problems

The development of software-intensive systems is a complex undertaking that is generally tackled by divide-and-conquer strategies (Unterkalmsteiner et al., 2015). Hence, it is challenging for companies to coordinate individual aspects of software development, in particular between requirements engineering and software testing (Unterkalmsteiner et al., 2015).

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Looking at the analysis performed on all data sources in this study, *scope creep* and *gaps in requirements* were found to be the most problematic issues for successful alignment of different phases of software development projects.

Figure 14 shows the network diagram of the responses from interviews regarding problems in successful alignment of requirements and testing. Software development professionals essentially agreed on scope creep and changing requirements to be the leading challenges that result in failed alignment between different phases of project including testing (see Figure 15). In addition, gaps in requirements and inadequate communication between teams were also found challenging in maintaining good alignment. Acceptance criteria defines how a particular feature could be used from an end user perspective. Therefore, inadequate definition of acceptance criteria can be difficult for testing professionals to design and build test cases. Lack of clear acceptance criteria, resource constraints, and limited knowledge about the product were also identified as alignment problems.

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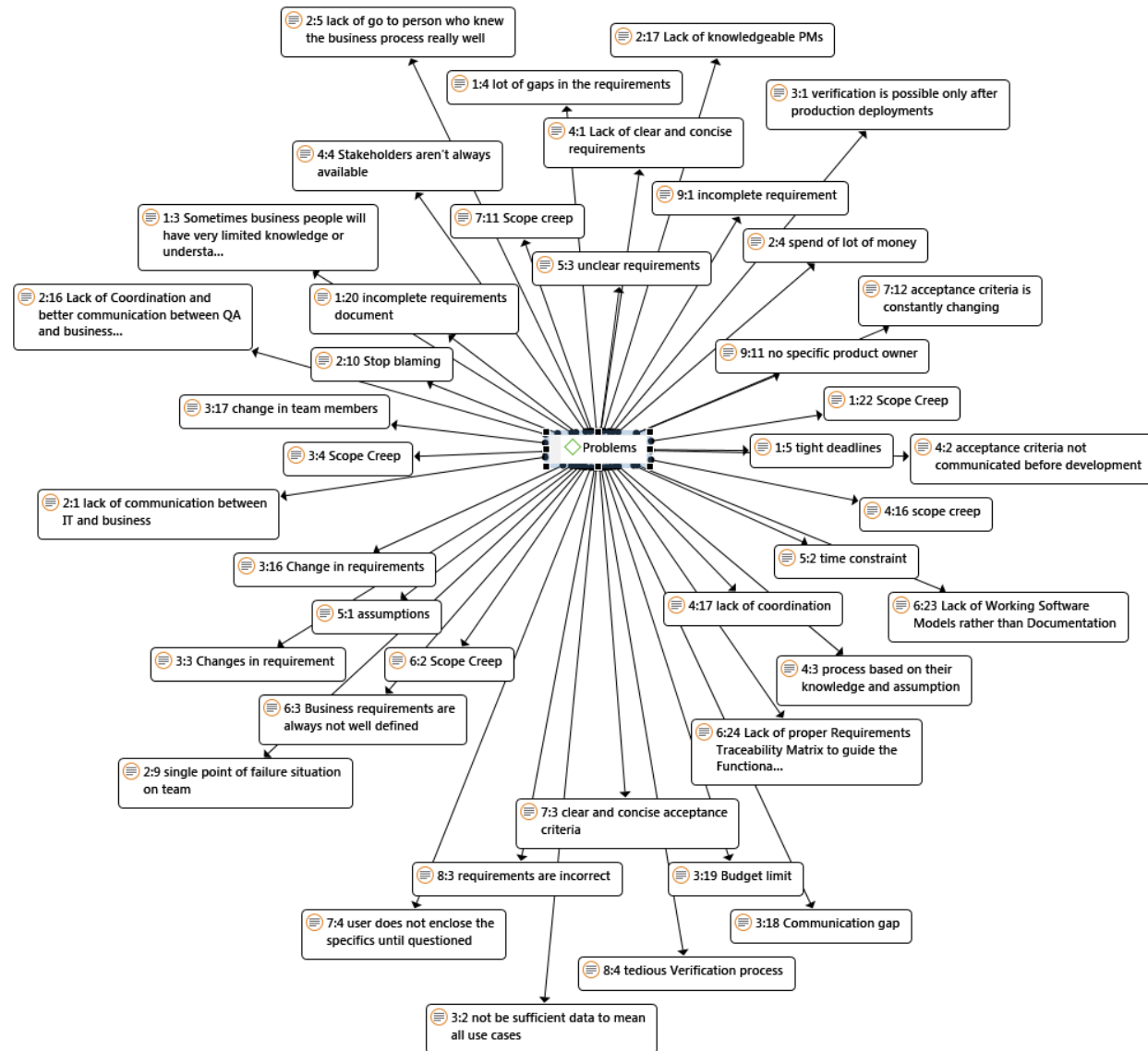


Figure 14. Problems in alignment – interviews network

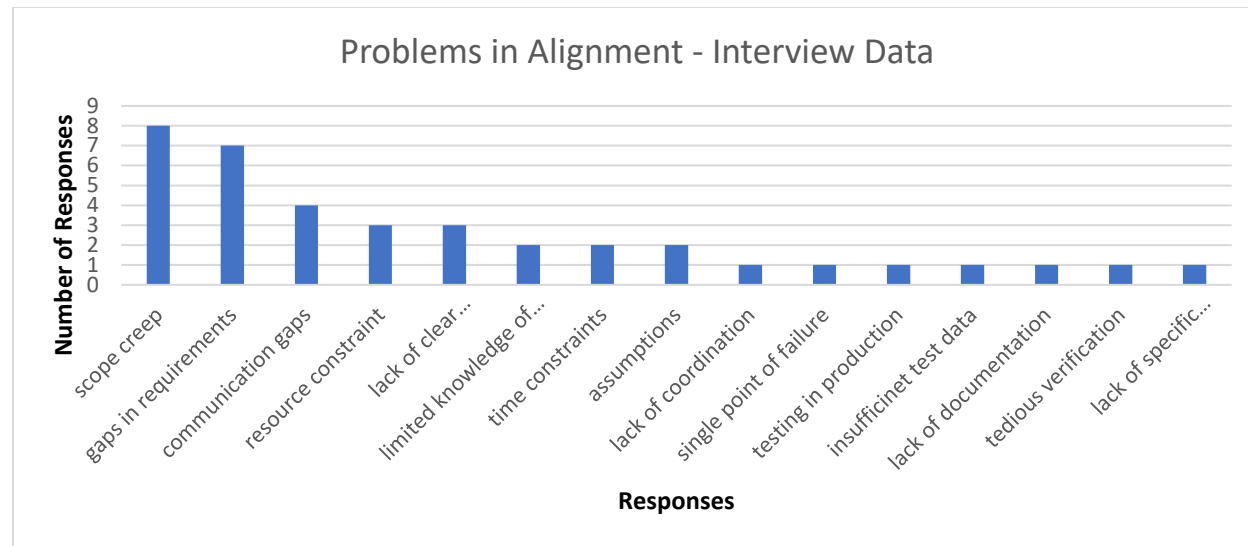


Figure 15. Number of responses by problems in alignment – interviews data

Moreover, assumptions, lack of coordination between multiple teams, and lack of documentation also could adversely affect smooth alignment during the development process. Unavailability of a separate environment for testing, and single point of failure situation in teams due to lack of cross training and knowledgeable staffs were also found to be prevailing in the studied organizations.

In addition, the analysis of organizational white papers also revealed similar problems reigning the industry. Figure 16 and Figure 17 summarize the problems in the technology industry.

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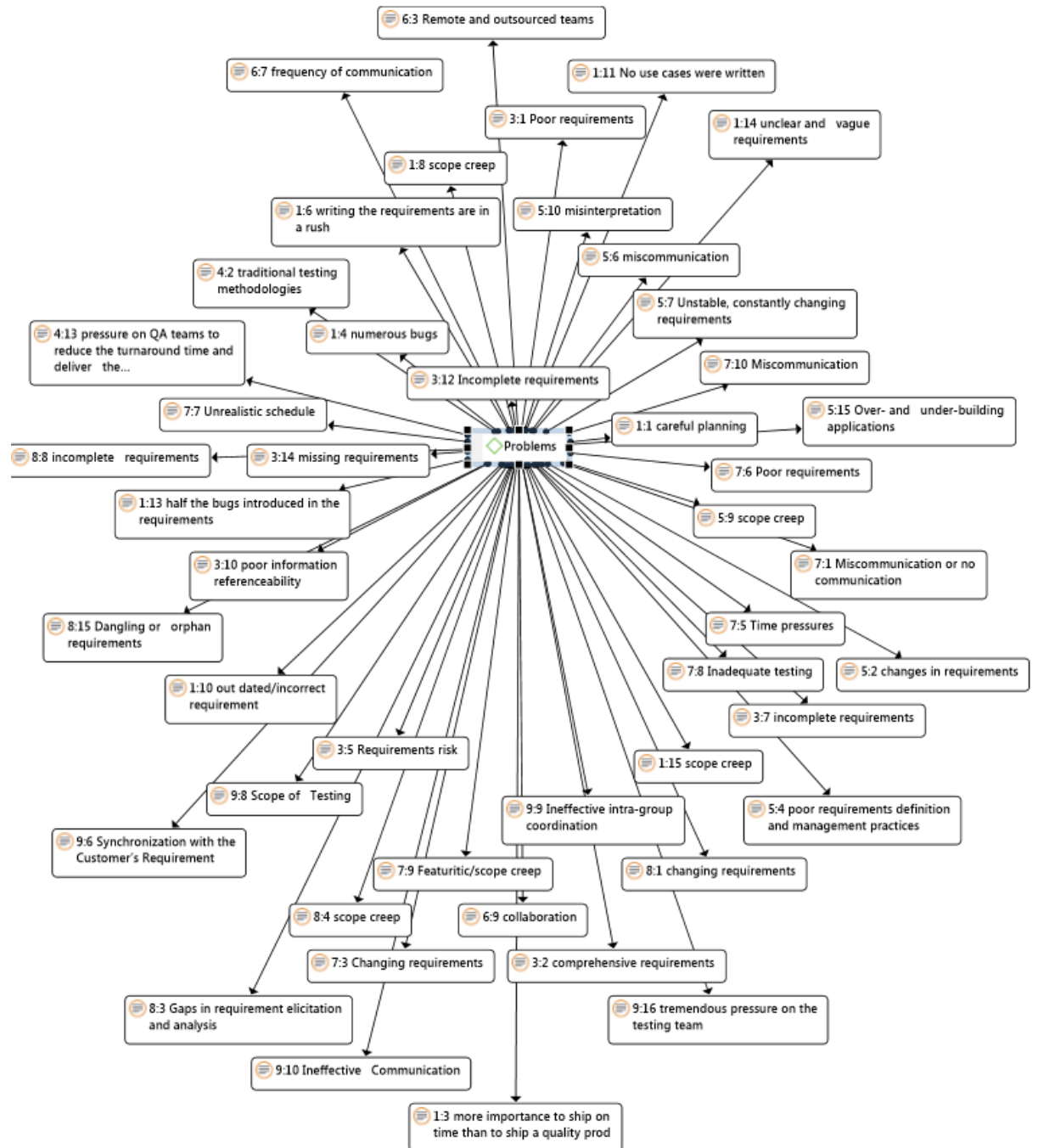


Figure 16. Problems in alignment – white paper network

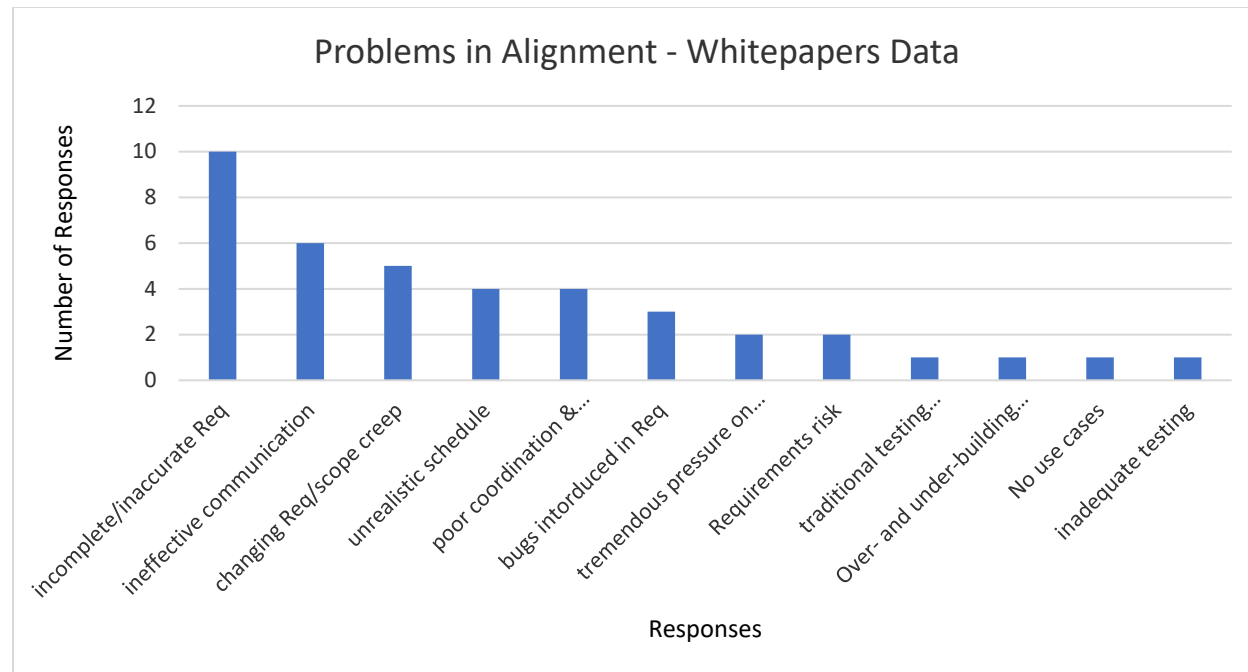


Figure 17. Number of responses by problems in alignment – whitepaper data

Incomplete and inaccurate requirements was found to be the key problem that could lead to failed alignment in the project. Ineffective intra-group communication and coordination with the development and other support teams were the common challenges faced by any testing project (IBM, n.d). In addition to changing requirements/scope creep and poor coordination, unrealistic timeline and requirements risk also adds tremendous pressure on the testing team later in the life cycle. IAG Consulting (n.d) defines requirements risk as the risk that the process of gathering business requirements will overrun by 2 times in time or cost, or that requirements documentation derived from this process will be unusable to control system design or implementation. Furthermore, over and under-building traditional testing methodologies and absence of use cases adversely affect validation and verification, resulting in poor alignment between the processes.

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Finally, findings about the common major problems from academic research papers were not much difference from the observation of interview data and industry whitepapers.

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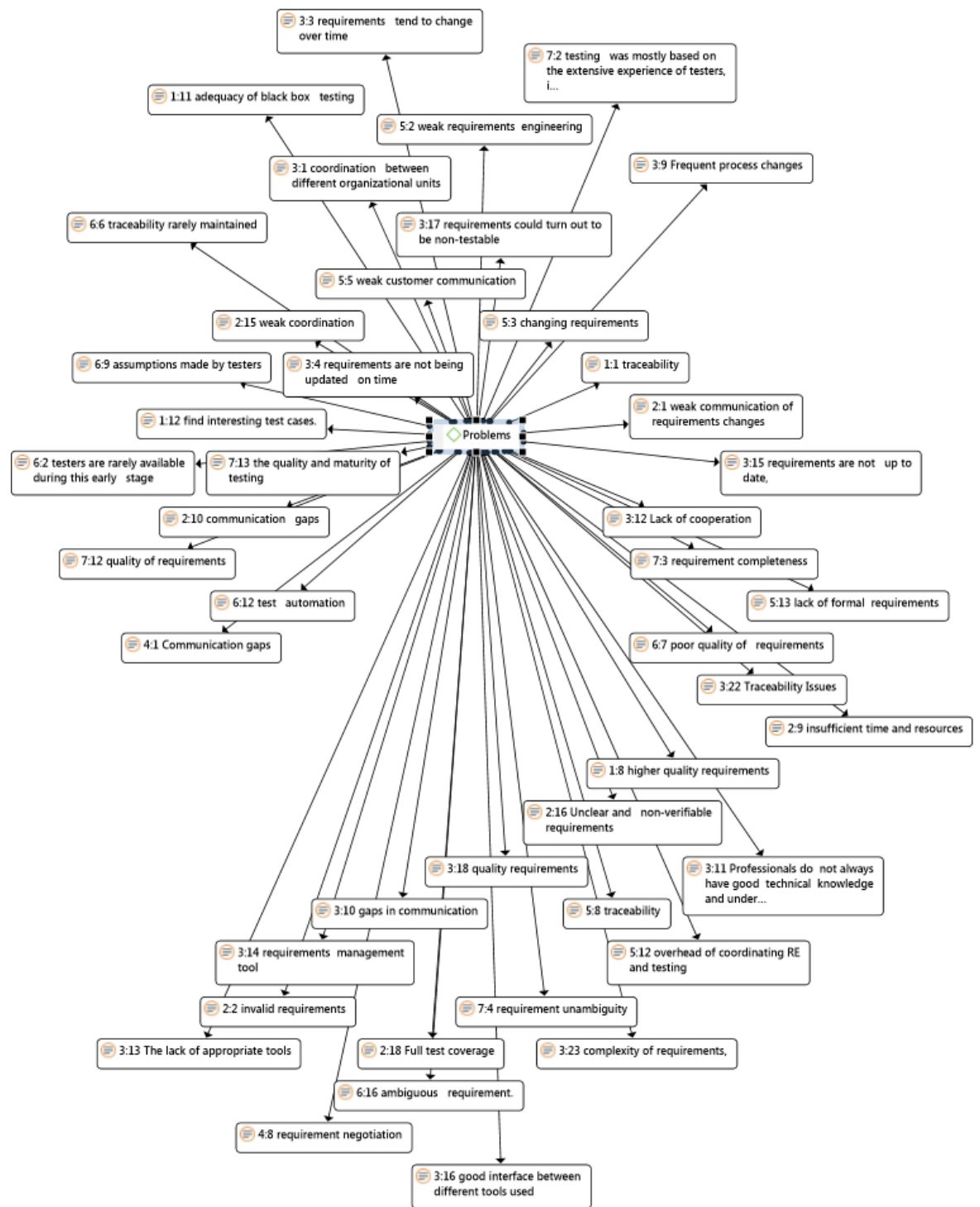


Figure 18. Problems in alignment – academic papers network

The data analysis of academic journal articles studying about need to establish strong link between requirements and testing also found incomplete requirements to be the greatest problem in strong alignment of different phases in development projects. Figure 18 and Figure 19 represent analysis and data collection map of the most common problems in software development identified from previous studies.

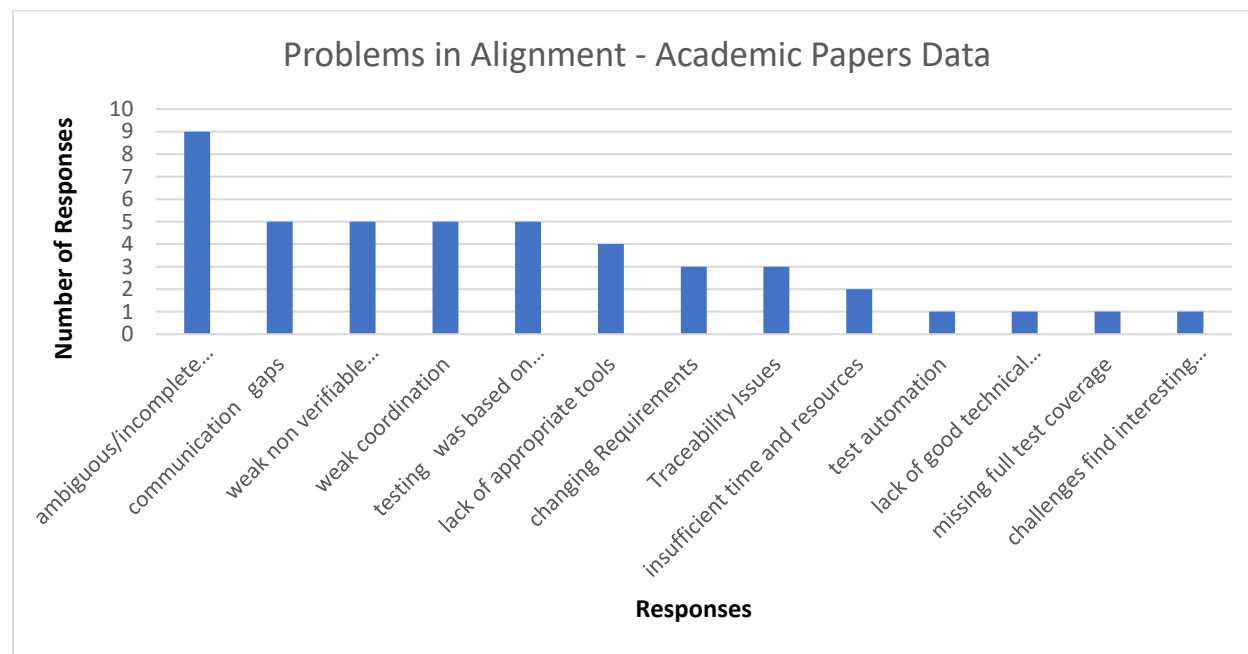


Figure 19. Number of responses by problems in alignment – academic papers data

Communication gaps and weak coordination negatively influence alignment. Building non-verifiable requirements, lack of appropriate tools and the practice of testing based on experience instead of requirements are few of the common problems that can be found within organizations. Similarly, traceability, time and resource constraints, missing full coverage, lack of interesting test cases are some of the other well-known but little mentioned common

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challenges in establishing good alignment between requirements engineering and testing practices.

Combined Analysis

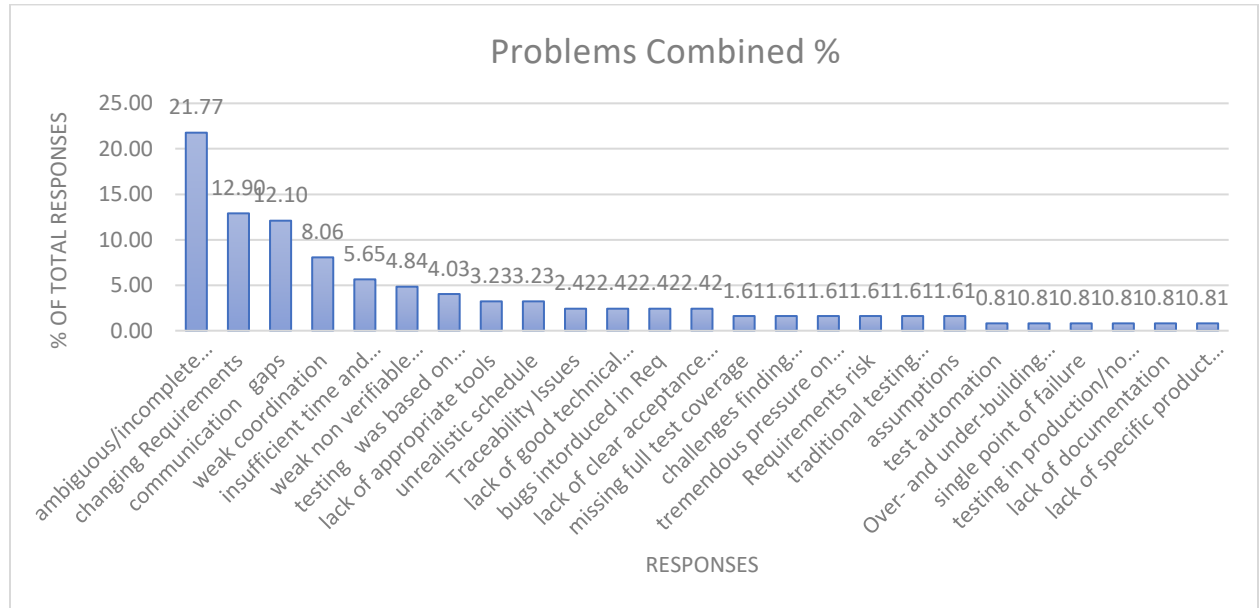


Figure 20 Percent of total responses by problems in alignment – combined data

Figure 20 presents combined analysis of problem findings from the entire study. This combined result portrays the results obtained from all data sources throughout the study.

Response Keywords	Response %	Responses
ambiguous/incomplete Requirements	21.77	27
changing Requirements	12.90	16
communication gaps	12.10	15
weak coordination	8.06	10
insufficient time and resources	5.65	7
weak non verifiable requirements	4.84	6
testing was based on experience instead of requirement	4.03	5
lack of appropriate tools	3.23	4
unrealistic schedule	3.23	4
Traceability Issues	2.42	3

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lack of good technical knowledge	2.42	3
bugs introduced in Requirement	2.42	3
lack of clear acceptance criteria	2.42	3
missing full test coverage	1.61	2
challenges finding interesting test cases	1.61	2
tremendous pressure on testing team	1.61	2
Requirements risk	1.61	2
traditional testing methodologies	1.61	2
assumptions	1.61	2
test automation	0.81	1
Over- and under-building applications	0.81	1
single point of failure	0.81	1
testing in production/no separate environment	0.81	1
lack of documentation	0.81	1
lack of specific product owner	0.81	1
	100.00	124

Figure 21. table representation of responses versus number of combined responses -

common problems in alignment

Figure 21 lists combined responses from all sources mapped with number of responses illustrated in total percentage. **Ambiguous and incomplete requirements were found to be the unanimous inference (21.77%) as the major problem in software development projects, followed by scope creep, weak communication and coordination.** Insufficient time and resources, non-verifiable requirements, lack of appropriate tools and utilities and testing practice based on experience instead of requirements were other significant issues related to poor alignment of requirements and verification process. Issues with traceability, lack of technical knowledge, bugs in requirements, clear acceptance criteria, test coverage, tremendous pressure on testing team, and requirement risk contributed to combined 16.13% of total responses. Traditional testing methodologies, assumptions lack of automation, practice of under and over building applications, single point of failure, lack of separate testing environment, inadequate

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documentation and lack of specific knowledgeable staffs comprised 8% of problems, which were not as prevailing, but could still be seen as setback in the industry.

How can alignment be improved

Requirements engineering, and testing offer two of the most important and complementary views of system development (Kukkanen, Vakevainen, Kauppinen and Uusitalo, 2009). Improving the alignment between requirements and testing would help to reach more accurate testing plan, which would improve project estimation (Barmi et al., 2011). This section will discuss the finding on how this alignment could be improved.

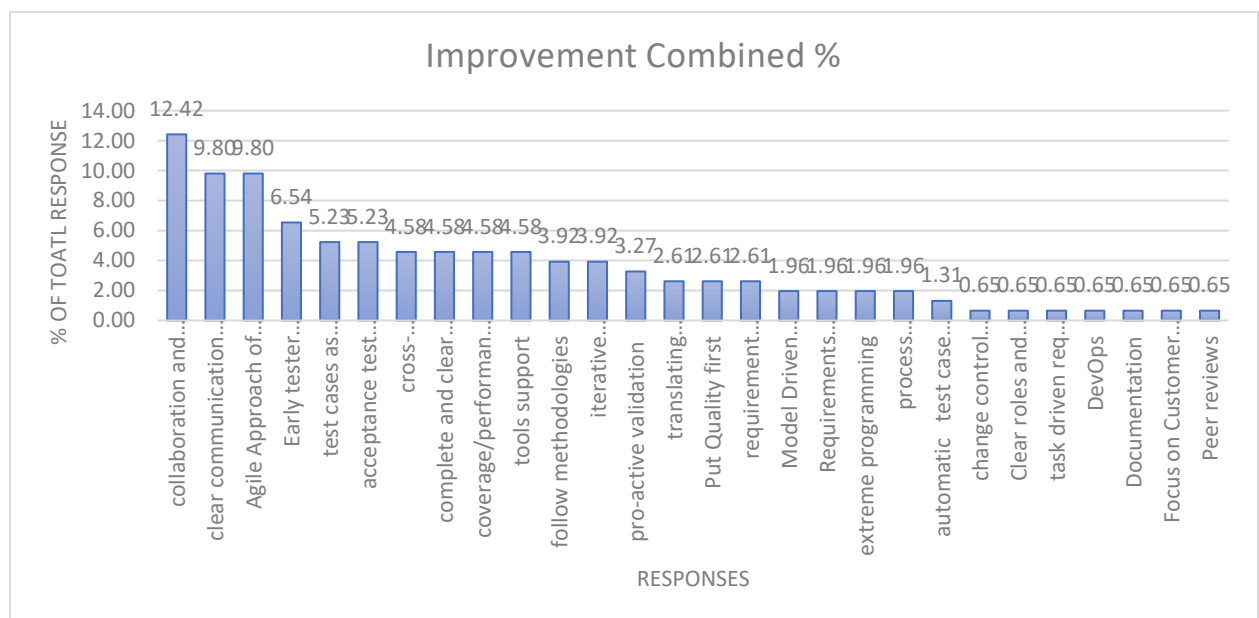


Figure 22. Improvement in alignment – combined data

Figure 22 presents the overall sets of the practices that could potentially establish a stronger link between requirements engineering and testing and quality assurance for process improvement. This finding includes combined reports of all concurrent studies from interviews, industry whitepapers and academic papers. Figure 23 presents combined set of recommended

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measures to establish a strong alignment between requirements and testing processes.

Collaboration cooperation between teams was found to be the most important aspect weighing 12.42% of responses in establishing and improving alignment.

Response Keywords	Response %	Responses
collaboration and cooperation	12.42	19
clear communication and interaction	9.80	15
Agile Approach of Integrating Requirements w/ Testing	9.80	15
Early tester participation	6.54	10
test cases as requirements	5.23	8
acceptance test cases to document requirements	5.23	8
cross-functional/trained teams	4.58	7
complete and clear requirements	4.58	7
coverage/performance metrics	4.58	7
tools support	4.58	7
follow methodologies	3.92	6
iterative requirement development	3.92	6
pro-active validation	3.27	5
translating requirements into scenario-based formal language	2.61	4
Put Quality first	2.61	4
requirement Management tools	2.61	4
Model Driven Architecture	1.96	3
Requirements traceability	1.96	3
extreme programming	1.96	3
process visibility/analysis	1.96	3
automatic test case generation	1.31	2
change control process	0.65	1
Clear roles and responsibilities	0.65	1
task driven requirement process	0.65	1
DevOps	0.65	1
Documentation	0.65	1
Focus on Customer Experience	0.65	1
Peer reviews	0.65	1
	100	153

Figure 23. table representation of responses versus number of combined responses -

alignment improvement measures

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Establishing a clear communication channel can help resolve conflicts quickly and ensure right information is communicated to the right individuals in a timely manner. This helps clear any doubts and removes risk of doing double work (Kukkanen et al., 2009). Another consensus among the research subjects was to implement and follow agile approaches of integrating requirements with testing. Early testers participation, building test cases as requirements and acceptance test cases documented during requirements were also found to be strong aspects to improve requirements-testing alignment. Moreover, providing adequate training, focus on complete and clear requirements, using tools to generate performance metrics were also important mentions throughout the study to help in strong alignment. There was found a need to follow some form of established framework of methodologies in managing iterative requirements development and testing efforts. In addition, proactive validation, scenario based formal language to create use cases, and focusing on quality rather than time or quality were few things that were common across the domain. Importance of traceability, extreme programming, process visibility, automation, change control process, clear role and responsibilities, DevOps, documentation, customer experience and peer reviews were some of the remaining response that comprised 11.76% of remaining responses on improving alignment between different processes in a project.

Conclusion

This thesis presented a systematic approach in identifying different challenges in requirements engineering and validation and verification processes. The paper also explored common problems associated with different phases of software engineering life cycle. Challenges in establishing a strong link between different phases insinuate issues with quality of products being developed and inefficiency of project life cycle. This study presented such

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challenges prevalent in different large-scale organizations in the industry. The goal of the study was to explore the current challenges in aligning requirements and verification process and identify prescriptive measures to counter such challenges for process improvement.

One of the greatest problems was found to be incomplete and ambiguous requirements. Often lack of knowledge about the specific system, communication gaps, resource constraint, and assumptions lead to requirements that do not entirely meet the customer needs. Requirements that are unclear, incomplete or too general pose more problems to the project than they do any good. Traceability is also a challenge across the domain and its importance is corroborated by other studies (Sabaliauskaite et al., 2010). Scope creep is another issue that has widespread impact on the industry. Being able to manage these challenges is the key to improve development processes and build effective products efficiently. There is an increased complexity of the application landscape (Infosys, 2017). The systems are getting more complex and the teams are getting more diverse, that requires improved collaboration and cooperation between the teams. Clear communication and interaction is an important solution to most of software development problems (Pointe, 2005). Requirements walkthrough and inspection as needed, use of management tools, intranet capabilities (private networks available for employees within the company), promoting up to date documentations can help shorten the distance between stakeholders and help promote teamwork and productivity. With the digital revolution, newer technologies are being adopted in a much faster pace. Hence, it is important to increase agility and integrate requirements engineering with testing from the early phases of development in order for the requirements and testing to be aligned right from the inception of the project.

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Appendix A: Interview Transcripts

A.1. Transcript 1.

Requirements, verification and Validation for Software Engineering Process Improvement.

- What is the current state-of-practice in alignment of requirements and testing in your organization?

Currently in our organization, requirements are gathered by a requirement analyst and then these requirements will be discussed with a development team. After the discussion, the development team will come up with a high-level user stories based on the requirements and these stories will be created in a TFS board by a requirement analyst attaching all the requirements associated to that story. Business will review and approve these stories/features before the software development begins.

1. What are the challenges in requirements related to verification and Validation?
 - Sometimes business people will have very limited knowledge or understanding of the system processes, all they can think of is doing a certain action in a software tool will yield a certain output. During the upgrade of these kind of processes the business can only say how they want the new process to function like but cannot provide all the needed requirements to the development team as they have very limited knowledge of all the business rules associated with that process. This could be because either the software process might have been used for a while in the Organization or the SME's might have already left the company. This will cause lot of gaps in the requirements even though we know what to verify and validate.
2. What are the challenges in verification and validation related to requirements?
 - In an ideal world we shouldn't have any problems with the verification and validation of a product provided the requirements are up to date. But this will not happen in most of the cases due to project tight deadlines, human errors etc. There are times in our organization when we demo a certain software feature to the business they will ask the developers to update few things, and most of the times if it's a small change we don't even bother to go back to the User stories and update the requirements. Finally, once the software is rolled out for testing the testing team will start creating bugs as the requirements document will say one thing but the way the software functions will be different.
3. What are the current artifacts and processes related to requirement-testing alignment?

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- We are using TFS as a project management tool to track all our project artifacts like User stories, tasks, bugs etc.
- What is the desirable future state in alignment of requirements and testing for Software Engineering Process improvement?
 1. How can the current alignment be improved?
 - Training is one area where the organizations can focus on for improving the current alignment. Sometimes developers are trained in different software methodologies but not the business. So, this will create gaps to bring people together and work together on a common project. So, training all the individuals in an Organization in a particular software methodology will help.
 - When a project work is going on identify all the key individuals required for a project and try to keep them in all the meetings associated with that project even though their scope is less as this will help to keep everyone on the same page and limit the number of surprises during the testing and verification of software.
 2. What are the expected benefits of an improved requirements-testing alignment?
 - Time & Money are the great factors that determine the performance of any organization. If the Requirements-testing alignment is improved this will eventually cut down the Organization costs and time which they can focus on other areas to improve.
 3. How can the alignment be measured?
 - When a project is going on document all the stumbling blocks that had raised because of the gaps in Requirements-testing alignment and do a retrospection after every project and incase if you find if they are lot of common cases that are causing this misalignment to correct them for your future projects.
- What are the common problems that you've encountered with Requirements Engineering and Validation and Verification.
 - Most of the items we had issues with the incomplete requirements document, requirements defined a business person with a limited knowledge which will cause the development to reach out to Requirements analyst multiple times to get the answers.

A.2. Transcript 2

Requirements, verification and Validation for Software Engineering Process Improvement.

- What is the current state-of-practice in alignment of requirements and testing in your organization ?
 1. What are the challenges in requirements related to verification and Validation?

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With the company that was acquired by Germany company, the culture and the lack of communication between IT and business was big set back. IT leaders wanted to build and develop software that they felt was right but failed to gather guild software based on business needs. Another problem was german project leaders wanted to implement the same business plan across all the globe which as a result most business requirements kept changing frequently and spend of lot of money before a project was complete.

2. What are the challenges in verification and validation related to requirements?

As a result of high turn overs in the company and when people working in the company in the same role for more than 20+ years retired or left the company there was always a lack of go to person who knew the business process really well. As multiple people changed in the same role, the business process had changed so much that the requirements never really made sense. Software code needed to be changed or updated every-time. Absolute absence of requirement verification and validation.

3. What are the current artifacts and processes related to requirement-testing

All requirements were tested live on production server with real customers. You can say no testing done. Bugs are fixed as it comes.

- What is the desirable future state in alignment of requirements and testing for Software Engineering Process improvement?

- 1. How can the current alignment be improved?

Stop blaming IT for everything. Employees at both business and IT should take responsibilities and communicate and work together. Keep egos aside.

- 2. What are the expected benefits of an improved requirements-testing alignment?

Better developed softwares, cost savings on software maintenance issues. Business is run effectively. Efficient softwares increases business revenue.

- 3. How can the alignment be measured?

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Pass ... lol

- What are the common problems that you've encountered with Requirements Engineering and Validation and Verification.

Lack of Coordination and better communication between QA and business owners is the biggest issue. QA not questioning Business owners when the requirement doesn't seem right, only for devs to find out during development.

Also. Lack of knowledgeable PMs is another big issue letting everyone running loose.

A.3. Transcript 3

Requirements, verification and Validation for Software Engineering Process Improvement.

- What is the current state-of-practice in alignment of requirements and testing in your organization?
 1. What are the challenges in requirements related to verification and Validation?
 - In some projects, verification is possible only after production deployments.
 - In some other projects, there might not be sufficient data to mean all use cases.
 - Testing might not have been completed on all areas.
 - Changes in requirement might affect earlier tested portion of projects if not tested again.
 2. What are the challenges in verification and validation related to requirements?
 - Requirements could change over time and if not properly documented, both business and developer might forget it. And after few months there will be searching of who, when and why change was requested or made.
 - All verifications might not be possible in test environments.
 - Direct production verification could be risky.
 3. What are the current artifacts and processes related to requirement-testing alignment?

Three cases we have are:

- Dedicated testing team helps in testing in some projects.
- Business helps in testing UAT/TEST.

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- Developer does UAT/Test and also PROD verification as per availability of resources.
- What is the desirable future state in alignment of requirements and testing for Software Engineering Process improvement?

1. How can the current alignment be improved?

In my view testing could be improved as follows:

- First circle verification should be done by developer on dev.
- Second cycle verification should be done by developer on test environment.
- Third cycle will be by QA team with details functional testing.
- Fourth cycle will be done by QA team with all use cases testing and possible other cases.
- Fifth cycle will be done by Business.
- Production verification after production deployment by business.

2. What are the expected benefits of an improved requirements-testing alignment?

- Satisfied customers
- Happy project team members

3. How can the alignment be measured?

- By quality of software delivered.
- Time
- Cost
- Resources

- What are the common problems that you've encountered with Requirements Engineering and Validation and Verification.

As per my past experience it could arise due to

- Change in requirements
- Unclear specifications
- Lots of change in team members
- Lack of resources
- Time limit
- Resource limit
- Budget limit
- Communication gap

A.4. Transcript 4

Requirements, verification and Validation for Software Engineering Process Improvement.

- What is the current state-of-practice in alignment of requirements and testing in your organization?
 1. What are the challenges in requirements related to verification and Validation?
 - Lack of clear and concise requirements from the stakeholders at the beginning of the project.
 - The verification and validations procedures to be followed are not always provided to the development team.
 - Requirements are not always to the point and the developers end up executing the validation and verification process based on their knowledge and assumption.
 2. What are the challenges in verification and validation related to requirements?
 - Stakeholders aren't always available to verify the requirements and this proves to be a roadblock.
 - When a module is complete, stakeholders aren't always available to test/validate the module. This delays the integration process.
 3. What are the current artifacts and processes related to requirement-testing alignment?
 - The techniques we generally implement consists of creating a prototype of the system, performing simple checks and inspections at the different stages of the project life cycle.
 - Creating test cases and executing them once the project or a module is complete.
- What is the desirable future state in alignment of requirements and testing for Software Engineering Process improvement?
 1. How can the current alignment be improved?
 - Adopting agile methodology can improve the current process drastically where the development life cycle will follow an incremental process. The module completed after each scrums can be tested individually and the

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development team will have a fully validated and verified system at the end of the life cycle.

2. What are the expected benefits of an improved requirements-testing alignment?
 - Increased testability of the individual modules.
 - Less complex validations and verification process as each of the modules will be tested individually.
 - Adopting agile methodology will also decrease the time required for performing verification. This will eventually help in saving resources,
 3. How can the alignment be measured?
 - The alignment of requirement and testing can be measured against the time and cost. Once the process is improved, the testing process will be less complex and the modules developed will be better validated.
- What are the common problems that you've encountered with Requirements Engineering and Validation and Verification.
 - Most of the time I have to work with incomplete or ever changing requirements. This makes verifications and validation challenging as I don't know what changes will be incorporated later in the project. Most of these changes/enhancements are requested by the business towards the end of the project and the development team has to get back to the white board to redraw the verification and validation strategy. This introduces added complexity to the project and the entire process becomes almost like a death march scenario.

A.5. Transcript 5

Requirements, verification and Validation for Software Engineering Process Improvement.

- What is the current state-of-practice in alignment of requirements and testing in your organization?
 1. What are the challenges in requirements related to verification and Validation?

There were assumptions from business that developer should know (like their process and details of it). Most of the times we miss the details of the requirements and finding it little difficult to accommodate them under same time constraint.

2. What are the challenges in verification and validation related to requirements?

Same as above. This is rare situations only though. Normally as a Lead I ask questions and clarify before design/Development.

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3. What are the current artifacts and processes related to requirement-testing alignment?

Normally happy path testing I do. Rest is all in TESTING TEAM hands 😊.

- What is the desirable future state in alignment of requirements and testing for Software Engineering Process improvement?

1. How can the current alignment be improved?

NMP Backend, Credit balance and Exact that I support are in good shape. But any you propose I will be okay to follow that.

2. What are the expected benefits of an improved requirements-testing alignment?

NA 😊.

3. How can the alignment be measured?

NA 😊

- What are the common problems that you've encountered with Requirements Engineering and Validation and Verification.

HA: (Same as question 1 answer)

There were assumptions from business that developer should know (like their process and details of it). Most of the times we miss the details of the requirements and finding it little difficult to accommodate them under same time constraint.

A.6. Transcript 6

Requirements, verification and Validation for Software Engineering Process Improvement.

- What is the current state-of-practice in alignment of requirements and testing in your organization?
 - UAT's are bridging the Scope Gap and involving in a better alignment of the requirements for testing purposes.
 - Need to create these UAT's that can be widely accepted by the teams so that the testing can be conducted in parallel to the Development.
 - Scope Creep can be allowed for only the tasks that have been validated by 50%.
- 1. What are the challenges in requirements related to verification and Validation?

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- Business requirements are always not well defined, there is always a need to organize before Documenting.
 - Eliciting the requirements rather than gathering through Surveys and Brainstorming sessions with the Stakeholders & Developers could serve the purpose of verifying before trying to validate.
 - Requirements Grooming sessions help the Product Owner to filter and prioritize them which involves verifying if they are within the scope of the business.
2. What are the challenges in verification and validation related to requirements?
- Communication and Coordination are the primary challenges in verifying the requirements which can be sorted out through Requirements Modeling.
 - Testers should be able to verify and validate the requirements which could serve the user purpose.
 - Data flows and Use cases could help the testers understand what the end user exactly needed.
3. What are the current artifacts and processes related to requirement-testing alignment?
- Requirements are needed to break down to simple elements to create User Stories for clear Epic's that defines the feature's user needs and wants which can provide solution.
 - Drafting a User Acceptance Test criteria is always the bigger challenge, as the verification & validation of the requirement is pre- described in the user story.
 - Acceptance criteria should always be in the sync with requirement so that half of the testers job could be facilitated.
 - UAT's are further created to provide the implementation part which can be verified and validated during the Idea-Thought process stage.
 - JIRA, RALLY, TFS are some of the tools that are used to assign the tasks and track down the bugs related to testing.
 - Functional Requirement Document (FRD's) specifies the assumptions to consider for testing the feature.
 - Also, these tools help in proper communication whenever there is a change in the requirements the modified user story is notified to the tester who are working on a common platform thus allowing to identify the changes in the UAT.
- What is the desirable future state in alignment of requirements and testing for Software Engineering Process improvement?
 - From the Project Management view, this alignment could organize the Project Schedule and the Costs involved leading to improved Product Quality to satisfy the customers.

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- UI/UX Mock ups could provide the real time working conditions of the features in the requirements engineering stage so that the testing conditions can also be evaluated.
 - Requirements should be analyzed through regular direct interactions with the developing and the testing teams which could avoid gaps by saving the time.
 - For fast paced projects, KANBAN framework better aligns the testers with the requirements from the 1st phase.
 - SCRUM framework also allows the testers to have review sessions with the requirements for any change requests or scope creep.
1. How can the current alignment be improved?
 - Working on any of the Team collaboration tools like Microsoft Project, TFS, JIRA notifies the entire team whenever a change or a development is being made.
 2. What are the expected benefits of an improved requirements-testing alignment?
 - The process of building a Product becomes Error free, developers can be more productive with the requirements-testing alignment providing the overall Blue Print.
 - Production drawbacks can be overcome as the verified & validated details are documented in advance.
 - This alignment process can act as Regulations for the development team from the End User Context.
 3. How can the alignment be measured?
 - The Functional and Non-Functional requirements needed to be mapped systematically over the manual and system testing which would provide the extent of the effectiveness of the alignment.
 - Specifying the Non-Functional requirements would be more effective in determining the acceleration of the software development process.
 - In SCRUM framework the velocity of the Sprint could also be an indirect measure provided the Requirements Engineering is aligned with testing process.
 - REST driven approaches are also being developed by few companies through research which can provide the effectiveness of the program testing.
- What are the common problems that you've encountered with Requirements Engineering and Validation and Verification.
 - Most of the problems start from the requirements gathering and analyzing as they form the basis.
 - UML diagrams should be used effectively to understand the Requirements Context, Purpose and the Goal.

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- Lack of proper Strategies in defining the Policies for requirements engineering provides ineffective and more error prone documentation for verifying and therefore validating the requirements.
- Lack of proper Requirements Traceability Matrix to guide the Functional and Performance testing.
- Lack of Project Management tools for team coordination and collaboration.
- Lack of Interactions in place of Policies.
- Lack of Working Software Models rather than Documentation.

Lack of reviewing the Change.

A.7. Transcript 7

Requirements, verification and Validation for Software Engineering Process Improvement.

- What is the current state-of-practice in alignment of requirements and testing in your organization?
 1. What are the challenges in requirements related to verification and Validation?
 - {RL} The challenge is understanding the product or application. The requirements do not always tell you how an application works prior to the enhancement. Receiving a demo from a SME before reviewing the requirements is helpful.
 2. What are the challenges in verification and validation related to requirements?
 - {RL} The challenges are clear and concise acceptance criteria. This often starts out as a high-level validation as the user does not enclose the specifics until questioned.
 3. What are the current artifacts and processes related to requirement-testing alignment?
 - {RL} The artifact we use is a Test Plan. This document describes the approach taken to test the requirements. SME or business sign-off of this document is required to ensure we are covering all applicable functionality.
 - {RL} We follow the SDLC process to ensure requirements are fully completed.
- What is the desirable future state in alignment of requirements and testing for Software Engineering Process improvement?
 1. How can the current alignment be improved?
 - {RL} The desired future state of requirements would be to include how the product functions today and how it will work tomorrow. Often the person who wrote or tested the function is not developing or testing the enhancement.
 2. What are the expected benefits of an improved requirements-testing alignment?

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- {RL} The benefits are understanding the current and future state of the product or function. This allows for more in-depth testing since the process and changes will be clear.
- 3. How can the alignment be measured?
 - {RL} This can be measured in the amount of additional meeting hours after the design phase. Since the requirements should complete after design, the number of hours wasted going back to the SME and reviewing the requirements will be saved.
- What are the common problems that you've encountered with Requirements Engineering and Validation and Verification.
 - 1. {RL} Scope creep. As the SME discusses the requirements, new requirements are identified and not allocated for. This makes the validation of the requirements difficult as the acceptance criteria is constantly changing.

A.8. Transcript 8

Requirements, verification and Validation for Software Engineering Process Improvement.

- What is the current state-of-practice in alignment of requirements and testing in your organization?

For some projects testing team gets involved in the requirements gathering phase so they are aware of the requirements and not wait till the product is delivered for testing.

- What are the challenges in requirements related to verification and Validation?
Requirements are not validated during the scope definition has a greater impact on the product delivery.

- What are the challenges in verification and validation related to requirements?
Verification process becomes tedious and sometimes impossible if requirements are incorrect.
If requirements are not validated, then we will not be building a system that business wants.

- What are the current artifacts and processes related to requirement-testing alignment?
Develop Test case, execute test case and track defects.

- What is the desirable future state in alignment of requirements and testing for Software Engineering Process improvement?
It is desirable to have Verification & Validation from the beginning of the project, that will help us to meet deadlines and in turn keep project in lower risk from a cost overrun.

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- How can the current alignment be improved?
More intense agile and requirements-testing will help the current alignment improve.
- What are the expected benefits of an improved requirements-testing alignment?
Requirements Testing helps to determine if a requirement is feasible from a time, budget and resources perspective.
- How can the alignment be measured?
Iterative agile process with milestones achievement can help in measuring the progress.
- What are the common problems that you've encountered with Requirements Engineering and Validation and Verification.
Sometimes even for small changes, following this process is an overhead which can be avoided.

A.9. Transcript 9

Requirements, verification and Validation for Software Engineering Process Improvement.

- What is the current state-of-practice in alignment of requirements and testing in your organization?
 1. What are the challenges in requirements related to verification and Validation?
 - Business not able to provide a complete requirement
 - Business should have identified SME and dedicate to project or requirement.
 2. What are the challenges in verification and validation related to requirements?
 - With incomplete requirements it is always a challenge for testers to build test cases beforehand.
 3. What are the current artifacts and processes related to requirement-testing alignment?
 - Submit basic requirement to IT or vendor
 - Gather requirement based request
 - Review requirement with business
 - Review requirement with developer and Architect
 - Estimate project
 - Start design and development
 - Developer Testing
 - QA testing.
 - Business testing

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- What is the desirable future state in alignment of requirements and testing for Software Engineering Process improvement?
 1. How can the current alignment be improved?
 - Need to have acceptance criteria of each user story or requirement
 2. What are the expected benefits of an improved requirements-testing alignment?
 - Less bugs and lesser timing of development and product delivery is quicker and lesser cost of development.
 3. How can the alignment be measured?
 - Developer and business should work together to be same page. Developer should have easy approachable to business person who is contact of business and clarify all question ASAP. Developer should give often demo, that's visualize the requirement for business.
- What are the common problems that you've encountered with Requirements Engineering and Validation and Verification.
 - Multiple contact persons in business
 - Not being able to find availability

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Appendix B: whitepapers used for data collection

B.1. American Software Testing Qualification Board, Inc. (2017) A Case Study: 14 Lessons Why Quality Doesn't Just Happen. Retrieved from: <https://www.astqb.org/sections/whitepaper-14-lessons-quality.php>

B.2. Canadian Engineering Qualifications Board Software Engineering Task Force. (2016). White Paper on Professional Practice in Software Engineering. Retrieved from: <https://engineerscanada.ca/publications/white-paper-on-professional-practice-in-software-engineering>

B.3. IAG Consulting The Requirements Experts (2016). Executive Guide to Business and Software Requirements. Retrieved from: <https://www.iag.biz/resource/executive-guide-to-business-and-software-requirements/>

B.4. IBM, Bangalore (n.d.) Challenges of Managing a testing Project: (A White Paper). Retrieved from: http://www.qaielearning.com/KnowledgePapers/Challenges_Testing_Project.pdf

B.5. Infosys (2017). QA Strategy to Succeed in the Digital Age. Retrieved from: <https://www.infosys.com/it-services/validation-solutions/white-papers/documents/qa-strategy-succeed.pdf>

B.6. Micro Focus (2011). Successful projects start with high quality requirements. In Micro Focus White paper. Retrieved from: <http://dthomas-development.co.uk/wp-content/uploads/2014/05/White-Paper-Successful-projects-start-with-high-quality-requirements.pdf>

B.7. Micro Focus (2016). Top 5 Software Development Challenges. In White Paper. Retrieved from: https://www.microfocus.com/media/white-paper/WP_Top-5-Software-Development-Process-Challenges_Final.pdf

B.8. Pointe Technology Group, Inc.(2005) Software Testing and Quality Assurance White Papers. Retrieved from: <https://pdfs.semanticscholar.org/0d9a/3ee66a46bf4c3a5bd3e9ac16f5bc01202110.pdf>

B.9. SQS India BFSI Limited (2015) Whitepaper: SQS Requirement Development & Management Framework. Retrieved from: https://www.sqs.com/_resources/whitepaper-requirement-development-and-management-framework.pdf

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Appendix C: Snapshots of the coding tool

C.1. Code Manager

The screenshot displays the ATLAS.ti Code Manager window. The left sidebar shows a tree view of code groups under 'Req and test Alignment'. The main area is divided into two panes. The top pane, 'Search Code Groups', lists code groups with columns for Name, Grounded, Density, Groups, Created by, Modified by, Created, and Modified. The bottom pane, 'Search Codes', shows a list of quotations for the 'Problems' group, with columns for ID, Name, Start, and End.

Code Groups	Name	Grounded	Density	Groups	Created by	Modified by	Created	Modified
Artifacts	17	0	Administrator	Administrator	6/26/2018 7:28 PM	6/26/2018 7:28 PM		
Benefits	18	0	Administrator	Administrator	6/26/2018 7:28 PM	6/26/2018 7:28 PM		
Improve	21	0	Administrator	Administrator	6/26/2018 7:28 PM	6/26/2018 7:28 PM		
Measure	6	0	Administrator	Administrator	6/26/2018 7:28 PM	6/26/2018 7:28 PM		
Problems	32	0	Administrator	Administrator	6/26/2018 7:28 PM	6/26/2018 7:28 PM		
Req-Challenges	21	0	Administrator	Administrator	6/26/2018 7:28 PM	6/26/2018 7:28 PM		
Test-Challenges	27	0	Administrator	Administrator	6/26/2018 7:28 PM	6/26/2018 7:28 PM		

ID	Name	Start	End
1:5	tight deadlines	1774	1788
1:20	incomplete requirements document	4169	4200
1:22	Scope Creep	1892	1949
2:1	lack of communication between IT and business	345	391
2:4	spend of lot of money	725	745
2:5	lack of go to person who knew the business process really well	1034	1095
2:9	single point of failure situation on team	916	1095
2:10	Stop blaming	1730	1742
2:16	Lack of Coordination and better communication between QA and business...	2271	2347
2:17	Lack of knowledgeable PMs	2497	2522
3:1	verification is possible only after production deployments	299	356
3:2	not be sufficient data to mean all use cases	406	449
3:3	Changes in requirement	526	548
3:4	Scope Creep	706	819
3:16	Change in requirements	2504	2525
3:17	change in team members	2580	2601
3:18	Communication gap	2715	2731

C.2. Interview Quotation Manager

The screenshot displays the ATLAS.ti Interview Quotation Manager window. The left sidebar shows a tree view of code groups under 'Req and test Alignment'. The main area is divided into two panes. The top pane, 'Search Code Groups', lists code groups with columns for Name, Grounded, Density, Groups, Created by, Modified by, Created, and Modified. The bottom pane, 'Search Codes', shows a list of quotations for the 'Problems' group, with columns for ID, Name, Start, and End.

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Measure	6	0	Administrator	Administrator	6/26/2018 7:28 PM	6/26/2018 7:28 PM		
Problems	32	0	Administrator	Administrator	6/26/2018 7:28 PM	6/26/2018 7:28 PM		
Req-Challenges	21	0	Administrator	Administrator	6/26/2018 7:28 PM	6/26/2018 7:28 PM		
Test-Challenges	27	0	Administrator	Administrator	6/26/2018 7:28 PM	6/26/2018 7:28 PM		

ID	Name	Start	End
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3:17	change in team members	2580	2601
3:18	Communication gap	2715	2731

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C.3. Query Manager

The screenshot displays the Query Manager interface. The top menu bar includes File, Home, Search Project, Analyze, Import & Export, Tools & Support, and Query Tool. The Query Tool tab is active, showing a search for 'Req-Challenges' and 'Test-Challenges'. The search results are displayed in a table with columns for ID, Name, Document, and Density. The table lists various search quotations, such as 'Sometimes business people will have very limited knowledge or understa...', 'lot of gaps in the requirements', 'Scope Creep', 'lack of communication between IT and business', 'failed to gather guild software based on business needs', 'business requirements kept changing frequently', 'lack of go to person who knew the business process really well', 'single point of failure situation on team', 'Changes in requirement', 'Communication gap', 'Lack of clear and concise requirements', 'acceptance criteria not communicated before development', 'Stakeholders aren't always available', 'scope creep', 'lack of coordination', 'assumptions', 'time constraint', 'unclear requirements', and 'Business process not followed during the process of develop...'. The bottom status bar shows 'Term Quotations 32 Scope Quotations 0'.

C.4. Whitepaper Quotation manager view

The screenshot displays the Whitepaper Quotation manager view. The top menu bar includes File, Home, Search Project, Analyze, Import & Export, Tools & Support, and Manage Quotations. The Manage Quotations tab is active, showing a search for 'ASTQB' and 'testing-challenges'. The search results are displayed in a table with columns for ID, Name, Document, Density, and Codes. The table lists various search quotations, such as 'careful planning', 'team coordination', 'more importance to ship on time than to ship a quality prod', 'numerous bugs', 'Don't reward for shipping on schedule. Base rewards on quality measures', 'writing the requirements are in a rush', 'Always include QA and other project team members in all reviews to g...', 'scope creep', 'Good unit testing is part of the development', 'out dated/incorrect requirement', 'No use cases were written', 'team effort', 'half the bugs introduced in the requirements', 'unclear and vague requirements', 'scope creep', 'open communication', 'put quality first', 'testable requirements', and 'Risk analysis'. The bottom status bar shows '100 quotations'.

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C.5. Network manager

