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Developing domain-specific AI-based tools to boost cross-enterprise knowledge reuse and improve quality

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Abstract. MHWirth observed that several quality issues surfaced during the product commissioning phase causing a negative impact on project cost, delivery time and customer satisfaction. By using root cause analyses, this research found several links between poor quality and lack of proper knowledge management. With better knowledge management, most of these quality issues could be addressed and solved at an earlier stage of the product life cycle. Today different barriers are preventing organizations from taking full advantage of previously generated valuable knowledge. This paper explores how the use of Artificial Intelligence can boost knowledge reuse. The goal is to empower faster and more informed decision-making based on lessons learned in the past to minimize waste, rework, re-invention and redundancy.

Introduction

Organizations in the oil and gas domain have suffered through several downsizing and large-scale layoffs in the past two decades. Releasing employees might solve the organization's short-term economic difficulties but is harmful in the longer term since the departing employees are causing loss of critical knowledge (Sumbal, Tsui, See-to, 2018). Organizations have to make an effort to fill knowledge gaps caused by turnover, retirement and job rotation. Therefore, organizations now realize that it is not the product itself but the knowledge behind the product that should be considered as their most valuable asset. Knowledge gained from one development project can be used as leverage in a competitive market, and the same knowledge can be reused to improve the robustness of future products by building upon previous experience.

This research was conducted in the oil and gas domain. MHWirth is an internationally based supplier with long experience delivering various complex solutions for the international onshore and offshore drilling market. The company has offices in 12 different countries worldwide and estimates that more than 500 platforms, drill ships, semi-submersible and jack-ups have equipment delivered by MHWirth.

Background

Akastor ASA was established in 2014 as an investment company after a demerge from the Aker Solutions Group. A portfolio of oil service companies, including MHWirth, shaped Akastor for long term value creation. As a descendant of the Aker-group, MHWirth inherited the project execution model (PEM) for guiding and monitoring complex projects. Recently MHWirth developed a proprietary DRIVE© model tailored from their own experience and with an aim to replace PEM. The model is illustrated in Figure 1. Overall the purpose of the DRIVE© model is to have a standardized coordinated delivery of complete projects [MHWirth, 2019]. Similar to PEM, DRIVE© is a gate-based model with predefined workflow and tasks that need to be executed and closed at each stage before entering next. This method helps the management to evaluate project progress and, if required, take measures for improvement.

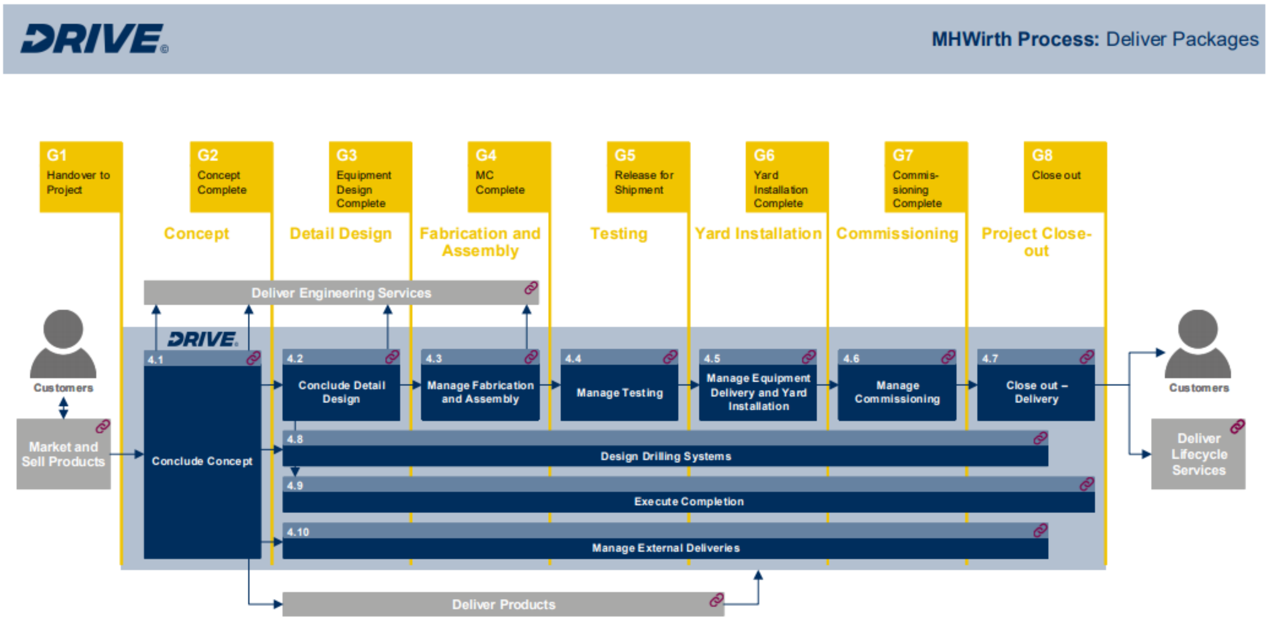

Figure 1: DRIVE© model [MHWirth]

After a project has been initiated and completed up to commissioning phase it is possible to have a retrospective view on the project execution. At this stage, it is possible to analyze non-conformities that surfaced during testing and verification up to this point. Despite several gate reviews, non-conformities are still able to slip through in the form of design issues, unfulfilled customer's requirements, outstanding mark-up in documents, software issues, interface problems, etc. These non-conformities can extend project execution, cause cost overrun and require re-engineering, which in the end results in customer dissatisfaction. MHWirth has a range of complex products that are often customized and manufactured at different locations. High variation in their deliveries makes it challenging to arrange test facilities where product engineers can verify their products thoroughly before they are shipped. Most of the integration and full-scale testing is performed during commissioning at the customer's location, i.e., shipyard or offshore installations. Therefore, several non-conformity issues end up surfacing during the commissioning phase where service engineers have been given an essential role as final quality assurance before the products are finalized and handed over to the customers. Service engineers' experience of non-conformity handling, integration testing and customer experience from commissioning phase is reflected in their technical reports. Unfortunately, this experience is not utilized fully since their technical reports are stored but seldom reused or analyzed. With a better infrastructure for knowledge reuse other service engineers and product engineers could benefit from findings in these reports.

The structured and unstructured documents present a formidable challenge at MHWirth. These documents reside within a number of disparate information systems such as Frames, WOSS, SharePoint, SAP, etc. As a result, just searching across all these different information sources is problematic. Service engineers during the commissioning phase must spend significant time to navigate through older Construction Change Notices (CCN) in Frames, or previously generated technical reports in

WOSS, to find relevant information that can aid them in their non-conformity handling. Without an effective knowledge reuse tool, this is a time-consuming task that most likely is neglected. Not only does difficult navigation inhibit knowledge reuse among service engineers but it also reduces knowledge sharing across departments resulting in product-engineers taking less informed design decisions, which can lead to further non-conformity down the production pipeline.

Systems engineering is an engineering discipline that aims to create and execute an interdisciplinary product development process to ensure that the customer and stakeholders' needs are satisfied in high quality, trustworthy, cost and schedule efficient manner throughout a systems' entire life cycle (INCOSE, 2015). Systems engineers focus on design and integration, and manage complex systems, which involve knowledge-intensive tasks, extensive problem-solving and decision-making activities. Therefore, both quality and knowledge management are important organizational project-enabling processes as defined in ISO/IEC/IEEE 15288.

Knowledge management (KM) takes advantage of the organization's most valuable assets, i.e., the collective expertise of its employees and business partners and facilitates its good use. KM can be described as processes that facilitate creation, access and reuse of knowledge using people, processes and technology (Cintra & Ribeiro, 2005). The terminology *knowledge* represents the understanding of a situation in its context and gives insight into the interactions within the system. It is the ability to identify leverage points and weaknesses and understand the future implications of actions and decisions taken to resolve problems (Stenholm, 2018). Further, knowledge can be divided into two forms; explicit knowledge and tacit knowledge. Explicit knowledge is often formally expressed in written forms by means of documents, procedures, software code, etc. While tacit knowledge is based on personal experience and insights, this form of knowledge is difficult to express since it is complex, unrefined often described as "know-how" (Stenholm, 2018).

Many organizations have embraced ISO 9000:2015 series as their quality management system. A certified organization consists of procedures describing how processes are performed, managed and how non-conformity is addressed. Continuous improvement is necessary to survive in a competitive drilling service market. To ensure quality MHWirth has implemented tools such as Non-conformity System (NCR), Preventive Action System (PAR), Frames Construction Change Notice (CCN) to identify, track and resolve non-conformities. Working towards continuous improvements requires a streamlined process where non-conformity is identified with their root cause and together innovative solutions are developed to resolve complaints and non-conformity. To carry out these processes, people need specific skills and knowledge. Experience and lessons learned can be expensive to gain and often are accumulated over an extended period of time. By emphasizing creating, sharing and reusing best practices and lessons learned, KM plays a crucial role in improving quality management (Cintra & Ribeiro, 2005; Stenholm, 2018; Mårtensson, 2000). The preserved and accumulated knowledge through time is called organizational knowledge and is an indicator of an organization's ability to learn from past experience thereby avoiding the repetition of previous mistakes and instituting adoption of proven good practice. In 2018, the International Organization for Standardization released standard ISO 30401:2018 to support organizations in developing knowledge management systems that effectively endorse and enable value created through knowledge.

According to the DIKW[1] pyramid (Ackoff, 1989), knowledge is built upon data and information. Data is described as a set of discrete objective facts or observations. By organizing and giving data context, it becomes information. Today organizations sit on a significant amount of stored data and information spread over different databases that are not being taken full advantage of. Storing data is the easiest part of KM and tangible for most organizations. But managing and analyzing a large amount of data to extract valuable insights without proper tool can be an overwhelming task and become a barrier to effective knowledge reuse (Riege, 2005). Therefore, KM can realize benefits

[1] The acronym stands for Data, Information, Knowledge and Wisdom, which were proposed by Ackoff as a layered view of the successive value of collected facts and observations gained through analysis.

from Artificial Intelligent (AI) as evidenced by the dramatic increase in interest to apply these methods to KM (NSTC, 2019). AI uses powerful computational capability to learn from experience, adjust to new inputs and perform human-like tasks (Arel, Rose, Karnowski, 2010). A KM infrastructure based on AI can effectively enable discovery of hidden organizational knowledge, smarter filter capability so only relevant information is extracted, automated reasoning, visualization of data to facilitate better decision making and make it accessible for the organization as a whole.

Natural language processing (NLP) is a major research area within AI that can be used to analyze and extract information from a variety of text sources based on three cognitive skills; learning, predicting and self-correcting (Khurana, 2017). Learning focuses on acquiring data and using algorithms to turn data into actionable information by extracting meaningful insights and patterns. Predicting uses gathered information to anticipate plausible future information, while self-correcting continuously fine-tunes algorithms to ensure the outcome is as accurate as possible. Cognitive search and sentimental analyses are two methods that are based on NLP understanding of human language. Cognitive search taps into organizations structured and unstructured data and with the help of AI can improve users' search queries by only extracting relevant information from multiple and diverse data, which enables knowledge discovery. Sentimental analyses are used to classify emotion within the text. For example, it is a method that can be used to determine between a positive, negative and neutral customer review of the product.

According to the International Data Corporation (IDC, 2015) 46% of workers cannot find the information they need almost half of the time. Info Centric Research (ICR, 2011) stated that 54% of decisions are made with incomplete and inadequate information. Therefore, AI can assist in turning the organization's data and information into actionable knowledge. Stenholm (2018, p. 01) asserts that “Actionable reusable knowledge presented at the right time to the right individual in a digital short condensed format will lead to better decisions, driving innovation and effectively reduce overall product realization lead-time.”

Vertical Pipe Handler (VPH) is one of many products in the MHWirth portfolio. The VPH (figure 2) system is designed to lift the stand and transfer to and from the fingerboard. It contains of two machines, Lower Guiding Arm and Bridge Crane. The system contains hydraulics, mechanical parts, and an instrument and control system that enables automatic sequences. For safe and efficient working conditions, all the VPH systems are controlled from the driller's control cabin (MHWirth). A component breakdown of VPH can be found in appendix C.

Figure 2: Vertical pipe handling (VPH) [MHWirth]

With this research, the author investigated MHWirth's employees’ awareness of KM to solve non-conformity. In addition, the research was used to explore methods that can be used to boost knowledge reuse and take advantage of explicit knowledge generated during the commissioning phase. Method were evaluated for their ability to break down knowledge reuse barriers and make actionable knowledge available instantly. Three questions (RQ) were proposed to direct the research.

RQ1) Can quality issues discovered during the commissioning phase be linked to poor knowledge management?

RQ2) How can cognitive search boost knowledge reuse and improve communication across different departments?

RQ3) How can DRIVE© model can benefit from cognitive search and sentimental analyses?

Methods & Tools

This research constitutes a case study of the author's employer and used a survey, interviews, literature review and document archives as sources of data. Data was collected by using a mixed method approach (Boh, 2008) which is a coordinated combination of quantitative and qualitative methods. For the quantitative method, Microsoft Forms© was used to generate an online survey that was used to gather statistical data from a larger group. These were complemented by in-depth interviews since interaction with an employee can clarify and give new perspectives to the case. Customer focus and continuous improvement and knowledge management were subjects for both surveys and interviews. The first two mentioned subjects are also the core values of the company.

Literature review was conducted on previous publications on systems engineering, quality management and knowledge management. Standards ISO 9001:2015 Quality Management, ISO 30401:2018 Knowledge Management Systems and ISO/IEC/IEEE 15288 were also reviewed. These were complemented with the INCOSE Systems Engineering Handbook. MHWirth internal documents such as technical reports, non-conformity reports, software change reports were analyzed.

During the research, several AI-based software platforms were explored by the author to find a solution that fits the purpose of this paper. The criteria were to find a platform that can extract a large amount of data from documents and make it useful for queries without requiring experience with high-level programming skills. The software should be able to demonstrate different use cases that can boost knowledge reuse. Author first attempted to use Neo4j, GraphDB and Protégé for this purpose but found their respective solutions to be complex and less likely to be implemented by MHWirth. Therefore, the author opted for platforms providing ready to use solutions and selected Watson Discovery and Natural Language Processing from IBM Cloud platform (Appel, Candello, Gandour 2017). Analyzing data from an entire enterprise can be an overwhelming task, therefore, to limit the research, only documents related to Vertical Pipe Handler (VPH) were analyzed.

Work & Results

Results from the online survey. To gain more insight into employee's attitudes towards non-conformity, customer focus and knowledge management, an anonymous survey was carried out in the early stage of the research. The survey was distributed online and contained 20 questions with multiple choice answers. The questions and the corresponding results are given in Appendix A. Employees were asked to choose the answer that described their current work environment best. The multiple-choice answers encouraged employees to reflect on the present and desired state (Welo, 2013).

Service engineers, product engineers, quality and technical management engineers (HSSEQ) and workshop workers were elicited for data collection (figure 3). In this way, the research was able to gather valuable insight into the survey topics from multiple perspectives. The engineering department contains 73 product and design engineers. 15 of them participated in the online survey. 6 of 49 available service engineers participated. This number could be higher but most service engineers were either out on an assignment or on time off. HSSEQ contains of 10 employees and 3 of them participated in the survey. In addition, employees from workshop and technical support contributed to the online survey.

After the data from the survey was collected, Microsoft Forms©' Idea functionality was used to analyses the results. This feature uses association rule analysis to provide insights across multiple questions by discovering patterns between the answers. Not all the ideas that were provided by Forms were useful, therefore data were exported to Excel for further association analysis.

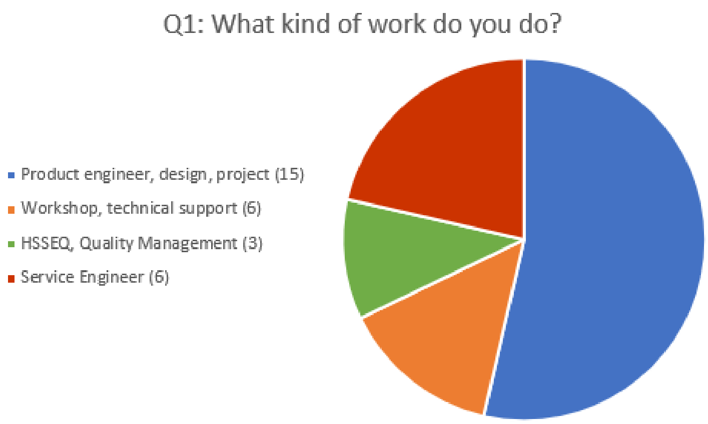

Figure 3: Participants in the online survey

Online survey questions 7 and 9. A large percentage of the total population (49%) who participated in the survey answered «product development, manufacturing and commissioning are not seen as knowledge-generating processes but only as a sequence of tasks necessary to design and produce a product that will meet customer specifications» and most of them (93%) answered «knowledge is generated, saved and used by the individual. Key competences are dependent on a few individuals». This feedback indicates low focus and awareness of knowledge management and an organizational culture that does not endorse knowledge sharing. Eventually, this will generate knowledge silos between departments and locations.

Online survey questions 8 and 12. The majority of all participants in the survey (67%) stated; «No effective system for sharing and spreading new knowledge in the organization exists. » In the group «Engineering and project management» 80% stated that feedback from commissioning is either «poor» or «feedback is valued but sometimes overlooked. »

Online survey questions 16, 17 and 20. Only 61% of the participants answered they have used the NCR system, and 83% expressed either «NCR doesn't contribute to continuous improvement» or «it helps to report, but the NCR system could be better. » Therefore, unsurprisingly several participants of the survey also stated that they used «direct communication with responsible persons through emails or phone calls» to report non-conformity. This feedback indicates that NCR is not the preferred method to report non-conformity.

Online survey questions 2 and 13. The majority of the engineering group (80%) stated they « receive customer requirements "over the wall" through sales, marketing or other departments". » The same group also expressed they «seldom experienced non-conformity. » 84% of all Service engineers «routinely interact directly with customers or end-users» and most of them (67%) «experience non-conformity often or always. » This suggests a typical divergence between field and office. Service engineers who routinely interact with the customers experience more non-conformity than product engineers at the office. This feedback indicates that not all non-conformity is reported back to product engineer, and some of the minor non-conformity is solved in the field by service engineer.

Results from the in-depth interview. In addition to the survey, semi-structured in-depth interviews were conducted. The purpose was to have a retrospective view on the non-conformity discovered during the commissioning phase and in collaboration with the employees, a root cause analysis was performed. The method "5 whys" was used for this purpose (Serrat, 2017). It is a simple method that helps to determine the relationship between different root causes of the same problem. The employees were presented the problem statement "commissioning activity halted due to non-conformity" and repeatedly asked "why" until a suggested root cause was identified. Similar to the online survey, the participants had a background from commissioning (3), HSSEQ (3) and engineering (4). Total 10 candidates were interviewed. This facilitated reflection on the same problem from different points-of-view.

Complementing with in-depth interviews gave the author better understanding of responses from the online survey. Lack of infrastructure for effective knowledge sharing means the employees need to rely more on their tacit knowledge. Service engineers work in rotation and often travel to different locations for each assignment either alone or as a team. With high variety in MHWirth products, service engineers face two challenges, time and application gap (Corin & Bergsjö, 2018). Each assignment will be slightly different which will require a different approach to handle non-conformity. After time spent off from work, service engineer's tacit knowledge begins to diminish and makes them more dependent on explicit knowledge. Several service engineers expressed that better knowledge sharing among them, explicit or tacit, could increase their productivity and help them make better decisions based on knowledge gained from others.

Product engineers expressed they received little feedback and would benefit from more input from operations to improve their work. Because of time constraint, they weren't able to reflect on previous non-conformities and learn from the past. In, general most employees agreed the current NCR system has room for improvement since most of them find it cumbersome to use. The in-dept interviews identified totally eight root causes and these are presented in their entirety in appendix B. Figure 4 presents a subset of these that can be directly related to knowledge management.

Review of the current state. With the current setup at MHWirth, to navigate through old technical reports employees have to access WOSS and make search queries based on either product code, rig number or equipment number. Employees need to be familiar with these codes beforehand or refer to MHWirth's coding manual. Searching through WOSS returns a list of documents sorted by document number, short description, date and comment section. Not all the documents listed in the search results might be relevant and the employees have to manually process the document one by one. It is a time-consuming task especially since the comment section usually does not provide adequate information. Frames and SharePoint have the same approach where documents are sorted by predefined categories. Currently, MHWirth is working on migrating most of their documents to SAP.

Neither WOSS, SharePoint or Frames are designed to process or analyze large volumes of data. They do provide indexing, tagging and keyword implementation to find information but fail to engage employees to discover organizational data that can assist them with data-based decision-making and increase their productivity.

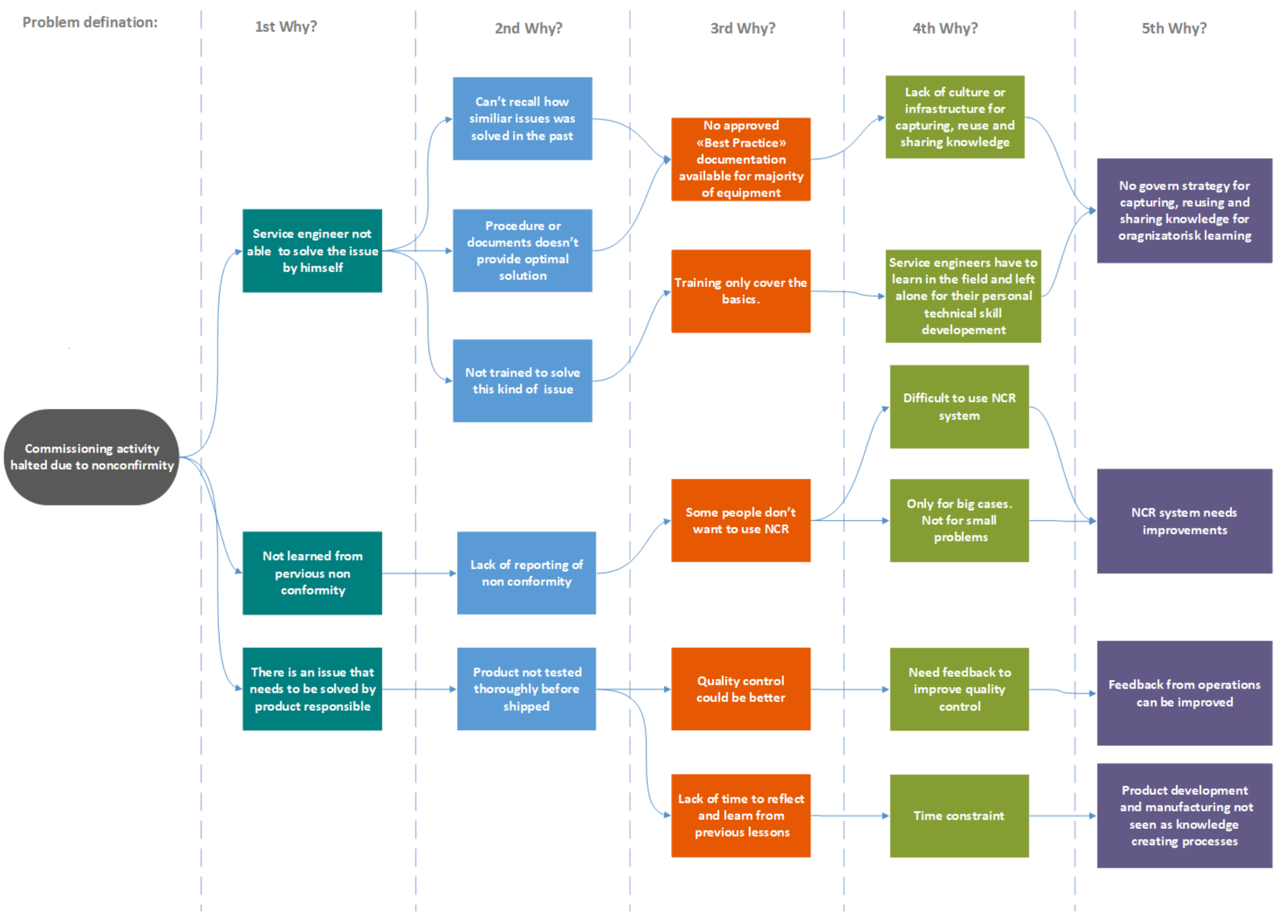

Figure 4: Five whys? Root cause analyses.

Developing AI knowledge reuse model. To boost reuse of previously gained organizational knowledge, the author used IBM Cloud platform to develop a domain-specific cognitive search and sentimental analyzer process as illustrated by the flowchart in figure 5. To enable data discovery across different platforms, the author extracted various documents of enterprise data from WOSS, SharePoint and Frames. Five hundred technical reports, technical guidelines and CCN over the past five years across various projects related to VPH were analyzed. These documents were typically generated during the commissioning phase, from service missions and technical support that provide insight into what kind of non-conformity our customers have been facing historically. The extracted documents are typically stored in Word or PDF format containing unstructured data with domain-specific language. Frequent use of abbreviations and technical terms will make little or no sense for analytic tools that are not familiar with the terminologies. The author first attempted to use text mining tools to extract entities and categorize them automatically, but most of the tools failed to deliver satisfying results. The suggested entities were either too or vague or incorrect. Therefore, it was necessary to build an architecture merging different abbreviations and defining the relationship between terminologies that can later be processed by a natural language processing (NLP) tool (appendix C). After viewing the results from pre-annotation small adjustments were made to the architecture to improve the results until a satisfactory score was above 0.75. This is an indication that the model has enough samples and corrections to build a fundament for an algorithm.

IBM provides a tool called Smart Document Control. Instead of analyzing text, the tool can be trained to look for fields inside the documents and make it possible to differentiate between relevant text and noise. Repeating text in documents such as header, footer and title create noise for the search engine and were filtered out. Instead, fields that contain information regarding customers and document authors were preserved. Further relevance training was carried out to fine-tune the algorithm before it was applied to the larger set of documents. At this stage the author had converted enterprise data into a format that could be processed by a cognitive search engine and sentimental analyzer.

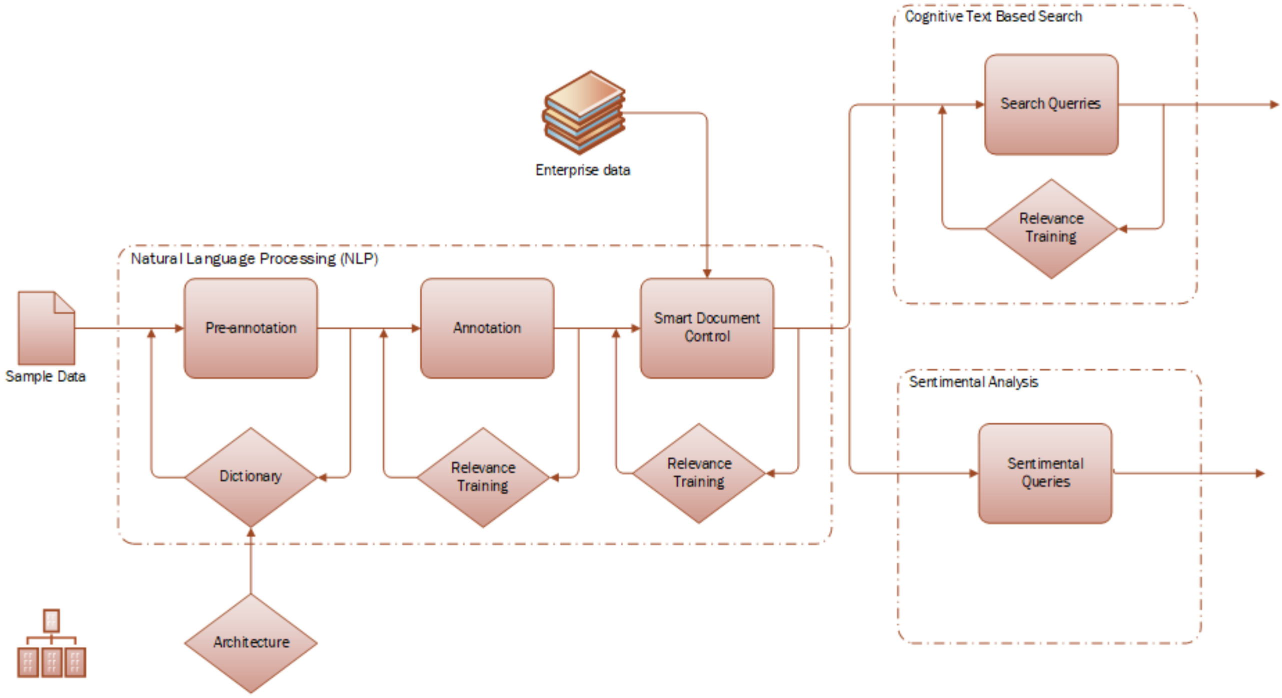

Figure 5: Developing domain specific AI tools.

Cognitive search. Cognitive search has a different approach than previously described search methods. It uses natural language-based search queries and returns results in text phrases. Employees don't have to rely on product code and can make search queries based on natural language formed as question. For example, user input is "Why can't I open fingerboard latch?" will search through the databases and will return the top three documents and only present sections that contain relevant information instead of the whole document. This enables the service engineer to quickly get insight into how the same or similar issues were handled in the past and can act accordingly. For product engineers this is valuable information to get insight into what kind of issues appear in operations and determine if further product or documentation improvements are required. Figure 6 shows result from the cognitive search.

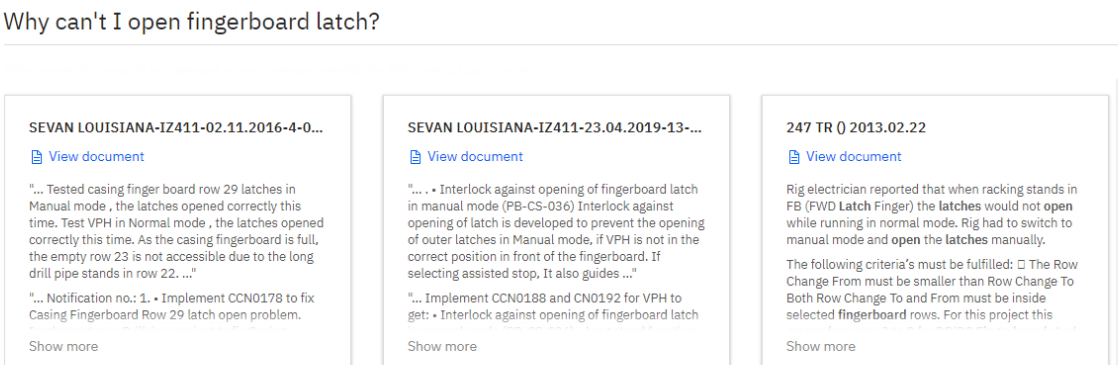

Figure 6: Text-based cognitive search result

Sentimental analysis. This method evaluates the text in the documents and extracts subjective information. It is a method often used to analyze a large number of customer feedback or sentiment on social media. The author conducted sentimental analyses on the gathered documents to investigate if it is possible to determine which product has more negative sentiment compared to others. By executing the sentimental analysis against the VPH architecture (described in appendix C), it was possible to identify which component of VPH has more negative phrases.

Figure 7 displays a query run on entity "hardware." This sort of analysis is not based on natural language and requires some skills to properly compose; the entity appears toward the end of the first line of the query. The results, given to the right, reveal that the hardware components "guide" and "trolley" have the majority of negative sentiments compared to other hardware. A higher number of negative sentiments represents more reported non-conformity for the specific hardware. The suggested reports were reviewed, and the sentimental sensitivity score was adjusted to <-0.65 until results were satisfactory.

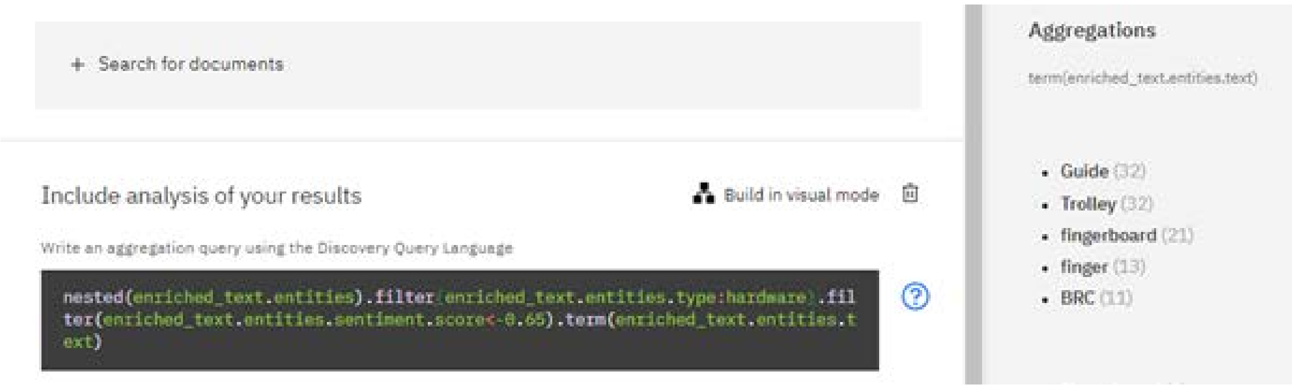

Figure 7: Sentimental analysis result of hardware

The same methods were also applied to entity "software" and "machine." The analysis, shown in figure 8, was able to differentiate between which software had the most reported issues in the past five years related to VPH. This enables us to get an overview where the majority of non-conformity is present before opening any documents.

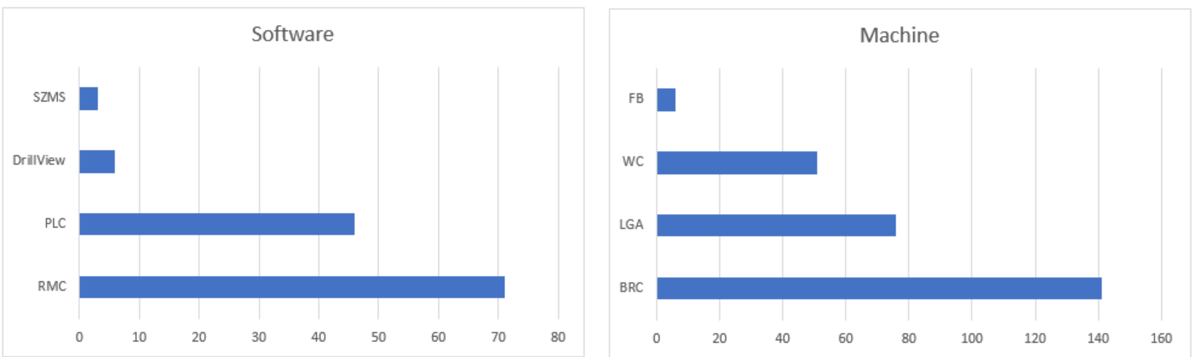

Figure 8: Sentimental analysis of Sofware and Machine

Discussion

RQ1: Can quality issues discovered during the commissioning phase be linked to poor knowledge management?

Using the results from a survey, followed by in-depth interviews. the author together with the employees identified several root causes for non-conformity that could be improved with better knowledge management. A summary of the findings can be categorized and visualized in a fishbone diagram (see Figure 9) to enable a better overview of the different root causes. In a socio-technical system like an organization, three types of categories of barriers exist that can prevent knowledge reuse; technology, organization and people (Riege, 2005).

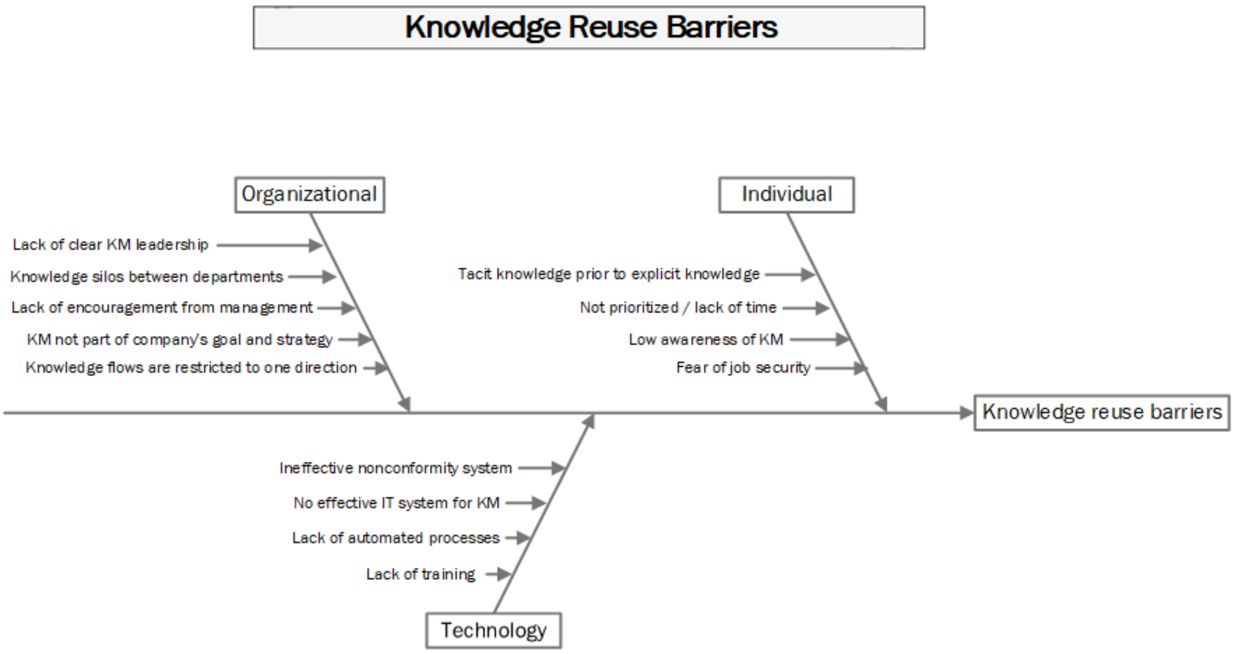

Figure 9: Fishbone diagram of root causes for knowledge reuse barriers (adapted from Riege, 2005)

Individual. During in-depth interviews, it was observed most employees generally had a low focus on knowledge management in their daily work. However, they understood that better knowledge sharing and reuse could improve their tasks, but these activities were not prioritized, encouraged or rewarded. Due to lack of knowledge sharing among engineers, their ability to resolve non-conformity depended on their own experience and skills (tacit knowledge). They preferred to handle non-conformity in one to one communication or by task groups resulting in suboptimal learning for the rest of the organization. In addition, some also feared that oversharing of their knowledge could put their position in jeopardy.

Organizational. Based on the research, MHWirth has no clear strategy that facilitates knowledge management as an integral part of the quality improvement system. The company already has a comprehensive system and the employer's commitment to address non-conformity but could benefit from better knowledge management. The key competence still depends on few individuals, which creates knowledge silos and prevents sharing between departments and locations. In addition, this prevents evolving and maintaining organizational knowledge and the ability to solve non-conformity on the organizational level. "Reinventing the wheel" and "not learning from past mistakes" were some of the phrases that were used during the interviews. Some product engineers highlight lack of feedback on how products are performing in operation as useful knowledge that could help them improve their products.

Technology. An IT system that facilitates effective knowledge management is missing. Instead, knowledge is stored in different databases in various formats creating informational knowledge silos, which makes finding relevant information a time-consuming task.

Employers had mixed experience of the current NCR system. In general, employees reported non-conformity on a regular basis and understood the benefit for continuous improvement but was not satisfied with the current NCR system. Some of employees found NCR system to be cumbersome for reporting minor non-conformities which can cause underreporting of non-conformity.

Summary. In summary, engineers in the field believe the quality of their customer interactions would be enhanced by access to a rich historical archive that could help them troubleshoot any difficulties they encounter. Product developers could draw on the same information to improve products. The quality manager could also tap into this reservoir to evaluate the overall company performance and customer satisfaction.

RQ2: How can cognitive search boost knowledge reuse and improve communication across different departments?

This research only analyzed a fraction of data available at MHWirth. The benefits from cognitive search increase with a significant amount of data analyzed and continuously improved over time by a large number of queries. As previous stated, this research was conducted in a compressed timeline such that it never aimed to be on that level. The focus was to highlight the importance and value of knowledge management to address non-conformity and suggest a suitable tool. During the research, other tools such as "A3" and "engineering checklist" (Stenholm, 2016) were considered to improve knowledge management. Previous research and have proved positive results applying these methods for effective knowledge sharing (Jensen, 2019) and cross-boundary communication (Singh, 2016). However, the author feared that A3 would just become another document that is generated, stored but seldom reused.

Databases in MHWirth rely solely on the use of metadata, where documents are tagged while being generated or stored. By categorizing documents by project, product or discipline engineers are able to find matching documents but manually have to process the documents to determine the relevancy of the information they are seeking. However, engineers need answers to solve their problems, not documents. Therefore, quality issues can't be resolved solely on categorized data; to be useful, data have to be analyzed and processed from a system of systems perspective. The use of metadata allows engineers to search for information within a specific category but, at the same time, limits the search and prevents a holistic view of the information potentially available.

Domain-specific cognitive search developed during this research enables the extraction of relevant information from various sources and its presentation in small phrases that make the information retrieved immediately actionable. Despite having a small sample size of documents, but with the help of the domain-specific dictionary, the cognitive search was able to deliver answers that can support engineers to take more informed decisions based on how related non-conformity was handled in the past. In addition to increased knowledge reuse, the use of cognitive search will also increase productivity because it removes the necessity to manually log in to different databases and switching between applications to extract information. This will reduce a significant amount of unproductive time. Unlike searching through WOSS, Frames or SharePoint, the cognitive search will develop and adapt to user queries over time. During this research, the relevance training of the cognitive search was carried out and the tool was able to adapt to user input and deliver more accurate results.

Knowledge of non-conformity handling during the commissioning phase can be reused by other departments. MHWirth has a 24/7 service where customers reach out for technical assistance if they have an issue with one of our products. In most cases, 24/7 support is able to solve issues by themselves, but in some cases, they have to seek assistance from product specialists, who in turn divert their valuable time to answer questions. By using cognitive search, the customer service representative will not just respond more quickly to customer's inquiries but also be less dependent on product specialists.

One of the drawbacks of cognitive search is its reliance solely on explicit knowledge found in documents. Tacit knowledge, employee abilities to handle non-conformity based on experience and know-how, also needs to be transformed into written form before it can benefit others. Another advanced option that was explored briefly and is explained in Appendix D is graphic search, which makes it possible to connect an individual with knowledge, to display relationships and potentially increase the availability of tacit knowledge.

Summary. The exploration into over-the-counter AI products supports the vendors' assertions that these tools can help break down data storage silos and increase the availability and relevance of harvesting information from corporate archives. As an experienced commissioning engineer, the author was able to establish a proof-of-concept process that supports the value of using AI methods to improve KM and increase the quality of the company products, both in design, installation, and after-sale customer support. One limitation of the research has been the compressed timeline and the relatively small amount of data that could be processed for this exercise.

RQ3: How can DRIVE© model benefit from cognitive search and sentimental analyses?

Since the DRIVE© model has been introduced recently and is still under development, it is too early to answer this question definitively. The model has not been completely adopted as the backbone of the company's project execution, so the main focus for the author is to analyze the current model and suggest improvements. Currently, MHWirth does not have a dedicated R&D department, therefore, the DRIVE© model was developed with manufacturing in mind. Unlike Systems Engineering's V-model, the DRIVE© model currently does not include any feedback channels that facilitate early validation of project execution. There is no process for front-loading knowledge generated by employees in later stages that enables reuse of organizational knowledge to support critical decision-making and problem-solving activities in the early stage of the project execution. Errors embedded in decisions made during early development stages can cause non-conformity in the latter stages of the production line. Resources that could have been spent on other innovative work has to focus on late design changes and other rework. The total cost to handle non-conformity increases exponentially through the product life cycle (INCOSE, 2015). Figure 10 illustrates the recommended changes.

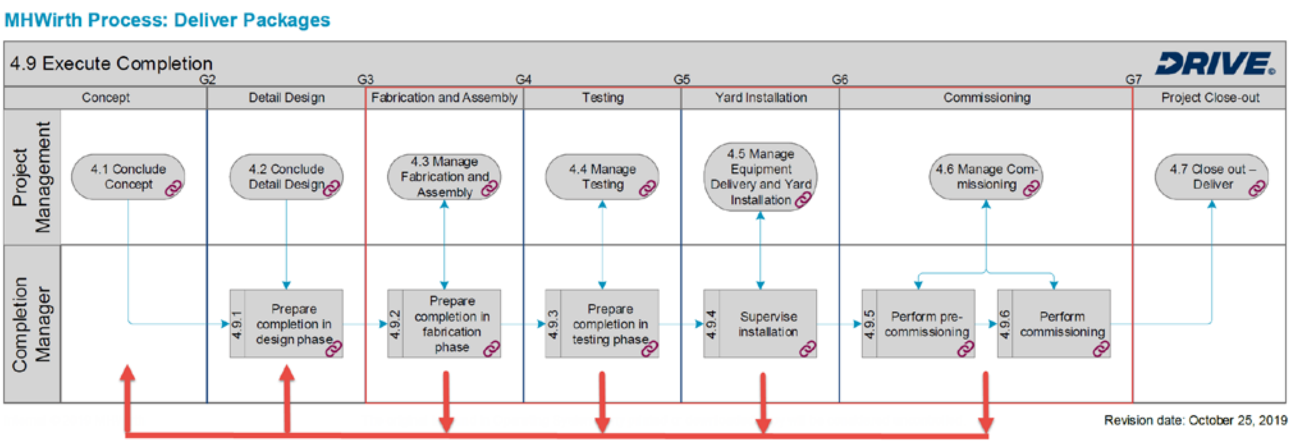

Figure 10: Suggested changes for DRIVE© model

After the project has been kicked-off and G1 closed, the project enters the concept phase. The DRIVE© model has an activity defined as "4.1.6 Manage product clarification." This is the stage where project management comes together with the concepts group and product departments for internal and external technical product clarifications. System and product concepts are reviewed and Technical Queries (TQ) are used to interact with customers. During this phase, knowledge-intensive tasks, extensive problem-solving and decision-making activities take place. To prevent ill-informed decisions and further non-conformity, organizational knowledge should be front-loaded and reused during this tender phase. Therefore, the knowledge gained from the latter stages such as manufacturing, testing, yard installation, and commissioning should be seen as valuable input for informed decision-making. Including representatives from these latter stages can be challenging, therefore knowledge needs to be available in other forms. A cognitive search built upon whole organizational data can empower faster and more informed decision-making based on lessons learned in the past to minimize waste, rework and re-invention.

In addition to using cognitive search, engineers can carry out a sentimental analysis of organizational data to gain insight into which products are not meeting the expected company quality standards. Sentimental analysis carried out in this research demonstrated that it is possible to separate products that have a higher amount of negative reports compared to other products. This enables engineers to discover which product is experiencing quality issues and do further investigation. These analyses can be front-loaded to the design phase to support the product engineer for making informed decisions to improve the products. After a correction has been made, the product engineer is able to measure the change in sentimental queries over time to monitor if the correction had the desired outcome. Product engineers can also benefit from graphic search, but the tool is more experimental and only presented in appendix D.

Gate reviews are important milestones for the project execution. Purpose of these reviews is to evaluate the project development progress according to the plan with a focus on HSSE, quality, time and cost. Representatives from HSSEQ together with project management will execute an audit of the project. Therefore, it is important to augment the "Gate Review Checklist" with previously gained lessons learned from other projects to prevent repetitive non-conformity. To increase transparency, findings from each gate review should be available immediately for dissemination of knowledge into the organization. Common practice is to carry out post review at end of the project where most of the knowledge has already been lost (Kotnour, 2000).

Summary. One deficiency of the current project execution model is a lack of formal feedback loops to bring later learning forward into new product development and product improvement. Feedback relies on adequate access to archival data, and improved KM using modern AI techniques is one way to facilitate knowledge sharing throughout the organization

Conclusion & future work

The main purpose of this research was to investigate MHWirth's employees' awareness of KM to solve non-conformity. MHWirth already has a comprehensive quality management system and employees' commitment to address quality deficiencies. Nonetheless, quality issues still surface during the commissioning phase. Therefore, to improve performance and reduce the root cause of these issues, management needs to look at methods than can contribute to improve the current quality management strategy. This research has highlighted the importance of having a retrospective view on non-conformity handling in the commissioning phase and learning from past experience. MHWirth could benefit of front-loading of knowledge generated during commissioning to early stages of product development to take better informed design decisions.

The research findings clearly indicate that current IT systems do not facilitate effective knowledge sharing. Therefore, this research investigated how MHWirth could benefit from AI tools to boost knowledge sharing and reuse. Cognitive search taps into organizational explicit knowledge and assists employees to take more informed decisions and increase productivity. Sentimental analysis can be used analyze trends and highlight which products are underperforming. However, these AI based tools have great capabilities but still require human interaction. When AI tools were left unsupervised, future iterations of the learning and feedback loop became less predictable. Therefore, it is important to have a clear strategy with well-defined architecture and use cases.

Implementation of cognitive search and sentimental analysis can enhance knowledge flow within the organization, but a tool alone is not a guarantee the knowledge shared will be knowledge used. This research highlights the individual and organizational cultural barriers that the company needs to overcome. Transition towards a knowledge driven organization requires commitment from top management to encourage processes that will promote cross-boundary knowledge sharing and reuse. The employees need to be convinced that sharing information is more beneficial than hoarding information. By focusing on capturing, sharing and reuse of proven good practice the collective expertise of the organization will surface and make MHWirth more information-driven and more transparent.

Future projects should apply systems engineering discipline to ensure that stakeholder needs as reflected in the root cause analysis exercise are met. Maintaining a focus on the importance of quality management and the continuous improvement of the project execution model will lead to happy employees and satisfied customers.

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——————, Operating System, Non-conformity, Corrective Action and Preventive Action

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Biography

Sajjad Sarwar has been working in the oil industry for 10 years. In 2009 he received his BSc degree in mechanical engineering with specialization in mechatronics from the University of Agder. Since then he has been working as a Service Engineer in various complex projects in the drilling market. In 2020 he earned a MSc degree in systems engineering from the University of South-eastern Norway.

Cecilia Haskins is an associate professor of systems engineering for the Norwegian University of Science and Technology. Her research is multifaceted and multidisciplinary with a focus on issues related to socio-technical aspects of lean systems engineering, improvements in project execution for production, and the education of the next generation of engineers. Cecilia has a PhD from NTNU, a MBA from Wharton Graduate University of Pennsylvania, and a BSc with honors in Chemistry from Chestnut Hill College in Philadelphia. She has been an INCOSE certified systems engineer since 2004.

Appendix A

Questions and analysis of responses from the online survey.

1. What kind of work do you do?

More Details

Sales and marketing, product ...	15
Workshop, technical support, i...	4
HSSE and Quality Management	3
Service Engineer	6

2. How do customer needs and requirements reach you?

More Details

I receive customer requiremen...	14
Marketing and other functions...	2
I routinely interact directly wit...	11
Through customer Purchase o...	9
Other	0

3. Which statement best describes the way our company works together with the customer to understand current and future customer's needs and requirements?

More Details

Customers do not have an int...	2
A few customers are viewed a...	14
Every customer has a central, i...	8
Other	6

4. How much impact do the customers have on product specification and design choices?

More Details

Company internal preferences...	4
Customer requirements, need...	12
"Customer first" is a core valu...	6
I don't know.	6
Other	4

5. How does feedback from customer reach you?

More Details

- Feedback from customers and... 4
- Feedback from customers and... 8
- Feedback loops are often filter... 9
- Feedback loops from custome... 5
- Other 2

6. How are complaints or warranty claims handled internally by our company?

More Details

- Complaints or warranty claims... 8
- The most frequent and seriou... 14
- Complaints and warranty clai... 5
- Other 3

7. What is the company attitude toward knowledge?

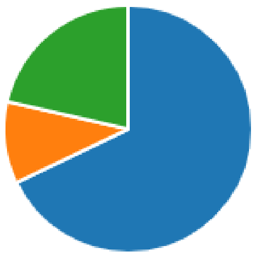
More Details

- Product development, manufa... 13
- The project manager has resp... 6
- Product development, manufa... 7
- Other 2

8. How is newly captured knowledge shared company-wide?

More Details

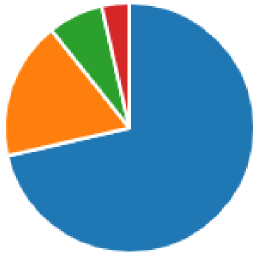
- No effective system for sharin... 19
- Knowledge is documented in ... 3
- Any knowledge gained is routi... 6
- Other 0



9. How does our company re-use captured knowledge?

More Details

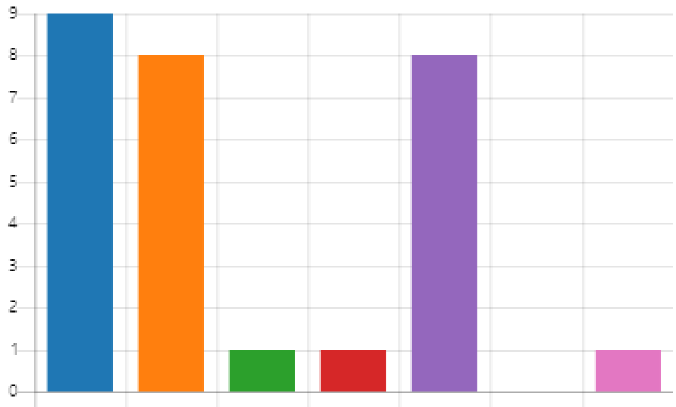
Knowledge is generated, save...	20
The company has a strategy f...	5
Knowledge is captured and st...	2
Other	1



10. How often do you re-use captured knowledge in your department?

More Details

Daily	9
Weekly	8
Monthly	1
Yearly	1
Project based	8
Never	0
Other	1



11. What action do you take to prevent nonconformity in your work?

More Details

I do my work to the best of m...	9
Actions are taken after custom...	5
I take action immediately, rep...	12
Other	2

12. How much impact do the nonconformity findings discovered during manufacturing or commissioning have on your work?

More Details

Limited influence. Poor or lack...	8
To some extent. Feedback is v...	12
Defined authority, responsibili...	5
Other	3

13. How often do you experience nonconformity in your work?

More Details

Often.	11
Seldom.	14
Never.	0
Nearly every project.	3
Other	0

14. How often do you report nonconformity?

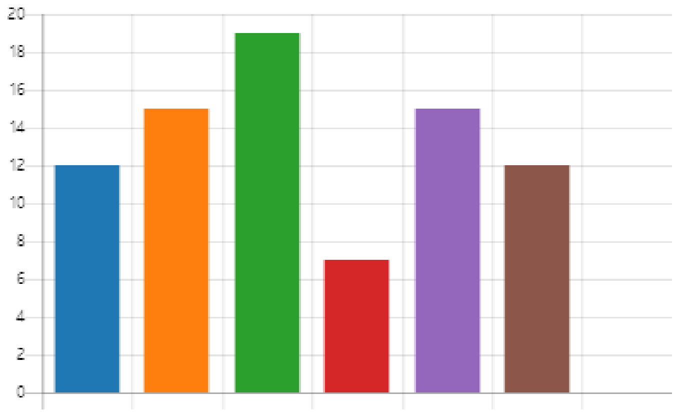
More Details

Always.	4
Often.	7
Seldom.	14
Never.	2
Other	1

15. What kind of nonconformity do you experience?

More Details

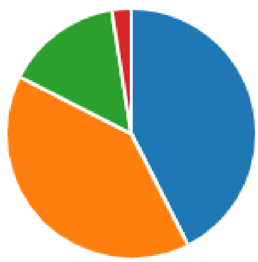
Incomplete or lack of procedu...	12
Incorrect documents such as ...	15
Software related issues.	19
Instrument related issues.	7
Mechanical, electrical or hydra...	15
Design related issues.	12
Other	0



16. How do you report nonconformity?

More Details

By using our Nonconformity (...	17
Direct communication with res...	16
I report back to my nearest su...	6
I don't. I am able to solve the ...	1
Other	0



17. Do NCR or Preventive Action Systems contribute to continuous improvement?

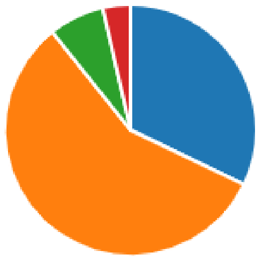
More Details

Yes, I do feel NCR or Preventiv...	4
It always help to report nonco...	18
No, I don't feel NCR or Preven...	2
Other	4

18. How often do you experience that the same or related nonconformity is recurring?

More Details

Often. Same or related nonco...	9
Seldom.	16
Never.	2
Other	1



19. How do you share knowledge gained after correcting nonconformity with your colleagues?

More Details

By writing reports, red mark u...	13
By informing my colleagues or...	14
I love using Yammer for this p...	0
I like to keep it to myself. If so...	1
Other	0

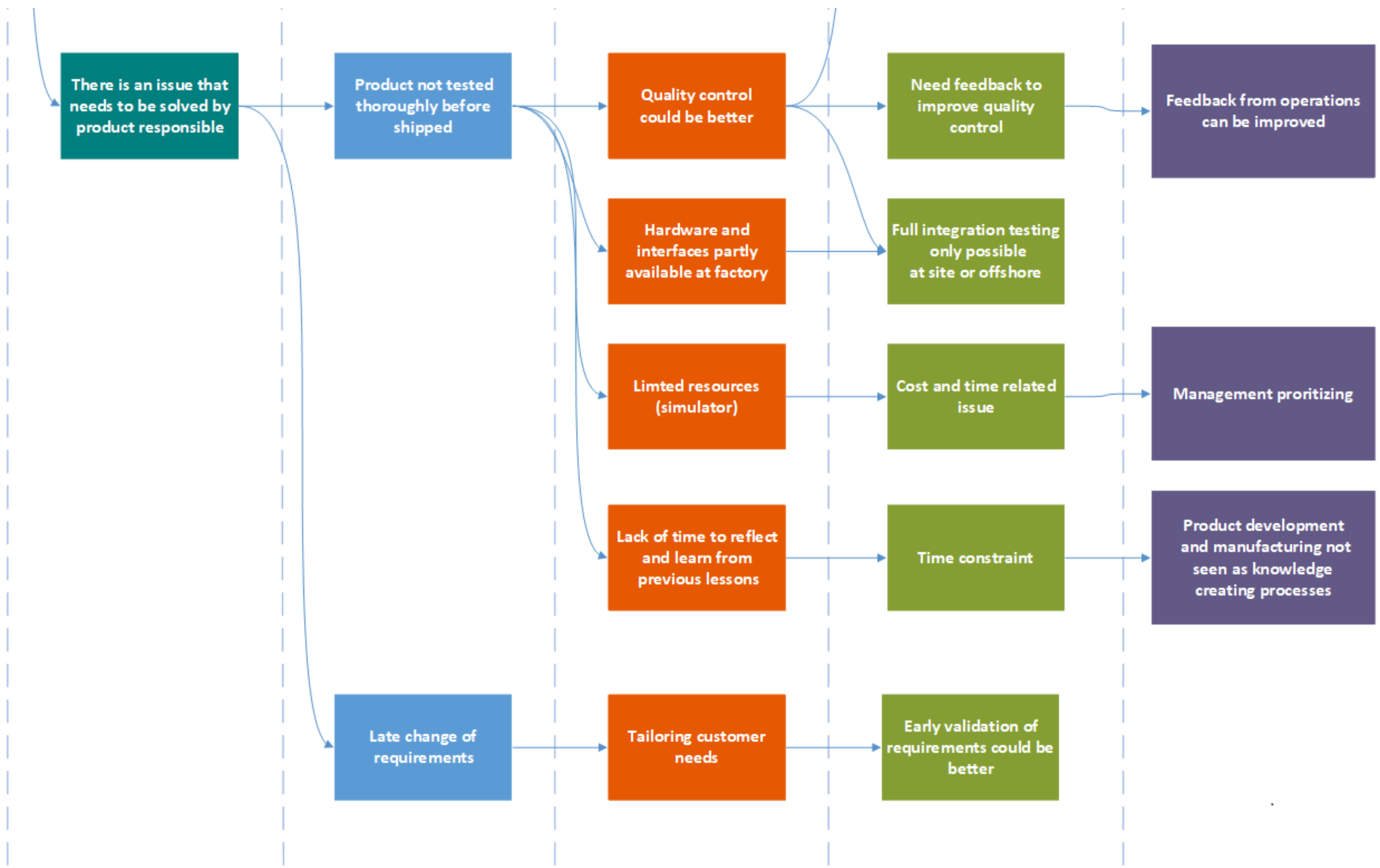
20. How affected are you by nonconformity in your daily work?

More Details

I'm able to focus on work and ...	6
I use significant time at my wo...	3
It occurs sometimes but I'm a...	17
Other	2

Appendix B

Figure 4 has been reproduced here to facilitate legibility and show all root causes identified during the research. Note, the figure extends over 2 pages.



There is an issue that needs to be solved by product responsible
Product not tested thoroughly before shipped
Late change of requirements
Quality control could be better
Hardware and interfaces partly available at factory
Limted resources (simulator)
Lack of time to reflect and learn from previous lessons
Tailoring customer needs
Need feedback to improve quality control
Full integration testing only possible at site or offshore
Cost and time related issue
Time constraint
Early validation of requirements could be better
Feedback from operations can be improved
Management proritizing
Product development and manufacturing not seen as knowledge creating processes

Appendix C

A top down decomposition of the Vertical Pipe Handler was chosen to define the relationships between the components. VPH system was split into subsystems hardware, instruments and software. This approach enables a strong capability to filter and analyze the data afterwards. As an example, the proximity switch is an electrical component, which is often described as "prox" in the reports. The switch is categorized as an instrument and same type is used by both the Lower Guiding Arm and Bridge Racking Crane which are subsystem of the VPH system. This approach is scalable and enables possibilities to look at intra-relationships such that the same architecture can be applied to other products provided by MHWirth.

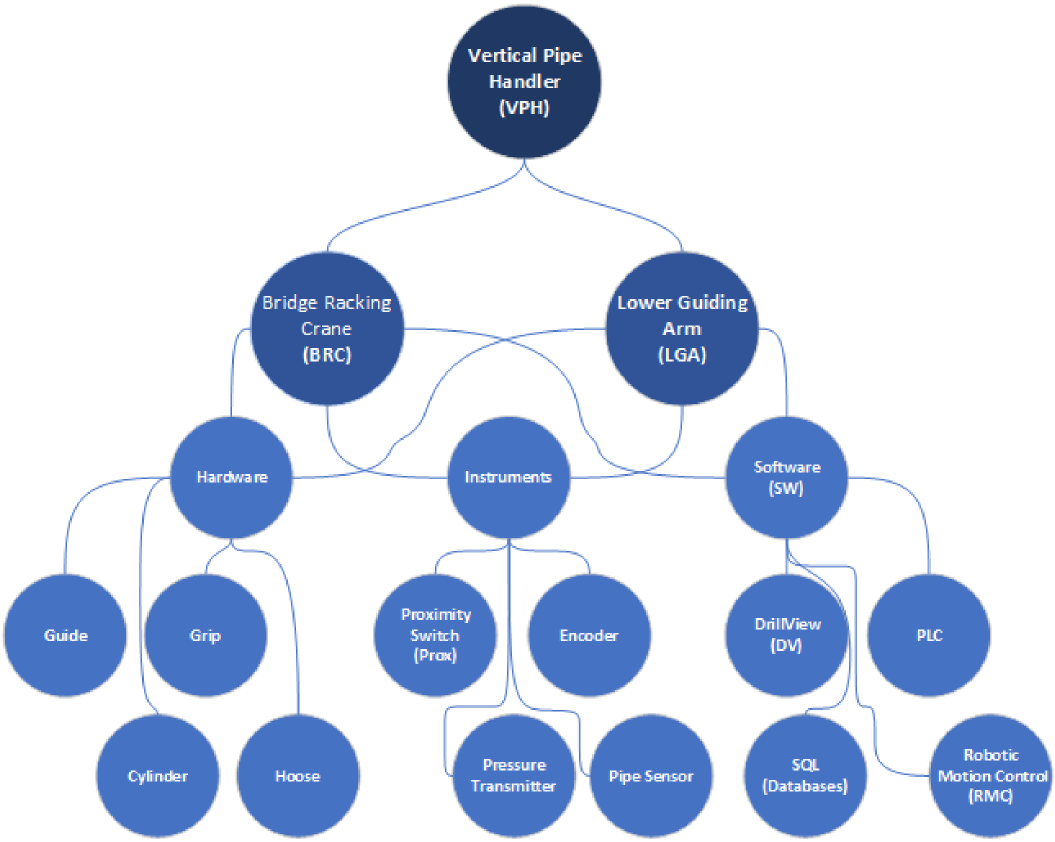


Figure C.1 – Information used to ‘teach’ the NLP about VPH

Appendix D

In some cases, a keyword search does not deliver satisfactory insights into the extracted data. Graphic search has a different approach from more traditional text-based queries. By presenting data as nodes, as illustrated in Figure D.1, the relationship implied in-between any two nodes can be explored and analyzed from a holistic perspective. Identical data that was used to build the fundament for a cognitive search can also be used for graphic search[2]. Visual Insight is an experimental prototype that can be used to visually explore connections identified by IBM's understanding of semantic elements, relations, concepts, and more. This method enables the user to have more holistic view of the content they are exploring. The tool can be used in following way[3]:

1. Search bar: use of key words to limit the search.
2. Navigation pane: to filter the search entities automatically extracted by IBM or apply tailored architecture[3].
3. Hovering over any node in the Network display will display its associated title and highlight its links to other nodes[3].
4. The Details pane provides more details about each document, including its classification and date (if available), a brief excerpt (with the option to open the full document), as well as the entities and concepts it is linked to[3].

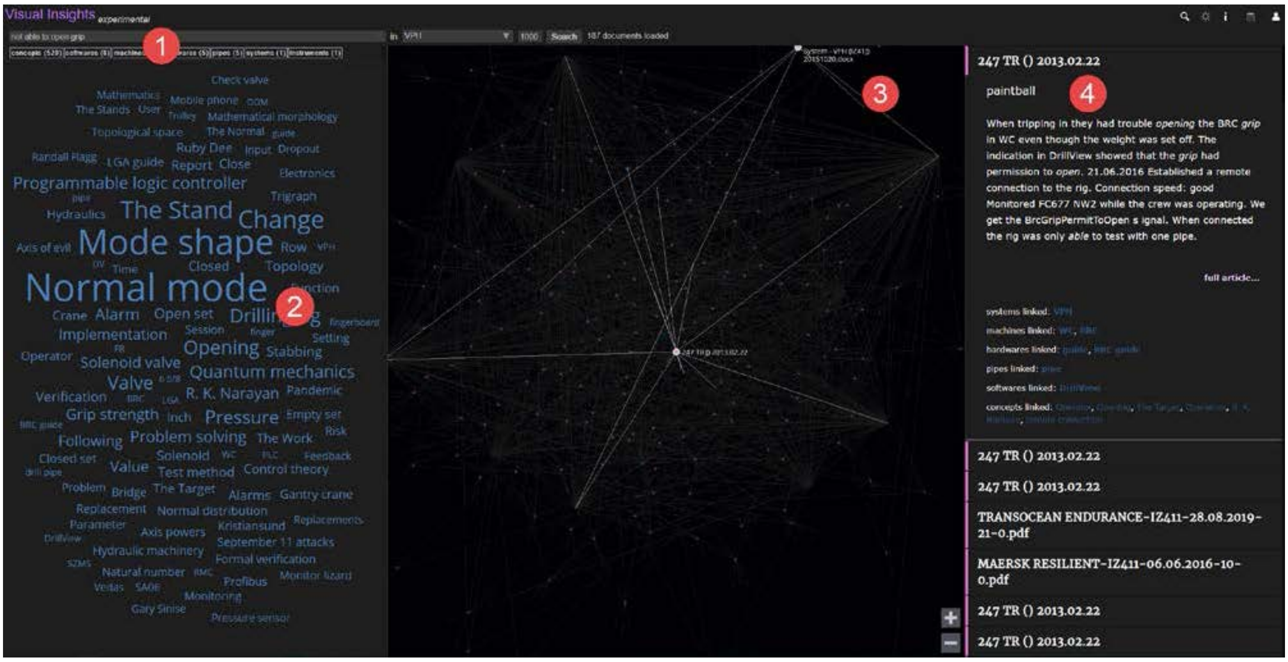


Figure D.1: Graphic search overview.

Based on the explicit knowledge obtained from the archived technical reports the author was able to determine, by a simple graphic search, which customer(s) had issues with LGA guide head. Another search could make a map of which employees have specific knowledge based on analyzed reports.

[2] Kaliyar, R. Kumar. "Graph databases: A survey," International Conference on Computing, Communication & Automation.
[3] https://visual-insights.bluemix.net/documentation/site/

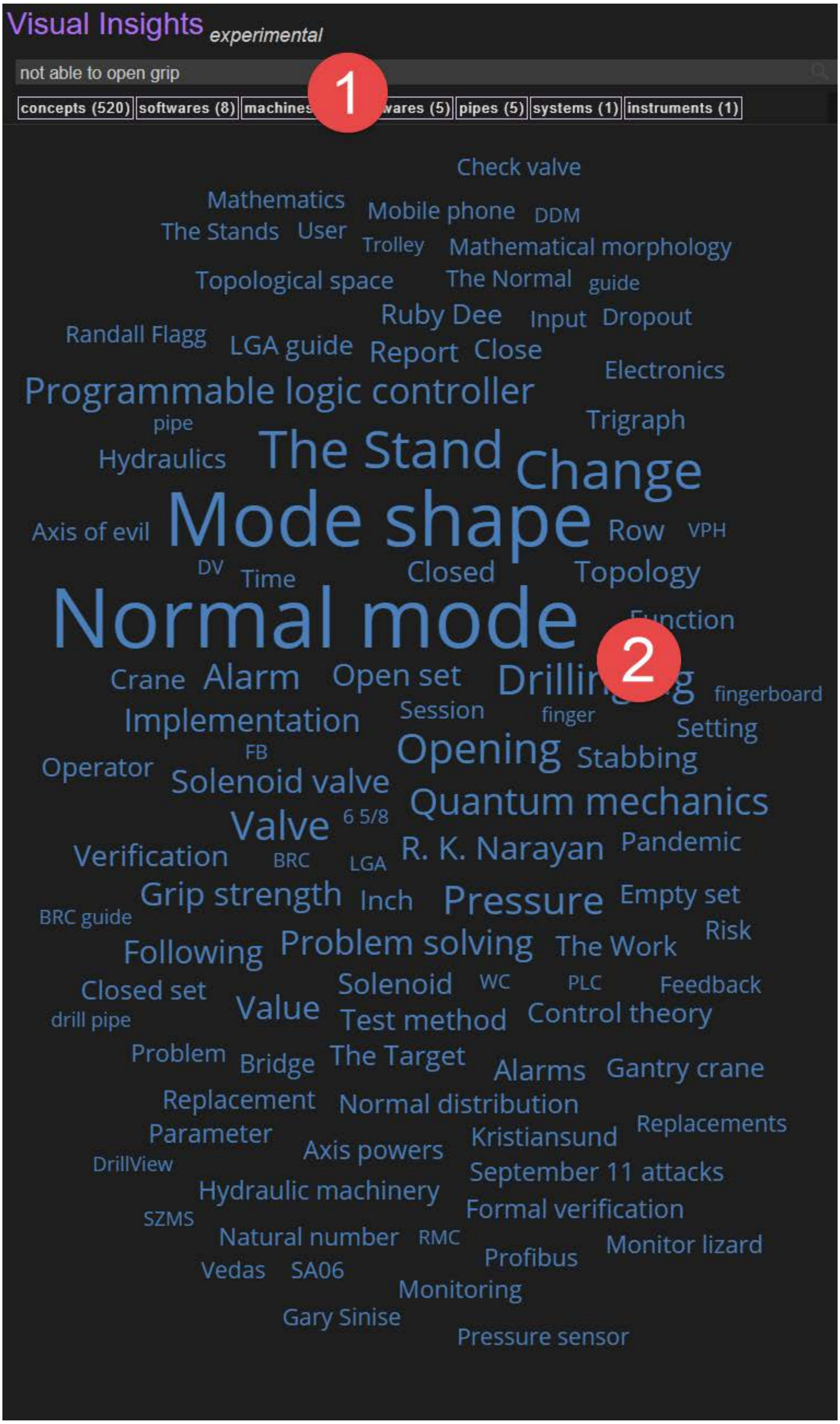


Figure D.2: Search bar, filtering options and extracted entities.

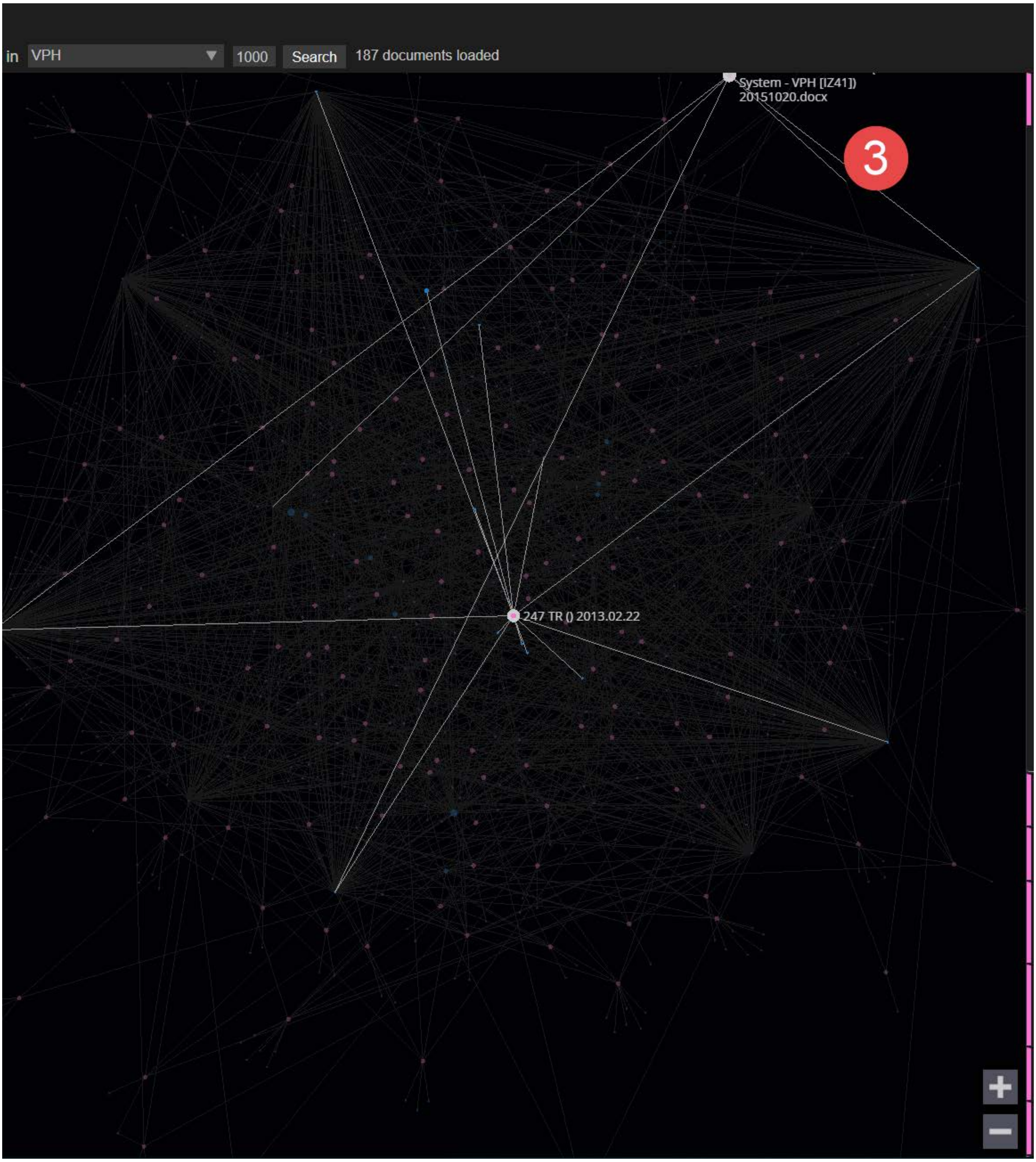


Figure D.3: Graphic overview of connected node based on search query.

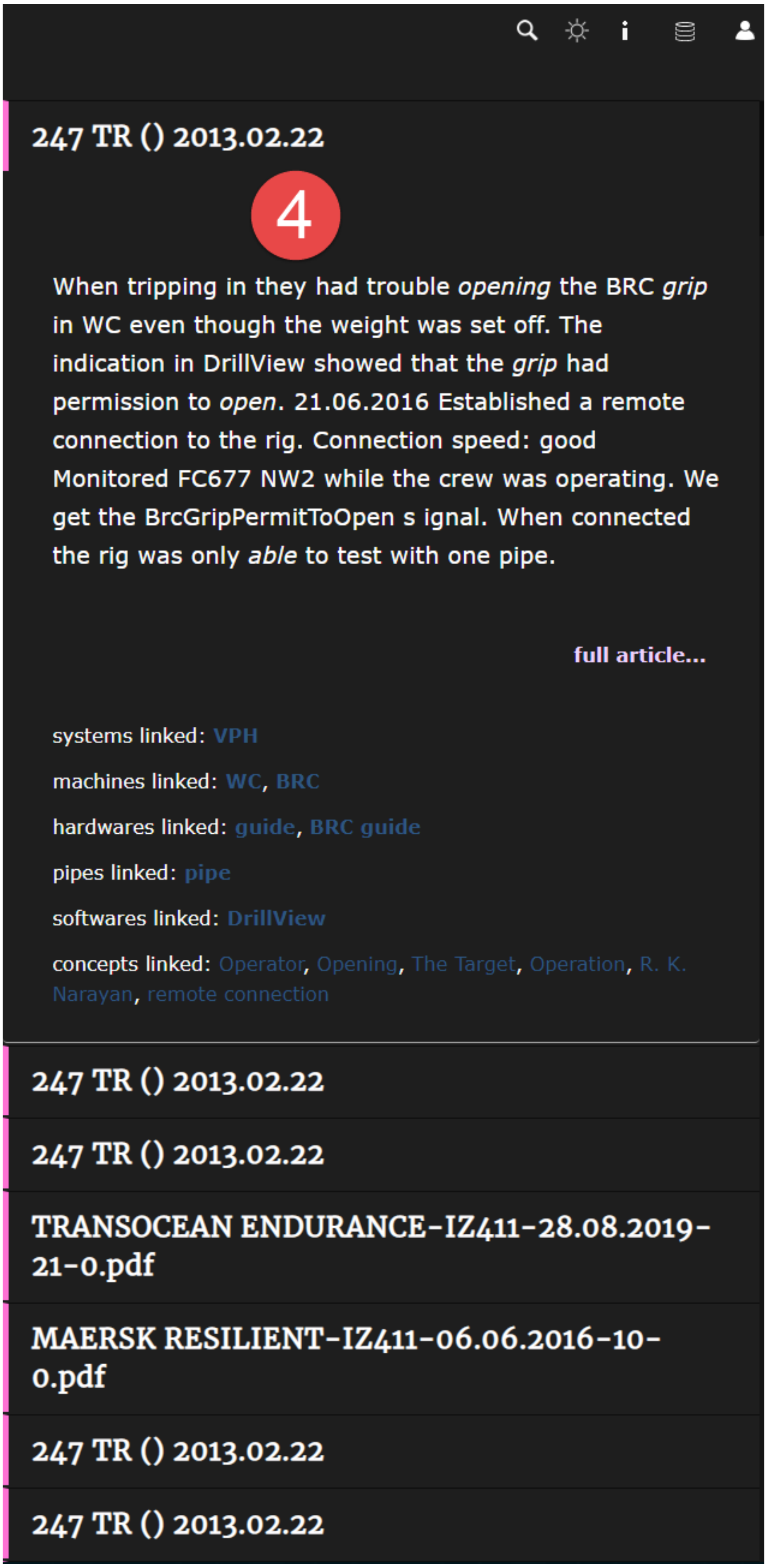


Figure D.3: Search results.