Maintenance Management Workflow Optimization

A Case Study on the Wärtsilä Fluid Management Process

Christoffer Herala

Degree Thesis
Energi- och miljöteknik
2022

DEGREE THESIS	
Arcada	
Degree Programme:	Energi- och miljöteknik
Identification number:	8411
Author:	Christoffer Herala
Title:	Maintenance Management Workflow Optimization: A Case Study on the Wärtsilä Fluid Management Process
Supervisor (Arcada):	Kim Roos
Commissioned by:	Wärtsilä Oyj

Abstract:

This thesis studies the usage of Business Process Reengineering for small scale process definition and optimization through a case study analysis of the Wärtsilä Oyj fluid management process.

Fluid management within Wärtsilä involves constant remote monitoring of customer engine fluid condition through laboratory testing and reporting. Each fluid management subprocess was defined and modeled in detail in Business Process Model and Notation in order to analyze the current process and evaluate potential needs of improvement through Bhaskar's proposed life cycle methodology for Business Process Reengineering, BPR-LC. The BPR-LC methodology relies on process-specific reengineering through analysis, redesign, evaluation, and implementation of a process. The thesis produced a comprehensive list of needs of improvement for the Wärtsilä fluid management process, mainly centered around the need for reduced manual tasks and improved data maintenance. The key identified improvement needs were a need for a fully automated fluid report entry system, a need for an improved analysis and reporting tool, and a need for a defined system for process-related data maintenance. These results support the conclusion that Wärtsilä needs to assign a product owner for the fluid management process.

The results of this paper support the usage of BPR and BPMN as valid methods for small scale process and workflow optimization and suggest that Wärtsilä should continue to investigate the implementation of these methods for other processes.

Keywords:	BPR, BPMN, Fluid Management, Maintenance Management, Workflow optimization, Process Modeling, Process Optimization, Wärtsilä Oyj
Number of pages:	44
Language:	English (Extended Abstract in Swedish)
Date of acceptance:	14.3.2022

CONTENTS

Figures

Tables

1 INTRODUCTION

1.1 Background

During the past three decades, the established methods for maintenance management have steadily evolved from time-based intervals towards the usage of multiple intelligent processes affecting maintenance intervals. This shift towards condition-based maintenance (CBM) also resulted in a shift towards seeing equipment maintenance management as a core solution to generating profit and value (Arthur, 2005). Therefore, as the field of maintenance management within the energy sector is rapidly developing and evolving into an infrastructure increasingly dependent on interlinked tools and software, the importance of continuous business process improvement with a focus on value-adding core processes is evident. There are various methods for process management and optimization, notably business process management (BPM) involving business process re-engineering (BPR) that have a long track record and numerous studies on efficiency and implementation, see (Lopez-Campos, et al., 2013) (Bäckström, 2020) (Abu Rub, 2014).

As data-based technology becomes more essential for large businesses, the validity and efficiency of their processes becomes a core focus. One of Wärtsilä Oyj: s most integral services for value-added business is equipment maintenance management. Wärtsilä Oyj utilizes a wide framework of processes to enable effective and traceable maintenance planning and management. Within the maintenance management processes exists a utility referred to as Fluid Management which consists of an ongoing active analysis of critical equipment fluid condition. Fluid Management encompasses the analysis of engine lubricating oil, cooling water, and fuel in order to deduce variations in equipment performance over time. The Fluid Management process within Wärtsilä Oyj plays an integral role in service optimization by aiming to support the use of condition-based maintenance, CBM, and enabling the use of Data-Driven Dynamic Maintenance Planning, DD-DMP. The potential possibilities within fluid management are still undeveloped and as the process and related technology constantly evolve, the impact of fluid management for enabling efficient and sustainable equipment operation also evolves. The current understanding of the Fluid Management workflow and process is vague and includes inefficiencies. The process is not sufficiently defined, and the understanding of the process workflow varies between departments. As the fluid management process relies heavily on both data flow from multiple sources as well as user input and interaction in multiple stages, a coherent and easily understandable model of the process has to be created in order to allow for evaluation of workflow efficiency that in turn will allow for continuous optimization. The Wärtsilä case is a clear example of a developed process lacking a process and workflow model and will in turn allow for research-based analysis of applicable methods for process and workflow optimization within the maintenance management processes sector. The Wärtsilä path towards knowledge-based development of sustainable technologies is increasingly dependent on adapting data-driven methods and systems which in turn gives relevancy to this thesis work. (Wärtsilä, 2021)

This thesis explores previously established methods for workflow and process optimization and evaluates methods for service process definition, building on past research on business process reengineering and process modeling through a case study of the Wärtsilä fluid management process.

1.2 Purpose & Disposition

1.2.1 Purpose

The purpose of this thesis is to define and model the Wärtsilä fluid management process to allow for analysis of its efficiency and need for workflow improvement in order to explore the efficacy of small-scale process- and workflow modeling within maintenance management.

The purpose of this thesis raises the following research questions:

- How is the Wärtsilä fluid management process currently structured?
- What are the needs of improvement within the Wärtsilä fluid management process?
- To what extent is business process reengineering a useful tool for small scale process and workflow optimization?

1.2.2 Disposition

The work of this thesis is structured as follows: The theory that constitutes the grounds on which the thesis builds upon is presented in section 2. Section 3 follows with a description of the method used to derive and evaluate the results. Section 4 contains the gathered results of the thesis work and Section 7 contains a discussion of the thesis work. section 6 contains the conclusions.

1.2.3 Delimitations

The scope of this thesis work will be limited to process development within maintenance management encompassing the energy sector, drawing conclusions based on the analysis of the Wärtsilä fluid management process optimization case. The scope of the case study will be limited in coverage to internal Wärtsilä processes and will not cover related third-party processes.

1.3 Wärtsilä Oyj

The commissioner for this thesis was the Maintenance Management department at Wärtsilä Oyj. Wärtsilä is a global actor in the energy and marine market, initially founded in 1834 in eastern Finland. The company has its roots in the sawmill industry from where an expansion was made to include the iron industry that laid the groundwork for the company now known as Wärtsilä. Today the aim of the company centers around the development of sustainable solutions in turn contributing to the decarbonization of the marine and energy business.

2 THEORY

2.1 Business Process Improvement

Within Business Process Management, BPM, exists a constant need to identify, design, and document business processes in order to allow for efficient and holistic process management and improvement. Within process improvement the need to engage the relevant experts of the process is crucial. Most process improvement projects begin with the identification of the process through process modeling and mapping, even in cases where the current process has an existing definition and model. (Logistiikan Maailma , 2021) The array of methodologies used in the field of process improvement is wide, although the core principles remain similar throughout. These principles circle around the need for constant improvement, the expulsion of non-value generating activities, better process workflow, and improved quality throughout the company or department. (Radnor, 2010) Furthermore, most process improvement methodologies use the same core principles to accomplish these needs. Zoe Radnor lists some of the most widely used methods for process improvement according to Baczewski (2005) in her 2010 paper on business process improvement methodologies as seen in Table 1.

Table 1 -"Characteristics and Comparison of Business Improvement Techniques" (Radnor, 2010)

Description	Where used	Focus
Lean -A way of working which identifies and eliminates waste to deliver improved value and service	– Where fast results are needed – Where shorter lead times and improved flexibility are critical – Where large numbers of front-line staff work together – Where limited performance data is available	– Process – Customer – Defect reduction – Waste reduction
Six Sigma -A structured approach to data-driven problem solving	– To reduce costs or increase volume – Where mature data analysis is in place – Where time exists to analyse the right data – Where specific training can be set up and sup ported	– Process – Customer – Defect reduction
BPR -An approach to transforming activity through process change	– Where IT is likely to be the main driver of change – Change is often done out of line	– Process

Kaizen -An approach to continuous incremental improvement, creating more value and less waste	– Where fast results are needed – Where the right group of people can be coordinated for a blitz approach	– Process – Customer – Defect reduction – Waste reduction
Benchmarking -A comparison with external organisations to highlight and develop best practices	– Where time exists to analyse external performance data – Where other improvement strategies are re quired	– Process – Customer – Defect reduction – Waste reduction
TQM -A way of working which focuses all participants on quality, driving long term success through customer satisfaction	– Where refocus on customer needs is required – Where formal management systems are al ready in place	– Process – Customer – Defect reduction
EFQM -An organisational framework de signed to improve competitiveness using the fundamental concepts of TQM	– Where self assessment and peer reviews are valued and repeated periodically	– Process – Customer – Defect reduction

2.2 Business Process Re-engineering (BPR)

One approach for the optimization of processes within service-centered businesses is Business Process Reengineering, BPR. BPR is a suitable method applicable to the Wärtsilä fluid management process due to its focus on standardization and simplification of business subprocesses. (Bhaskar & Singh, 2014) BPR aims to restructure flawed business processes through a global assessment of the core goals and mission of the organization. BPR “identifies, analyzes, and redesigns an organization's core business processes with the aim of achieving dramatic improvements in critical performance measures, such as cost, quality, service, and speed.” (United States General Accounting Office, 1997) BPR is often thought of as involving radical changes to a business process and has throughout research been classified to pertain mostly to process improvement heavily involving IT. Despite this, the methods within BPR has shown to be fruitful even within processes relating more to management, further strengthening the validity of its use towards the Wärtsilä fluid management process. (Bhaskar & Singh, 2014)

2.2.1 BPR Framework & Implementation

The general framework of BPR involves taking an initial process from its current state to a developed future “to-be” process. Radnor (2010) describes the BPR process as having seven essential criteria for success and a need for continuous oversight and review, see Figure 1.

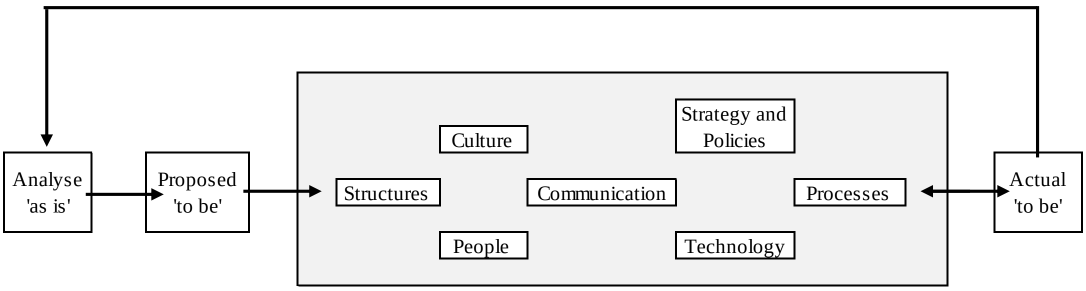


Figure 1 - BPR Process (Radnor, 2010)

The implementation of BPR towards an existing business process can be defined according to the following essential success factors: (Adesola & Baines, 2005)

- Understanding of the process and its relation to core business needs
- Modeling and analysis of the process
- Benchmarking of the process and its outcome
- Implementation and redesign of the process according to analysis results
- Assessment and review of improved process performance feedback to allow for further redesign

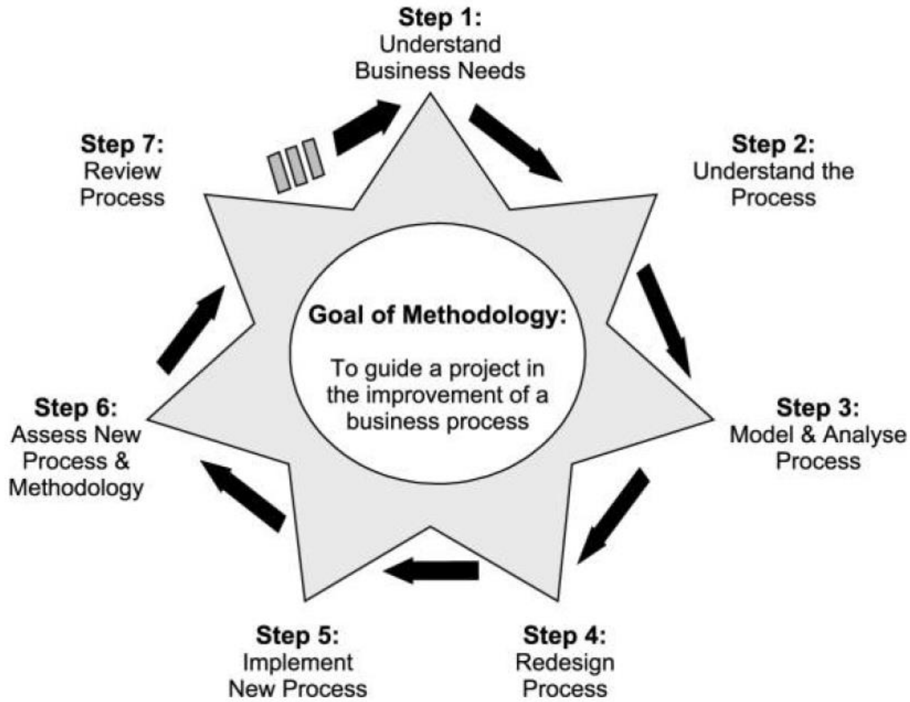


Figure 2 - Model for business process improvement (Adesola & Baines, 2005)

According to Adesola & Baines (2005) and later underscored by Radnor (2010), enabling successful process optimization through BPR requires the definition and understanding of the process and business goals as a foundation. This initial step seen in Figure 2 encompasses the development of strategic objectives, evaluation of current practices, the establishment of measurable targets, as well as identification of the process architecture. In addition, the creation of a clear and coherent process model should result as a byproduct of this step. As a part of the process analysis and redesign stage, several business analysis techniques may be used. Business analysis techniques include but are not limited to problem analysis (Dennis, et al., 2009), root cause analysis (Arnheiter & Greenland, 2008), duration analysis (Fooladi & Roberts, 2000), activity-based costing (Brierley, 2011), Benchmarking (Radnor, 2010), and business process analysis and activity elimination, BP&AE (Tsaih & Lin, 2006). Grant states that problem analysis (PA) aids in finding solutions to issues within business processes through a system where “Users are asked to describe problems of existing systems because they are familiar with the strengths and weaknesses.” (Grant, 2016)

2.2.2 The BPR-LC Methodology

The Wärtsilä fluid management process is as previously mentioned constantly evolving and in need of a process management method with accommodation for constant review. The BPR life cycle methodology was brought forward by Bhaskar (2018) as a fully involved method for BPR that is based on continuous review. This methodology is based on Cross et al.'s (1994) framework for BPR, Lowenthal's (1994) framework for BPR, as well as Roberts' (1994) framework for BPR. Bhaskar argues that the proposed methodology seen in Figure 3 provides benefits relating to the project management and scheduling of BPR as well as serving to help in the selection of tools and methods for specific BPR project tasks. Furthermore, The BPR-LC methodology contains benefits in the use of IT for enabling new processes rather than automating existing ones.

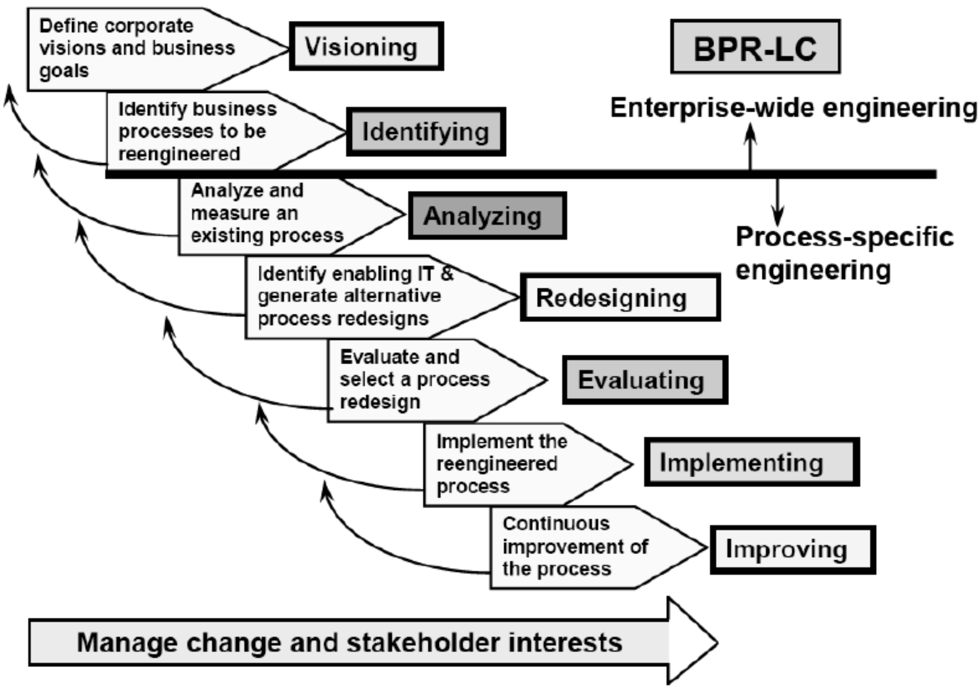


Figure 3 - BPR-LC Methodology (Bhaskar, 2018, p. 18)

Through the BPR-LC methodology, the business-wide steps are separated from the process-specific steps which allow for initial evaluation of company values and goals but also detailed analysis of critical business processes, which is essential concerning the Wärtsilä fluid management process.

2.3 Process Modeling & BPMN

In general, process modeling within the business process management sector is crucial, and correctly defined processes provide advantages for reducing uncertainties in decision-making, reducing non-essential tasks, overseeing people and material resources through viable methods, and thus limiting spending. (Jasiulewicz-Kaczmarek, et al., 2018, p. 4) The BPR process and framework rely heavily on the modeling of business processes as a prerequisite to analysis and redesign. (Bhaskar & Singh, 2014) Throughout the field of BPM, there are several viable modeling languages and solutions such as Unified Modeling Language, UML; Integration Definition, IDEF; and Business Process Model and Notation, BPMN. (Campos, et al., 2009) The focus of BPMN is business wide understanding and usability, factors that can be considered beneficial towards the Wärtsilä fluid management process optimization project. UML and IDEF are more closely related towards software-centered process modeling and not as easily understood by all business users. (Jasiulewicz-Kaczmarek, et al., 2018, p. 5)

Business Process Model and Notation, BPMN, is a standardized modeling language aimed at creating process models with high usability throughout an entire business. Jasiuleqicz-Kaczmarek, et al. (2018) state that BPMN serves to “provide a notation that is readily understandable by all business users, from the business analysts … to the business people who will manage and monitor these processes”. In this sense, BPMN serves to unify process design and process implementation holistically. (Jasiulewicz-Kaczmarek, et al., 2018, pp. 4-5) One of the primary benefits of BPMN is its capability to be used for the modeling of complex processes on both a high level and a detailed level which is applicable to the Wärtsilä fluid management process structure. (Bäckström, 2020, p. 4)

2.4 Wärtsilä Equipment and Maintenance structure

2.4.1 Dynamic Maintenance Planning

With a focus on value addition by reducing downtime through condition-based approaches to maintenance, Wärtsilä launched the Dynamic Maintenance Planning, DMP process in 2011. DMP aims to deliver reduced operating cost advantages at about 5%-

15% maintenance-wise. Further benefits are delivered through DMP by reducing both planned and unplanned downtime through condition monitoring-based extension of maintenance intervals. (Klockars, et al., 2011) DMP relies on engine operating data, maintenance history, and results of scheduled endoscopic/opening inspections to determine future maintenance intervals. In June 2020, Wärtsilä launched an addition to the standard DMP concept referred to as DD-DMP, Data-Driven Dynamic Maintenance Planning. DD-DMP "enhances the … existing Dynamic Maintenance Planning solution by utilizing digitalization and Wärtsilä's extensive capabilities in analytics. It is an integral part of the company's Lifecycle Solutions value proposition and adds further customer benefits and value not possible with conventional DMP solutions." The main value-added with the use of DD-DMP is the reduction of on-site visits required by the traditional DMP concept. DD-DMP makes use of engine fluid condition history for analysis as well as enabling customers to perform endoscopic inspections utilizing their own resources, which further reduces both costs and downtime. (Wärtsilä Corporation, 2020)

2.4.2 Fluid Management

For customers with contracted maintenance agreements, Wärtsilä offers fluid management as an included service. Fluid management aims to record and support the maintenance of optimal engine fluids quality for cooling water, lube oil, and fuel oil through means of constant monitoring and follow-up of analyzed fluid samples. Fluid management plays a key role in the utilization of DMP and serves as a supporting process together with other engine monitoring services Wärtsilä offers through condition-based maintenance. (Wärtsilä Corporation, 2021) In addition, the large potential benefits of optimum performance of the fluid management process are yet to be explored and developed. Constant monitoring of engine fluid conditions plays an integral role in the development of efficient engine operation. The potential for development of live fluid data derived from onboard sensors have been proven in the shell VitalyX pilot and subsequent possibilities for utilization need to be evaluated. (Zacks Equity Research, 2021) In order to facilitate further research and development of the fluid management process, the current process needs to be evaluated for efficiency and validity.

3 METHOD

This thesis will be conducted as a case study. Although there are several perspectives regarding whether case studies classify as research methodology on a standalone basis, it is debated that their use allows for far more in-depth analysis and investigation of a specific topic compared to that of a nomothetic approach with a large number of research participants or objects. Furthermore, case studies are often useful tools throughout exploratory research to identify new ideas that can further be strengthened by continued research. (McLeod, 2009) As Yin stated, regarding the usability of case study research, "The in-depth focus on the case, as well as the desire to cover a broader range of contextual and other complex conditions, produce a wide range of topics to be covered by any given case study." Thus, the case study method can, for detailed research objectives, produce relevant data not easily obtained through a study of isolated variables. (Yin, 2011, p. 4) The application of case study research has also moved from concerning descriptive and explanatory research objectives to possessing validity regarding evaluative research as documented by the U.S Government Accountability Office, according to Yin (2011, p. 5).

3.1 The Case Study

The Wärtsilä fluid management process in its current state will be evaluated using Bhaskar's proposed methodology for BPR. As the initial enterprise-wide stages of the framework are irrelevant for this specific study, the evaluation will begin with the modeling and analysis of the existing process. The Wärtsilä fluid management process will thus be modeled through BPMN process diagrams using data available from internal company databases as well as information retrieved from stakeholders within the company. The generated process model will be presented to end-users and internal company stakeholders and evaluated for possible methods of improvement using the PA method as defined according to Grant (2016) in Section 2.2.1. As a result, "to-be" process models will be generated in BPMN and evaluated for possible implementation, highlighting process areas in need of re-engineering.

3.2 The Wärtsilä Case

The Wärtsilä case serves as an excellent research object as the fluid management process has been in place for about five years but has never been formally modeled for review of optimization. Internally between experts, it is widely known that the process in its current state is not reliable and there are needs for improvement. By conducting an evaluation on how business process management can be used to define and highlight areas of optimization for the Wärtsilä fluid management process, the aim is to apply these results towards conclusions on the relevancy of BPR and process modeling for the optimization of small-scale business processes. The validity of the thesis work will be affected by the gathering of data given that the fluid management process is yet to be formally defined within Wärtsilä. Any official literature pertaining to the process as-is will provide difficult, sometimes impossible, to obtain. The definition of the current process along with identification of development needs will therefore be dependent on correspondence with expert end-users within each subprocess as well as personal experience from working with the process during a period of three years. Any bias derived from my position at the commissioning company will be avoided however there will by nature exist an inherent bias due to these circumstances.

4 RESULTS

4.1 Current Fluid Management Process Definition

The fluid management process within Wärtsilä can be structured into three major subprocesses with a fourth bilateral supporting process and two initial customer processes. From start to end, the fluid management process includes:

1. Customer fluid sampling
2. Laboratory or onboard analysis and report creation
3. Report data entry (Wärtsilä)
4. Data Analysis (Wärtsilä)
5. Reporting of results (Wärtsilä)

As a supporting process for the Wärtsilä processes, fluid management master data maintenance is required as a bilateral supporting process which includes the maintenance of fluid limit related data within Wärtsilä systems. The above stated contents of the current fluid management process in its entirety are visualized in the BPMN diagram seen in Appendix 1.

4.1.1 Customer Fluid Sampling & Analysis

The fluid management process begins with acquiring a fluid sample from the engine. The sampling methods vary slightly depending on the type of fluid sample:

- Lube Oil
    - Samples are taken from the engine crankcase and the engine serial number, as well as the engine nickname and sampling date, should be noted.
- Fuel
    - Samples are taken from a location either preceding or following the fuel separators if existing. When preceding, the bunker report may be used and when taken after the separator, the sample should be sent for independent laboratory analysis. Both before separator and after separator fuel samples

are required for optimal analysis of fuel condition and separator performance. The fuel type, system, sampling point, and date should be noted for each sample.

- Cooling Water
  - Cooling water samples are taken per cooling system. This can vary depending on whether the cooling system is a separate high and low temperature system or a common system. The system type, engine nicknames, serial numbers, as well as sampling date should be noted for each sample.

After a fluid sample is taken, it should be sent to an independent laboratory for analysis. For cooling water only, an onboard analysis using test kits provided by cooling water product manufacturers can be acceptable. However, laboratory analysis still needs to be conducted at the intervals specified in the maintenance agreement.

4.1.2 Fluid Data Entry

Once the fluid reports have been sampled from the engine and chemically analyzed through laboratory or onboard analysis, the reports need to be sent to Wärtsilä for internal database entry. The master database for fluid reports is currently Salesforce CRM. Within the Salesforce environment exists the fluid reporting object where fluid reports are stored. The entry of fluid report analysis results is currently carried out through four different methods, depending on the type of fluid reporting that has been agreed upon with the customer. These methods are the following:

1. Manual entry through the Salesforce fluid entry portal
2. RPA entry through the Salesforce fluid entry portal
3. Customer entry through the Wärtsilä Online portal
4. Direct integration between Salesforce and laboratory API

Fluid reports are entered manually through the Salesforce fluid entry portal if it is agreed upon with the customer that Wärtsilä will handle the fluid report data entry and no Robotic Process Automation, RPA, is existing for the specific laboratory or report type. Reports that are entered manually are forwarded to the Wärtsilä common mailbox for fluids reporting by the customer directly, or through the Contract Manager. The Vaasa Expertise Centre has a dedicated responsible expert for manual fluids entry that handles these cases. If a trend is seen with an increased amount of reports arriving from the same laboratory or with identical layouts, the possibility for the development of an RPA for that specific report type will be evaluated. If deemed to be needed, an RPA will be created. For larger contracts or fleets, the RPA method was introduced as a fast solution for increasing report workload but currently requires continuous maintenance as report layouts vary and change with time. If it has been agreed with the customer that they are responsible for fluid data entry, the customer will enter reports directly through the Wärtsilä Online environment. In practice, this means that the customer will receive the fluid analysis report from the laboratory or onboard tests and enter the required values directly into Wärtsilä's online customer interface, eliminating extra correspondence between the customer, Wärtsilä, and the laboratory.

The final current option for data entry towards Salesforce is direct integration with the laboratory database. Progress in this sector is currently ongoing and the Data Bridge team within Wärtsilä has so far developed a pilot project with a smaller laboratory analysis vendor. The pilot proved efficient and progress is currently being made towards integration with larger-scale laboratory analysis vendors.

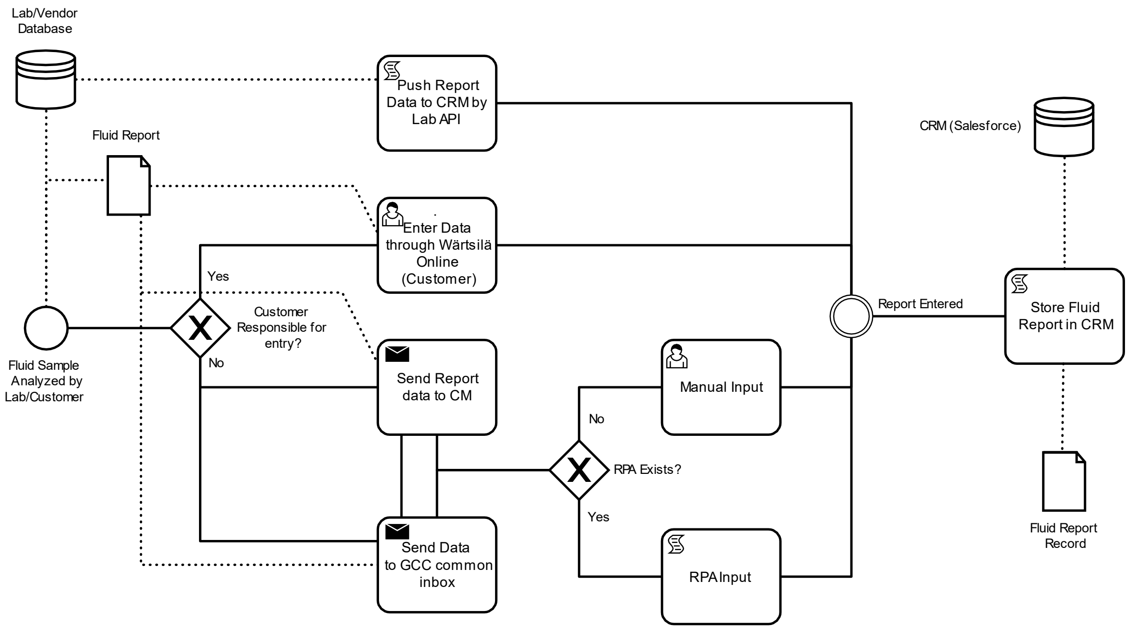


Figure 4 - BPMN Diagram of the Fluid Management data entry subprocess

4.1.3 Data Analysis & Reporting

All raw fluid data is stored in the Salesforce fluid reporting object. From this database, the fluid report data is pushed to interlinked services for analysis according to Wärtsilä specified fluid limits as seen in Figure 5. Currently, fluid data from Salesforce is pushed to Wärtsilä Online and QlikSense for analysis and visualization purposes.

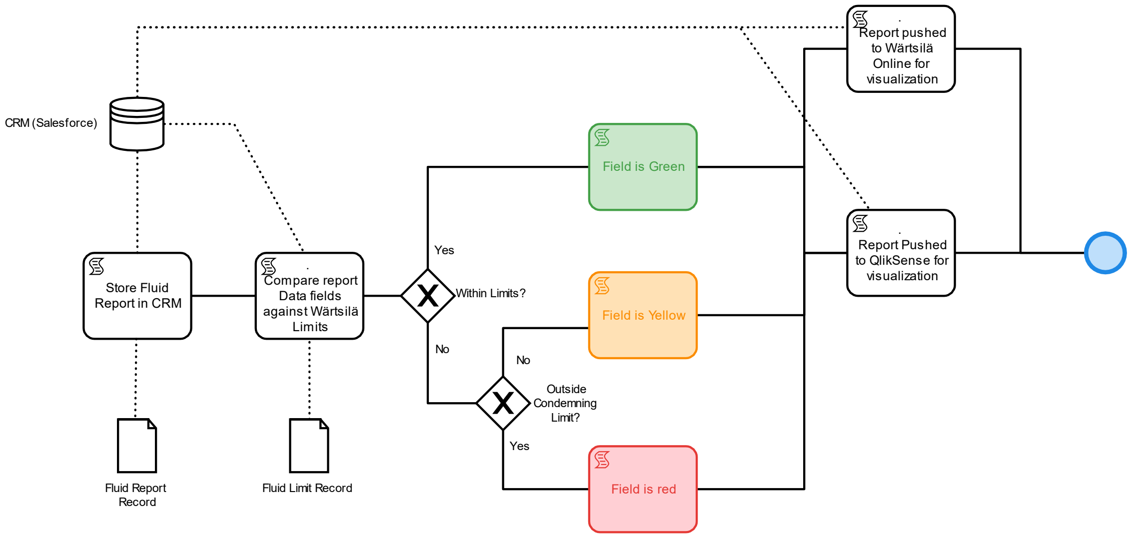


Figure 5 - BPMN Diagram of the Fluid Management data analysis subprocess

Currently, there is no company-wide established workflow or interface for neither internal nor external reporting of fluid conditions. In practice, for installations with maintenance agreements, fluid reports are currently reviewed based on data from QlikSense by the responsible asset diagnostics expert prior to the core team meeting for the pertaining customer installations as seen in Figure 6. As Asset Diagnostic experts are responsible for a set number of installations together with the non-frequent reporting intervals, this poses a demand for constant follow-up of submitted reports as there is no notification option for new reports. For Performance-Based Logistics (PBL) agreements, reporting of fluid data analysis results is agreement-wide. Reports encompassing the entire fleet are submitted to the customer at an agreed-upon interval.

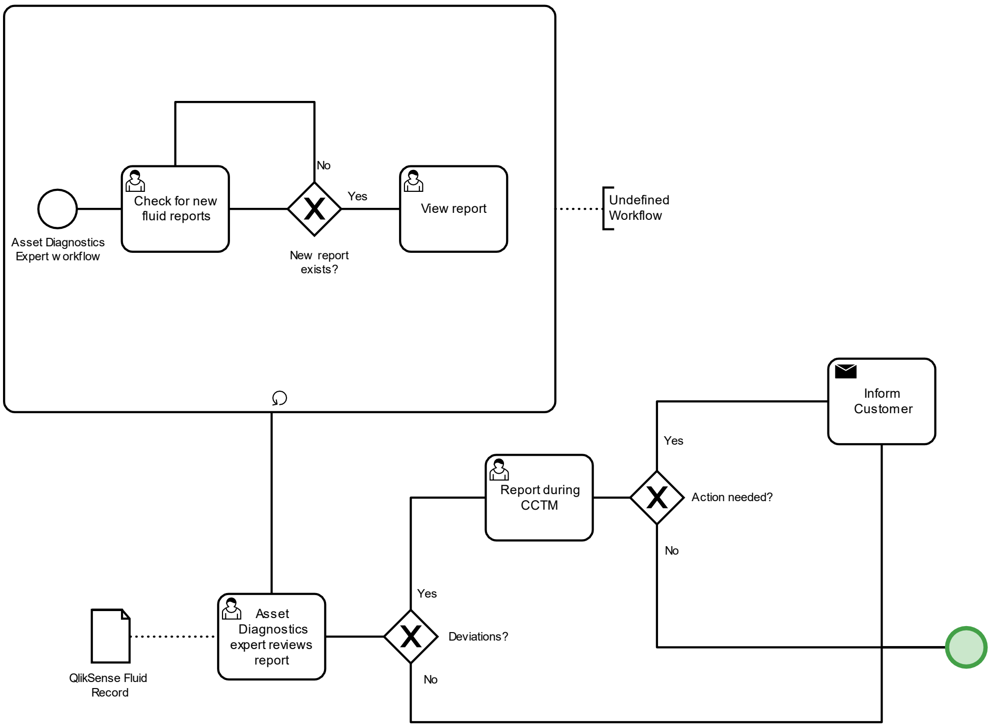


Figure 6 - BPMN Diagram of the Fluid Management reporting subprocess

4.1.4 Fluids Limit Data Maintenance

As the fluid management process relies heavily on information retrieval from the Salesforce database as well as data within Wärtsilä Online and QlikSense, the maintenance of the information within these services is integral for reliable fluid management performance. The most essential element of Fluid Management master data is the Wärtsilä specified fluid limits.

The Technical Services sector of Wärtsilä develops and defines fluid limit parameters. Limits are defined separately for each fluid type: lubricating oil, fuel oil, and cooling water. Within these categories, limits are also separately defined for each type of fuel oil, type of cooling water product, and type of lube oil. Different engine types also have separate limits. These limits are stored in bulletins that are released yearly when a sufficient number of changes or additions to fluid limit parameters have been made. The fluid management process requires the referencing of Wärtsilä approved limits during the data analysis stage. Thus, within Salesforce exists the fluid report indicator limits object, where the limits are stored for reference towards the fluid report data. There is a separate object for general limits for all three fluid types, as well as a separate object specifically for lubricant type-dependent fluid limits. At the launch of the Fluid Management process, the then active fluid bulletins were loaded into the Salesforce fluid report indicator limits object. Recently, it was identified by stakeholders working on the development of the Fluid Management process that a defined process for the maintenance of limits stored in the Salesforce object is missing. As an interim solution, fluid limits are currently manually updated in Salesforce as new bulletins are released as seen in Figure 7.

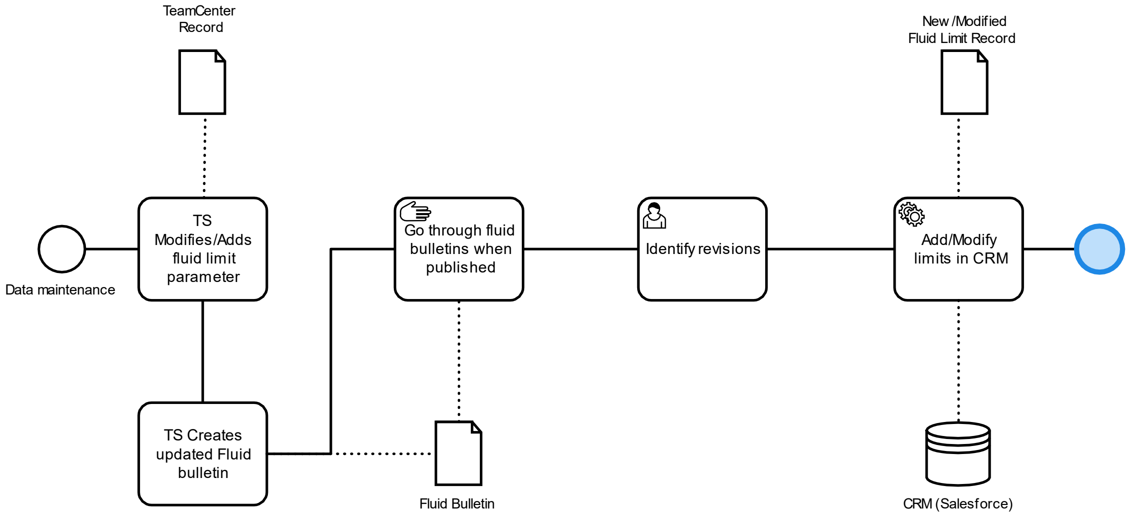


Figure 7 - BPMN Diagram of the Fluid Management limit update subprocess

4.2 Optimization Needs

4.2.1 Data Entry Optimization

The main identified current problem within the data entry subprocess is the persistence of manual tasks that have the possibility of introducing human error into the data stream. As seen in Figure 4, there are currently two methods for manual input, customer or Wärtsilä, and two methods for automated input, Robotic Process Automation, RPA, or laboratory Application Programming Interface, API. At this stage, the most widely used input method for smaller customers is manual report entry by Wärtsilä. The most common data entry method for major customers is RPA entry by Wärtsilä, see Table 2. For this data, smaller customers have been defined as customers with 1-3 contracted installations and major customers have been defined as customers with 4 or more contracted installations. By looking at the total amount of reports entered since the start of the fluid management process we can see that the majority have been entered using RPA. Comparing this to the total per installation we see that manual entry takes up the majority in this category. This deviation is likely related to the higher efficiency of RPA input compared to manual, resulting in a higher overall report entry. In addition, customers that have a large fleet of contracted installations are more likely to use large laboratories that have a developed RPA in use at Wärtsilä and submit reports on a tighter interval.

Table 2 - Method of Fluid Data Entry for Marine Installations, extracted from Wärtsilä Salesforce database

Category	Method of Report Entry			
	API	Customer	Manual	RPA
Total: All Reports Entered	0,10%	0,87%	25,39%	**73,64%**
Total Per installation	1,9%	4,5%	**62,6%**	31,0%
Total Per installation: Smaller Customers	0,0%	0,0%	**87,0%**	13,0%
Total per installation: Major Customers	3,8%	9,0%	38,5%	**48,7%**

As the goal for the data entry subprocess is to reduce errors that arise from manual input, customer and Wärtsilä manual entry will need to be abolished. Looking at Table 2 it is clear that the major current problem is manual input by Wärtsilä, taking up 25% of total entered reports and applied to 62% of customers. Considering that a move towards customer fluid entry will result in an identical amount of manual labor in turn not providing a reduction in possible human errors, the current remaining options are RPA and laboratory API integration. The use of fluid entry RPAs has greatly aided in the reduction of both time and errors for the reports that they are developed. However, the key issue with RPA usage in terms of fluid entry is the usage of resources for development and maintenance. As customers are receiving fluid reports in many varied formats that might change over time, RPA development must be constantly ongoing. For larger fleets with a common laboratory, this is less of an issue as the fluid data can be received from the customer in a fleetwide report. When considering customers that do not have many contracted installations, the use of RPAs becomes ineffective. If RPAs were to be developed for each report type received, the labor for development and maintenance would far outweigh the perceived benefits. This then leaves the continued development of laboratory APIs. As previously mentioned, development is currently ongoing in this area. The usage of APIs would encompass the flow of data directly from the customer-contracted laboratory to the Wärtsilä Salesforce database. From Table 2 we can see that API entry currently takes up less than 1% of entered reports. At this stage, the only API in production is a pilot that was conducted on a smaller laboratory not serving many of Wärtsilä's customers. If continued development leads to the inclusion of larger-scale laboratories, reporting workload and errors would essentially be eliminated for both the customer and Wärtsilä. This leaves an end goal of full API integration as seen in Figure 8 for all major laboratories used by Wärtsilä's customers. However, there will not be a feasible method towards full integration for all laboratories as some are only serving a few customers. Thus, the option for manual entry by Wärtsilä will still be needed for special cases.

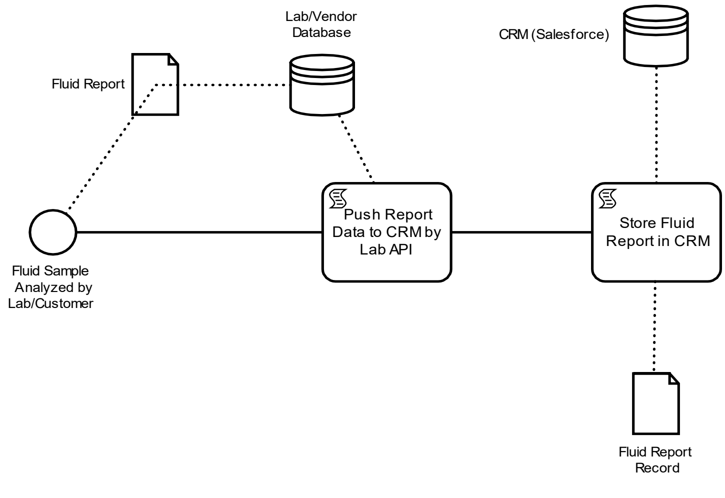


Figure 8 – BPMN Diagram of the Fluid Management data entry subprocess optimization suggestions

4.2.2 Data Analysis & Reporting Optimization

The main current issues that exist within the data analysis and reporting subprocesses were identified to be the lack of an efficient analysis tool to be used by analysis experts and no clear reporting guidelines. Upon review with Asset Diagnostics experts, in charge of fluid data deviations monitoring according to current workflow, it was evaluated that automatic notifications for fluid data deviations were needed. As well as a possibility for case creation in the event of serious fluid data deviations that would also allow for historical fluid deviation follow-up. The current fluid analysis visualization tool is a customized QlikSense view. As QlikSense is not a viable option when it comes to more advanced functions involving automated notifications and case creation, the analysis subprocess is undergoing a move to the Expert UI platform. The Expert UI platform is currently used by the Asset Diagnostics department for engine condition monitoring based on operational performance data, meaning the responsible experts according to the current WoW are already familiar with the platform. In order to comply with the by Asset Diagnostics perceived requirements for data analysis, it was identified that the following functions need to be available within the Expert UI fluid management portal:

1. Email alerts for deviations in fluid quality (To AD expert)
2. Email alerts for missing fluid reports according to the interval (To MP or CM)
3. Email alerts when new reports exist in the system (To AD expert)
4. Automatic triggering of a potential fluid case if deviations exist
5. Possibility to escalate fluid case status upon review by AD expert.
6. Tracking of fluid case history

With the addition of the above-mentioned functions within the fluid management portal in Expert UI, the aim is to reduce the lead time for report analysis, be able to inform customers of missing reports immediately, and allow for simple fluid deviation tracking to benefit the DD-DMP process. As case creation and Email alerts are already in place for the Expert Insight portal within Expert UI, the framework required for similar functions within fluid management already exist, further simplifying the integration of these functions. Another benefit with a move to Expert UI for data analysis and visualization is the direct integration of fluid limit data. Previously in QlikSense, the fluid limit parameters were extracted manually from salesforce and stored separately in QlikSense, this causes an issue within the data maintenance subprocess as fluid limits will need to be updated separately in QlikSense after the changes have been made in the Salesforce database. With the move to Expert UI, this data would be synchronized with Salesforce to avoid the time loss and possibility of errors from manual data updates, as well as guarantee that fluid limit parameters are up to date. As seen in Figure 9, these changes result in the addition of a quantitative performance indicator dependent on the availability of fluid reports. Whether this information will be pushed to Wärtsilä Online will need to be further evaluated. During the recent Production Management Tool, PMT, project within the Salesforce database, data objects for sampling intervals were created preliminarily to enable this development of the fluid data analysis subprocess. This data object within Salesforce still requires the responsible maintenance planner to manually enter the sampling intervals and needs to be considered for further optimization.

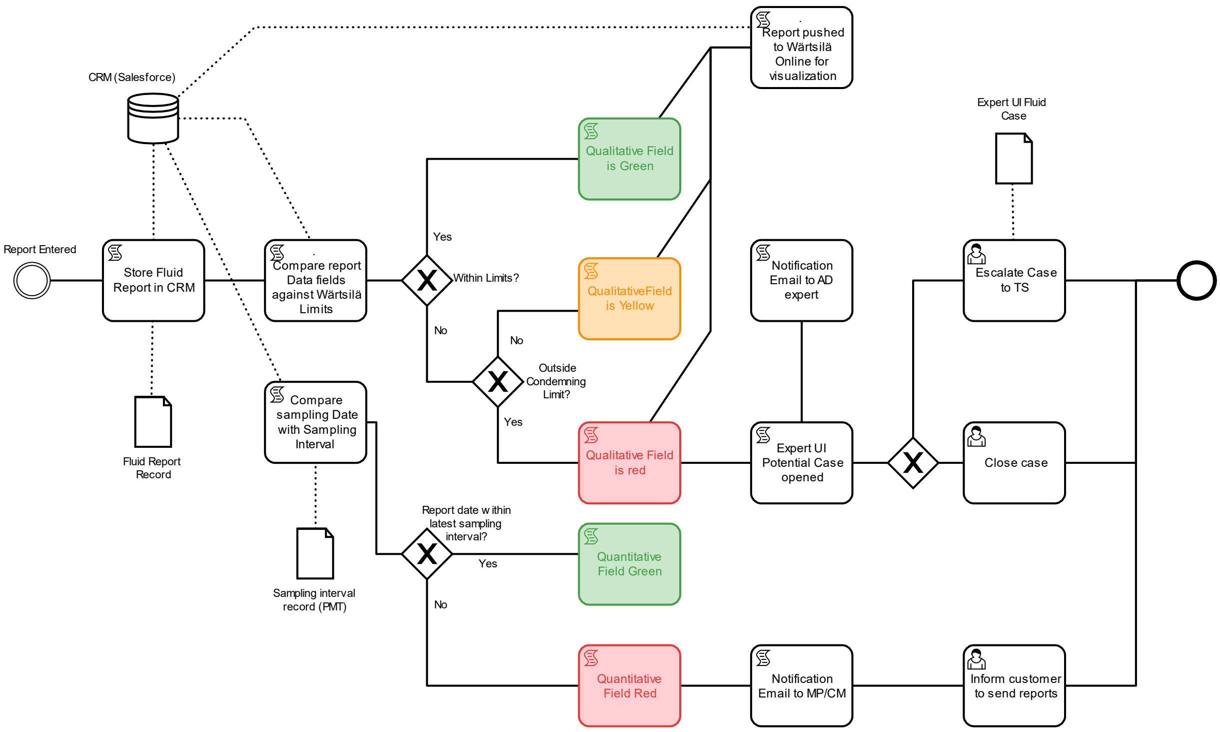


Figure 9 - BPMN Diagram of the Fluid Management data analysis & reporting subprocess optimization suggestions

4.2.3 Fluid Limit maintenance Optimization

The continuous data maintenance of fluid limits in Wärtsilä databases was identified to be lacking recently. As mentioned in Section 4.1.4, the correct analysis of fluid reports is dependent on the fluid limit parameter data within the Salesforce database. The previous limit data maintenance model was identified to have shortcomings in lead-time as new fluid bulletins are not released each time a fluid limit parameter undergoes revision. This would result in a possibility for outdated fluid limits in the Salesforce database during the timeframe from fluid limit parameter revisions to fluid bulletin revision, which could extend up to a year and would in turn affect the fluid analysis subprocess. In order to reduce lead-time for updating fluid limit parameters within Salesforce and eliminate the possibility for human errors in the process, the ideal development should lead to automated data flow directly from Teamcenter to Salesforce as seen in Figure 10. This however

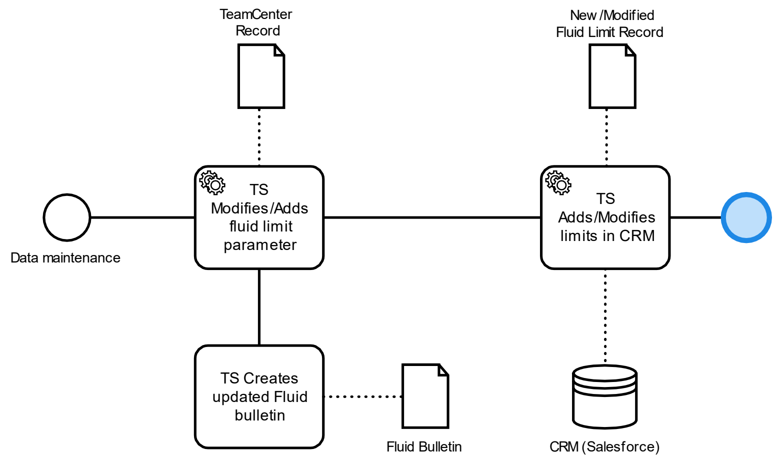


Figure 10 - BPMN Diagram of the Fluid Management limit update subprocess Ideal optimization suggestions

would require development outside a realistic scope for optimization of the fluid management process. Another identified possibility would be for experts within Technical Services to simultaneously update Salesforce and Teamcenter. However, the resulting process would still include manual tasks, and training within the Salesforce limit-creation environment would need to be held for personnel not otherwise in need of its functions. Upon consulting the responsible experts within Technical Services, it was identified that each change or addition of a fluid limit parameter takes place through an engineering change order (ECO) in the Wärtsilä Teamcenter database. Within Teamcenter exists a function for automated email notifications following the creation of an ECO within a specified category. By utilizing these notification emails, a feasible solution to fluid limit parameter maintenance within Salesforce would be to assign a responsible expert to receive these notifications and in turn, perform the necessary data maintenance within Salesforce as seen in Figure 11. In this scenario, no major changes must be made within the existing software architecture and only one expert needs training within Salesforce fluid limit maintenance.

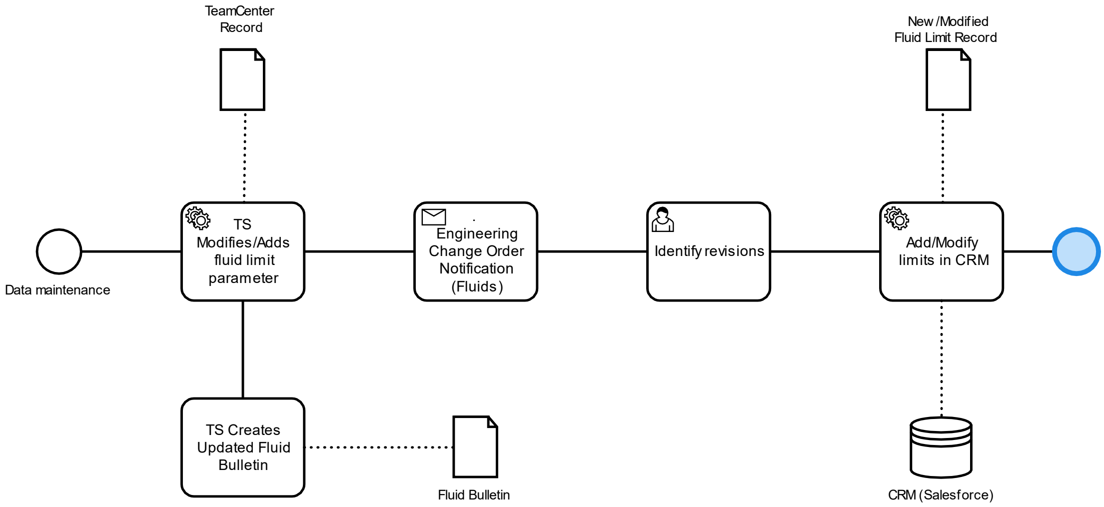


Figure 11 - BPMN Diagram of the Fluid Management limit update subprocess 1st Stage optimization suggestions

4.3 Usage of BPR and BPMN

The modeling through BPMN of each subprocess of the Wärtsilä fluid management process showed positive results in providing a more clear and coherent understanding of the process to relevant stakeholders within the company. BPMN proved to be a viable modeling language for the process and had great usability in incorporating both manual and automated tasks into a single process model. This together with identification of cost and time engulfing tasks allowed for detailed analysis of stages of the process in need of reengineering. The usage of Bhaskar’s methodology for BPR proved to be a viable method for analysis of the Wärtsilä fluid management process. The creation of process models for proposed changes served to further aid in a clear department-wide understanding of the process, as well as allowing for continued development in the future.

5 DISCUSSION

The main reasoning used to identify the optimization needs presented in the results relies on the elimination of manual tasks that introduces the possibility of human errors. For the optimization needs specified in the results to be viable, I would consider the first critical development needs to consist of enabling efficient and reliable data maintenance within the process. Specifically, data maintenance regarding fluid limits. The validity and usability of the entire fluid management process is dependent on constantly ongoing maintenance of fluid limits. As research and development regarding engine fluid parameters is a constantly ongoing matter, there will always be a need for data maintenance in this sector. Fluid limits change with the development of new lubricating oils, cooling water treatment products, and fuels. The correction of the shortcomings identified in the section 4.2.3 will reduce wrongful analysis for future reports entered. As a part of this thesis work, several outdated fluid limits were identified and corrected to reduce any inaccurate data within Wärtsilä fluid-related systems. Due to this discovery, the suggestion for optimization seen in Figure 11 would serve to guarantee the validity of fluid limit data without the need for major development projects. This proposed process change needs to be developed immediately to reduce the possibility of future errors within the process. The initial development suggestion seen in Figure 11 will require an assigned responsible expert to oversee the data maintenance of fluid limits until an automated process can be established.

Once a process has been established that guarantees the validity of Wärtsilä fluid data and limits, the next step should be to improve the validity of the submitted report data. In my opinion, this is only achievable by an attempt towards fully automated report entry. The foundation for automated report entry has already been laid out as a laboratory API. Future development will be dependent on identifying laboratories with enough customer coverage that are also willing to cooperate towards API integration. After an API has been developed for a given laboratory and piloted, protocols for roll-out to customers must be established. Even with wide laboratory API coverage, small-scale laboratories will be ineffective for API development. Thus, these will still need to be handled through manual entry, facilitating the continued need for a resource in this sector. For efficient progress in future laboratory API development and integration, there is a need for a responsible expert to lead this effort.

After the validity of submitted report data and fluid limit parameters can be considered reliable, development in the reporting and analysis subprocess falls next in line. I would consider improvement needs in this area to center around the ongoing transition from QlikSense towards the Expert Insight portal for fluid analysis. The requirements for analysis tool optimization reported in Section 3.3.2 will serve to improve tracking and storage of fluid data and join both fluid management and engine condition monitoring to the same platform. This transition would provide means of further development in widening the usage of fluid data by providing simple and viable methods for research on relationships between engine fluid parameters and engine operational parameters. Easily traced fluid history will serve to streamline the decision-making model for fluid anomalies, enabling the use of DD-DMP. The integration of historical fluid anomaly cases in the new Expert Insight based fluid management environment will need to be further considered and evaluated for implementation. This area needs more development and an assigned responsible expert would be beneficial for development as the process evolves.

From the results, we can interpret that the mobilization of these developments would provide largely beneficial in improving the efficiency, sustainability, and validity of the Wärtsilä fluid management process in its entirety. However, in accordance with Bhaskar’s methodology for BPR, the process will need to undergo further evaluation and reengineering once these changes would be put in place. In my opinion, this facilitates an initial critical need for a fluid management process owner within Wärtsilä in order to enable the mobilization of the above listed optimization needs. Many of the current inefficiencies within the fluid management process can be partially accounted for by the lack of a responsible expert in charge of the maintenance and development of the process. If these needs are not met in the near future, Wärtsilä will potentially deviate from their contractual obligations regarding fluid management.

The identified optimization needs specified in the results are relevant only based on the integrity of the initial definition of the process. The results are currently theoretical, and a practical mobilization of the specified optimizations will likely result in additional improvement needs surfacing, facilitating the need for continuous review and improvement. This case study was only conducted on one of Wärtsilä's many business and service processes and did not involve extensive research on multiple processes within maintenance management. Thus, further research and evaluation on the validity of these methods on other processes is needed. Wärtsilä should continue to explore the use of BPR in terms of smaller scale process optimization.

The results of this thesis are also affected by my capability and knowledge of process modeling and BPR. I am not an expert in neither modeling through BPMN nor methods for BPR and only possess limited knowledge and experience in the subjects. Bhaskar's methodology for BPR was followed so the evaluation for improvement needs within the process should be repeatable given an equal understanding and definition of the Wärtsilä process. Despite this, the redesign of a process can be accomplished through a variety of methods and solutions of which many can result in equal benefits.

The needs for improvement proposed in this thesis work aim to bring forward solutions that facilitate the least amount of resources for development. There are evidently solutions not explored within the scope of this thesis that could contribute largely to the optimization of the fluid management process. The suggestions for optimization brought up in this paper are limited by the scope for development of the process by Wärtsilä. Still, as the proposed needs for improvement are purely theoretical, their mobilization might not be viable due to resources needed and further investigation is needed regarding their mobilization.

The scope of this thesis was unable to include any continuous review as the mobilisation of the identified optimization needs was not be carried out during the timeframe of the thesis work. Further research is needed regarding the validity of Bhaskar's BPR methodology through the lifecycle of the process although this thesis work provided beneficial results in terms of initial process redesign. The identification of IT enabled total process changes rather than redesign as specified in the process redesign step of Bhaskar's BPR methodology was difficult to cover under the scope of this thesis work and will require further evaluation and research.

The implications of fluid management optimization for Wärtsilä go far beyond the scope of this thesis work. As the fluid management process evolves and the validity of the concerned data increases, the possibilities for internal development will increase exponentially. With the move of fluid analysis towards the Expert Insight environment, research and development regarding the company-wide usability of fluid data will evolve. The condition of an engine can theoretically be widely identified through analysis of the condition of engine fluids and development in this sector is largely dependent on a relevant and reliable process for measuring the condition of these fluids. Today the gathered data has narrow usage and as the process evolves it will play a key role towards accomplishing the targets set forth by Wärtsilä towards creating increasingly sustainable technology and solutions.

6 CONCLUSION

The first objective of this paper concerned the definition of the existing Wärtsilä Oyj fluid management process. This initial objective was executed through the use of BPMN after careful consideration of viable modeling languages. The decision towards the utilization of BPMN as a modeling language derived from the key objectives of process reengineering explained in Bhaskar's methodology for BPR and centered around a company-wide understanding of the process modeling language. The initial definition of each subprocess facilitated analysis of the current workflow through discussions with end-users and personal knowledge of the process. The modeling of each fluid management subprocess through BPMN was successful and the resulting process models were able to be shared with process end-users for review. The created model is listed in Appendix 1 and detailed models in Figures 5-8.

The second objective involved the analysis of the process models created as a result of the fluid management process definition and in turn the creation of "to-be" process models. This step was conducted according to Bhaskar's methodology for BPR and followed the steps listed in Section 2.2.2. The evaluation of possible improvements can be considered successful as needs for optimization were identified within all subprocesses and subsequently modeled in BPMN seen in figures 8-11. The stages of each subprocess were also reduced, and manual tasks were identified and removed or considered for automation. The need for a fluid management process owner within Wärtsilä was identified in order mobilize and oversee the identified development needs within fluid management data maintenance, data reporting, and data analysis.

The final objective of this paper consisted of the analysis of the usability of BPR as well as process modeling for small-scale process definition and optimization. The results concerning this research objective stem from the successful completion of objective 1 and 2. The Wärtsilä fluid management process was able to be defined through the use of BPMN modeling and stages of each subprocess were positively identified for needs of improvement through the use of BPR. With these results, BPR and process modeling were identified to be viable options for small-scale process definition for Wärtsilä. Further research is needed to facilitate the application of these results towards small-scale process and workflow reengineering within the maintenance management sector and Wärtsilä could see benefits from incorporating the use of BPR towards other processes.

The conducted case study can be considered successful considering the completion of all research objectives set forth in the beginning of the thesis. The improved process model seen in Appendix 2 aims to better fulfill the targets of the fluid management process. The identified optimization needs will serve to aid in the development of related processes as well as enabling fluid management-based research into sustainable equipment performance.

EXTENDED ABSTRACT IN SWEDISH

Introduktion

Under de senaste årtiondena har vikten av väldefinierade och välstrukturerade processer inom teknikbranschen stigit kraftigt som en följd av en global övergång mot informations- och mjukvarucentrerad verksamhet och verktyg. Det finns en stor mängd etablerade metoder och verktyg för processhantering och modellering, i synnerhet 'Business Process Reengineering' också känt som BPR. Inom energisektorn av teknikbranschen i Finland är Wärtsilä Oyj verksamt som en tillverkare av produkter och tjänster inom marin- och energikraftsmarknaden. Inom deras underhållsplaneringssektor utnyttjar Wärtsilä en process känd som 'fluid management' som består av kontinuerlig översikt av Wärtsiläs kunders motorers vätsketillstånd. Detta omfattar analys, rapportering, och uppföljning av kylvatten, smörjolja, och bränsle.

Målet med denna avhandling är att först definiera och modellera Wärtsiläs vätskeanalysprocess för att sedan möjliggöra en analys av dess effektivitet och behov av processoptimering. Genom detta ämnar man kunna undersöka effektiviteten av småskalig processförbättring och modellering. Detta syfte kommer att utforskas genom en fallstudie av Wärtsiläs 'fluid management' process.

Teori

Inom området för processhantering, känd som 'Business Process Management', finns det en hel del olika verktyg och etablerade metoder för utvärdering och utveckling av effektiviteten inom företagsprocesser. Denna avhandling behandlar huvudsakligen processhanteringstekniken 'Business Process Reengineering' hädanefter förkortad till BPR. Målet med BPR är att öka effektiviteten av bristfälliga företagsprocesser vilket kan inkludera allt från en total omformulering av processen till en standardisering och förenkling av delprocesser. Denna avhandling utforskar mer specifikt metodiken för BPR framtagen av Hari Lal Bhaskar, känt som 'BPR Life Cycle'. Bhaskars metodik baserar sig på kontinuerlig utveckling och skapar mervärde inom BPR projektets planering samt urval av verktyg och metoder. Bhaskars metodik för BPR består av en initial identifiering av processer i behov av omkonstruktion som sedan resulterar i grundlig analys och modellering av den nuvarande processen. Därefter utvärderas möjligheter för optimering och förenkling och en ny processmodell tas fram. Efter den nya processen implementerats återgår man till identifieringsskedet som en del av metodikens krav för kontinuerlig utveckling. Under processens identifiering bör processen modelleras för att möjliggöra effektiv utvärdering av bristområden. I denna avhandling valdes processmodelleringsspråket ’Business Process Modeling Notation’, hädanefter förkortat till BPMN, på grund av att dess fördelar inom företagsomfattande förståelse. Fördelarna med BPMN inom processförbättring är dess möjlighet till förening av planerings- och implementeringsskedet samt kapabilitet för modellering av komplexa processer på detaljnivå.

Metod

Denna avhandling utförs i form av en fallstudie. I Fallstudier fördjupar man sig på ett eller några få fall för att få en detaljerad kunskap och en bättre förståelse av det man undersöker istället för att undersöka all data som finns tillgängligt eller samtliga processer. Som en del av fallstudien kommer Wärtsiläs vätskeanalysprocess utvärderas enligt Bhaskars metodik för BPR. Studien kommer att omfatta modelleringen av processen i BPMN för att möjliggöra en grundlig analys av processens styrkor och brister. Material kommer att samlas från interna databaser och intressenter inom Wärtsiläs avdelning för underhållsplanering. Till följd av att de genererade processmodellernas optimeringsmöjligheter har utvärderats kommer en blivande processmodell föreslås i form av BPMN. Wärtsilä fallstudien fungerar som ett relevant undersökningsobjekt eftersom deras vätskeanalysprocess har varit verksam i drygt fem år men aldrig blivit formellt modellerad eller undersökt för dess brister. Internt är det välkänt att processen innehåller svagheter och till följd av denna undersökning ämnar man kunna dra slutsatser gällande effektiviteten av BPR och processmodellering för småskaliga företagsprocesser. Giltigheten av denna studie kan påverkas av bristen på litteratur gällande processen från Wärtsiläs sida, eftersom den aldrig blivit officiellt definierad och tillgänglig dokumentation är bristfällig. Någon partiskhet härstammande från min anställning vid Wärtsilä kommer att undvikas.

Resultat

Wärtsiläs vätskeanalysprocess består av rapportinmatning, dataanalys och resultatrapportering. Initialt inkluderar processen också provtagning och rapportering men dessa utförs av kunden och relaterar på så sätt inte till denna studie. Som en stödjande process fungerar också vätskeanalysprocessens dataunderhåll. För datainsättning finns det för tillfället 4 metoder vilka inkluderar manuell insättning av Wärtsilä, manuell insättning av kunden, halvautomatiserad insättning med användning av robotiserad processautomatisering ’RPA’, och insättning genom direkt kommunikation med laboratoriets servrar med användning av ett gränssnitt för applikationsprogrammering ’API’. För dataanalys används för tillfället mjukvaran QlikSense, data förvaras i databasen Salesforce och visualiseringen sker i QlikSense. Det finns inte någon företagsomfattande etablerad metod för rapporteringen av analysresultaten i den nuvarande processen. Dataunderhållsprocessen omfattar uppdateringen av vätskeanalys gränsvärdena som förvaras i Salesforce databasen på basis av de värden som ges ut årligen av Wärtsiläs avdelning för teknisk service. I nuläget finns det ingen definierad metod för dataunderhåll inom vätskeanalysprocessen. Processerna beskrivna ovan kan ses i de genererade processmodellerna i figurerna 4–7.

De producerade BPMN modellerna utvärderades för ineffektivitet och felsannolikhet med hjälp av intressenter från respektive avdelningar inom Wärtsilä. Från modellerna identifierades bristfälligheter relaterade till ineffektiva manuella processer och saknande av pålitliga verktyg. Inom datainsättningsprocessen identifierades behovet av en övergång till totalt automatiserad insättning. Inom datarapportering och analysprocesserna identifierades ett behov för mer hållbara verktyg som skulle möjliggöra enklare uppföljning av datahistorik samt förenkla dom berörda experternas dagliga arbete genom automatiska alarmerings-notiser vid förekommande av avvikande data. Inom dataunderhållsprocessen konstaterades det krävas en omedelbar tilldelning av en temporär metod för dataunderhåll som i framtiden bör ersättas med en automatiserad process. Förslag på omarbetade processer kan ses i figurerna 8–11 och i bilaga 2.

Utvärderingen och modelleringen av processen med hjälp av BPR och BPMN visade sig vara effektiv. Modelleringen av processen gav slutanvändare och ledning en förbättrad överblick av processen. Användningen av Bhaskars metod för BPR visade sig vara relevant för Wärtsilä fallet.

Diskussion & Slutsatser

De huvudsakliga förbättringsbehoven inom Wärtsiläs vätskeanalysprocess består av etableringen av en pålitlig metod för dataunderhåll, en helautomatiserad metod för datainsättning, och ett mer omfattande system för analys och rapportering av resultat. Initialt bör dataunderhållsmetoden instiftas för att vätskeanalysprocessen i sin helhet ska vara giltig, vilket är ytterst kritiskt. Till följd av detta bör datainsättningsmetoden automatiseras för att undvika manuella misstag som kan leda till ogiltiga resultat under analys och rapportering skedet. Varefter detta har utförts bör rapporterings och analysverktygen kombineras och förbättras för att öka kvalitet och effektivitet.

Efter att dessa förbättringar har inrättats bör man repetera analysen i denna avhandling i enlighet med Bhaskars BPR process för att åstadkomma kontinuerlig granskning av processen och möjliggöra vidare förbättring. För att både de identifierade utvecklingsbehoven samt framtida optimering ska vara möjlig krävs det enligt mig en produktägare för vätskeanalys inom Wärtsilä.

Giltigheten av de genererade resultaten är påverkade av min kunnighet inom BPR och processmodellering. Denna avhandling omfattade endast en av Wärtsiläs många processer inom underhållsplanering och framtida forskning inom andra processer behövs.

Det går att dra slutsatsen att denna fallstudie lyckades eftersom forskningsmålen uppfylldes. Wärtsiläs vätskeanalysprocess modellerades i BPMN och utvärderades för optimeringsbehov i enlighet med Bhaskars metod för BPR. Användningen av BPR och BPMN visade sig vara effektiva för småskalig processoptimering och Wärtsilä bör utvärdera dess användning för framtida processoptimering.

REFERENCES

Aalst, v. d. W., Desel, J., Reisig, W. & Rozenberg, G., 2004. Business process management demystified : a tutorial on models, systems and standards for workflow management. *Lecture notes in computer science* , pp. 1-65.

Abu Rub, F. A. F., 2014. *A business process improvement methodology based on process modelling, applied to the healthcare sector.* s.l., International Conference on Web Information Systems and Technologies.

Adesola, S. & Baines, T., 2005. Developing and evaluating a methodology for business process improvement. *Business Process Management Journal* , 11(1), pp. 37-46.

Arnheiter, E. & Greenland, J., 2008. Looking for root cause: a comparative analysis. *The TQM Journal*, 20(1), pp. 18-30.

Arthur, N., 2005. Development, implementation and application of a condition based maintenance assessment tool for the uk oil and gas industry.. *Int. Journal of COMADEM,* 8(4), pp. 2-9.

Bäckström, K. H., 2020. Determination and Implementation of Suitable BPMS Solutions: A journey into a strive for a data driven enterprise.

Baczewski, R. A., 2005. Four Methods for Improving Performance: A Comparison. *Healthcare Financial Management* , 59(7), pp. 101-102.

Bhaskar, H. L., 2018. Business process reengineering framework and methodology: A critical study. *International Journal of Services and Operations Management,* 29(4), pp. 527-557.

Bhaskar, H. L. & Singh, R. P., 2014. Business Process Reengineering: A Recent Review. *Global Journal of Business Management*, 8(2), pp. 24-51.

Brierley, J., 2011. Why the proper definition of ABC matters. *Advances in Management Accounting,* Volume 19, pp. 225-249.

Campos, M., Fernandéz, J., Díaz , V. G. & Márquez, A. C., 2009. A new maintenance management model expressed in UML. In: R. Bris, C. Guedes Soares & S. Martorell, eds. *Reliability, Risk, and Safety* . London : CRC Press, pp. 501-509.

Cross, K., Feather, J. & Lynch, R., 1994. *Corporate Renaissance: The Art of Reengineering.* Malden: Wiley Blackwell Publishing .

Dennis, A., Wixom, B. & Tegarden, D., 2009. Systems Analysis and Design: An Object Oriented Approach with UML Version 2.0.

Fooladi, I. & Roberts, S., 2000. Risk management with duration analysis. *Managerial Finance,* 26(3), pp. 18-28.

Grant, D., 2016. Business analysis techniques in business reengineering. *Business Process Management Journal,* 22(1), pp. 75-88.

Jasiulewicz-Kaczmarek, M., Waszkowski, R., Piechowski, M. & Wyczolkowski, R., 2018. Implementing BPMN in Maintenance Process Modeling. *Advances in Intelligent Systems and Computing* , Volume 656, pp. 300-309.

Klockars, T., Eykerman , A. & Mayr, I., 2011. Making The Most of Perfect Maintenance Timing. *Twentyfour7*, January , pp. 64-65.

Logistiikan Maailma , 2021. *Process Improvement* , Tampere : Reijo Rautauomaan Säätiö.

Lopez-Campos, M. A., Marquez, A. C. & Fernandez, J. F. G., 2013. Modelling using UML and BPMN the integration of open reliability, maintenance and condition monitoring management systems: An application in an electric transformer system. *Computers in Industry* , 54(5), pp. 524-542.

Lowenthal, J. N., 1994. *Reengineering the Organization: A Step-by-Step Approach to Corporate revitalization.* Milwaukee: ASQC Quality Press .

McLeod, S. A., 2009. *Case Study Method,* s.l.: Simply Psychology.

Radnor, Z., 2010. *Review of Business Process Improvement Methodologies in Public Services,* Warwick : Advanced Institute of Management Research.

Roberts, L., 1994. *Process Reengineering: The Key to Achieving Breakthrough Success.* Milwaukee: ASQC Quality Press.

Tsaih, R. & Lin, W., 2006. The process-wide information organism approah for the business process analysis. *Industrial Management & Data Systems* , 106(4), pp. 509-522.

United States General Accounting Office, 1997. *Business process reengineering assesment guide,* s.l.: United States General Accounting Office, Accounting and Information Management Division.

Wärtsilä Corporation, 2020. *Wärtsilä's Data-Driven Dynamic Maintenance Planning solution optimises engine maintenance.* s.l.:Wärtsilä Oyj.

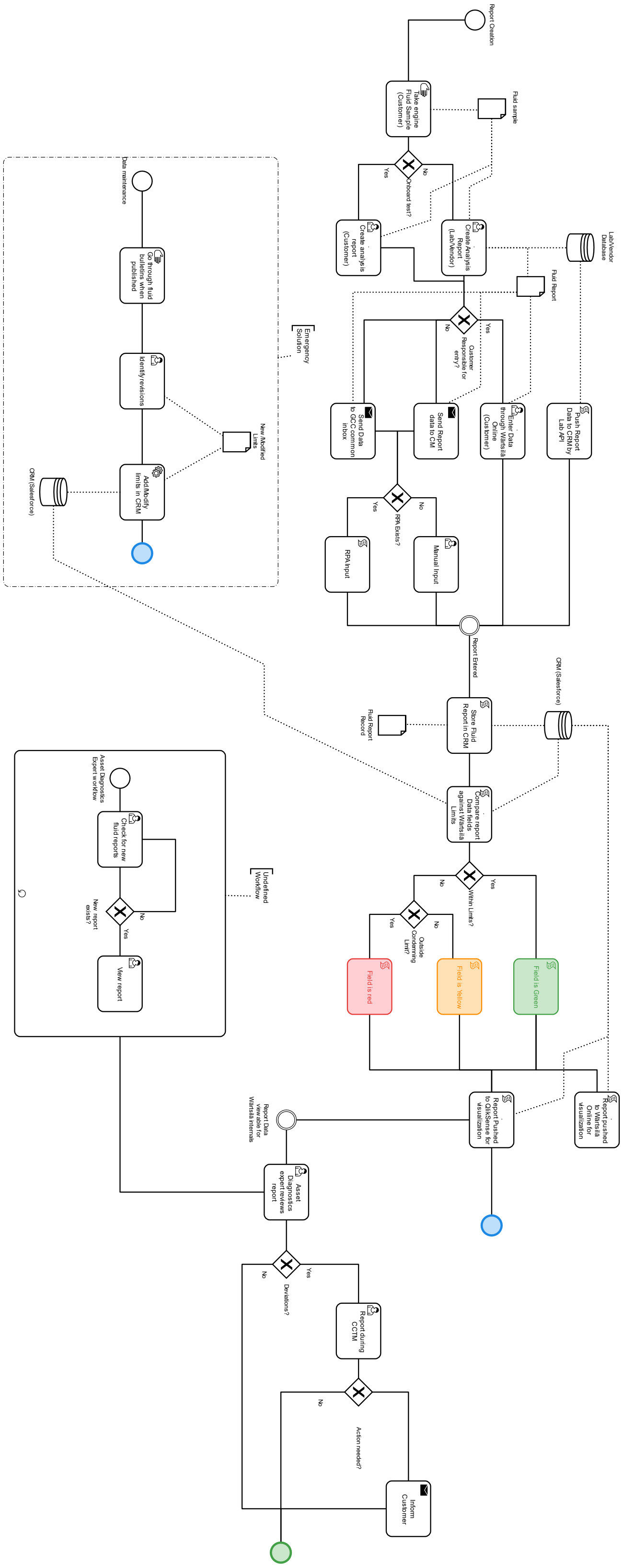
Wärtsilä Corporation, 2021. *Wärtsilä Optimised Maintenance - Improved availability and cost predictability.* s.l.:Wärtsilä Oyj.

Yin, R. K., 2011. *Applications of Case Study Research.* 3 ed. s.l.:SAGE.

Zacks Equity Research, 2021. *Shell (RDS.A) Launches VitalyX Oil Condition Monitoring Platform,* s.l.: Entrepreneur Europe.

APPENDICES

Appendix 1 – Current Fluid Management Process



Appendix 2 – Proposed Fluid Management Process