A web-based dashboard to facilitate progress management of pathology workflows

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Abstract

The Department of Pathology at Haukeland University Hospital in Bergen (HUS) has in recent years experienced a growing demand for their services. An aging population in combination with heightened use of personalized medicine has led to an increase in both the number of samples that needs to be analyzed and the complexity of the examinations. In spite of this, the workforce resources has not increased correspondingly. To tackle both current and future demand, there is a need to optimize the workflow in the laboratory.

Throughout the project presented in this master thesis, an artifact has been design and developed using the design science research methodology. The focus has been on examining the use of data visualization techniques and dashboards to better utilize the vast amount of data that exists about the workflow in the laboratory. A possible solution to visualize metrics of the pathology process to facilitate progress management at the Department of Pathology is presented. As part of the design process, we have identified novel ways to visualize metrics to provide additional insight of the workflow process in real-time. The results from the evaluation of the artifact contributed to an improved design, as well as the discovery of potential benefits of using such an artifact in a real setting. Additionally, future work has been identified in order to further increase the potential the artifact can have for the Department of Pathology.

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Acronyms

DP Digital Pathology.

DSR Design Science Research.

DSRM Design Science Research Methodology.

HUS Haukeland University Hospital in Bergen.

HVL Western Norway University of Applied Sciences.

LIS Laboratory Information System.

PiV Pathology Services in the Western Norway Health Region.

U-700 Unilab-700 laboratory information system.

UiB University of Bergen.

UiS University of Stavanger.

WP(s) Work Package(s).

Chapter 1

Introduction

1.1 Motivation

Life expectancy in the world is increasing and people are living longer. The World Health Organization argues that societies need to adapt across all sectors in order to tackle the challenges related to this historical demographic shift [1]. One of the challenges associated with an aging population is the increased demand for high-quality health care. According to Mans and colleagues, healthcare around the world is currently experiencing increased costs and long waiting times [2]. Furthermore, they argue that there is pressure on today's healthcare organizations to improve productivity and reduce waiting times.

These challenges are also relevant to the field of pathology. New and improved treatments combined with increased use of personalized medicine have been a contributing factor to the aging population that all countries are experiencing. As an example, the Norwegian Cancer Registry [3], reports that more and more people are dying with cancer rather than of cancer. This is important to notice as pathologists are considered to be at the hearth of cancer prevention and care [4]. Following this, it is easy to understand that the general demand for improved productivity within healthcare, as expressed by Mans and colleagues above, is of uttermost importance within pathology as well [2].

Pathology is the study of diseases. The presence of a wide range of diseases, including cancer and tumors, is detected based on analysis of cell and tissue samples. Hence, in many cases, an examination by a pathologist is required before being able to conclusively establish a diagnosis. For optimal patient care, it is essential that the diagnoses are accurate, specific, and sufficiently comprehensive. Additionally, it is desirable that a diagnosis is made in the shortest possible amount of time. According to Kargl et al, "the goal of every pathology laboratory is to report results to clinicians and patients as fast as possible" [5].

Niazi et al. [6] argue that the current pressure experienced by pathologists is trending toward digitalization. Laboratory Information Systems used at pathology laboratories are gathering vast amounts of data about their processes. Mans et al. [2] argue that the goal of healthcare organizations should not be to collect more data, but to exploit this "data to realize more efficient and effective care processes."

The workflow at a pathology lab is a complex process consisting of both manual and automated activities. A specimen has to go through a series of processing stages from the time it is registered in the lab until it is ready to be analyzed by a pathologist, as seen in Fig. 1.1.

After a specimen has arrived at the laboratory and been registered in the Laboratory Information System, a gross examination of the specimen is performed. During this examination, areas of interest are cut into smaller pieces and placed in cassettes. Following, the tissue is put into a machine that performs dehydration and clearing before it is embedded in paraffin wax. The paraffin solidifies the tissue and allows for it to be sectioned. Then, the tissue is cut into thin slices that can be placed on glass slides and delivered to the next stage for staining. Since most cells are transparent, histochemical stains are used to provide contrast and highlight structures within the tissue, making it easier to analyze. Lastly, before the tissue is ready to be sent to the pathologist for a final examination, a cover slip is put over the tissue as protection [7].

Figure 1.1: Simplified workflow at a pathology laboratory, from [8]

There are not only pathologists involved in the diagnostic preparation process. Lab technicians and junior pathologists are essential participants in this process as well. In addition, automated machines and instruments such as processors and stainers have contributed to making the preparation process more efficient. Seifert et al. [9], however, argue that the remaining manual work, such as grossing, embedding, and cutting, has to be closely monitored in order to prevent deterioration of the quality of patient care.

Several studies have shown promising results by using dashboards and graphical visualizations to improve the quality of pathology processes. The use of these dashboards has resulted in the discovery of bottlenecks [9], [10], improved turn-around times [10], [11], better staff performance [12], and more efficient workflows [9]–[12], among other things. While these dashboards have provided promising results so far in their respective laboratories, there is still potential for further improvements. However, a limitation of the created solutions is that they are all client-specific, and thus cannot be directly applied at the Department of Pathology at HUS. These studies will be presented in more detail in Section 2.4.

The processes in the pathology workflow are captured by Laboratory Information Systems (LIS). LIS solutions are a fundamental part of modern pathology labs, but the pre-built functionalities of the information systems do not address every laboratory's needs. Seifert and colleagues argue that there is still untapped potential in the combined use of LIS and data visualization techniques [9].

The general challenges within the field of pathology are also experienced at the Department of Pathology at Haukeland University Hospital (HUS) in Bergen. In recent years, the department has seen a significant increase in the number of incoming specimens. Due to the heightened use of personalized medicine, the examinations have become more complex, resulting in more time being spent on each analysis. However, despite the increase in workload, the workforce resources have not increased correspondingly. This has put pressure on the Department of Pathology to optimize the workflow processes in order to handle the growing demand.

The workwise challenging situation at HUS presents an opportunity to explore the use of dashboards and data visualization techniques to improve their pathology workflow process. There exists a great quantity of data in the laboratory information system used in the department. This data is, however, of little use without appropriate tools that can help in extracting meaningful information from it.

Graphical visualizations can provide timely insight to both the staff working in the lab and the administration. For the operative staff, real-time information about the processes in the lab can function as motivation to improve performance [12]. For management, historical statistical analysis can help to uncover trends and anomalies in the process. Furthermore, a better overview of the workflow process might eventually help the management in evaluating lab performance and positively impact resource planning [9].

1.2 Problem Description

A set of challenges related to the workflow and resource planning at the Department of Pathology at HUS has been identified [8]. This includes, but is not limited to:

1. Variability in the sample quantity from day to day and during the year
2. High variability in the type and number of examinations per sample, often with a high degree of complexity
3. A lot of manual work that requires the right skills and qualifications
4. Employees at the laboratory with different skills and different productivity levels
5. Insufficient flexibility when staffing workstations in the laboratory and fluctuations of available workers per day
6. Pathologists with different sub-specialties: Each sample should ideally be allocated to the right pathologist

To manage the demanding situation at the Department of Pathology at HUS, there is a need to develop a more efficient workflow and optimize the use of the available resources. Pathology Services in the Western Norway Health Region (PiV) is a strategic research project between Helse Stavanger and Helse Bergen, together with the Western Norway University of Applied Sciences (HVL) and the universities of Stavanger (UiS) and Bergen (UiB). The main goal of this project is to assess and develop methods and tools utilizing digital technology to improve the quality and performance of pathology services [13].

PiV comprises multiple work packages (WP(s)) focusing on different aspects of the digitization project, with WP7 concentrating on investigating the means for workflow optimization. It is WP7 that has the main responsibility of addressing the aforementioned challenges related to the workflow. The aim of WP7 is "to develop and implement software for optimization of the pathology workflow" to minimize the time between a specimen arriving at the lab and a diagnostic report being sent in response.

An initial meeting was held with two project members from PiV WP7, Patrick Stünkel (Postdoctoral researcher) and Friedemann Leh (Pathologist and Head of Histology lab at HUS). At this meeting, the lack of tools to utilize the potential of the vast amount of data from the LIS was emphasized as an impediment to resource planning and organization of the sample flow. The statistical reports provided by the Unilab-700 laboratory information system (U-700) have proven to be inadequate for the existing needs regarding resource planning and simulation requirements. As a temporary substitute, Excel is currently used as the main reporting and planning tool. The process of exporting the necessary data from the Unilab database and importing it to Excel is, however, rather cumbersome and inefficient. The quality and format of the data in the database are not supported in Excel. Thus, a manual cleansing of the data has to be performed before creating formulas for interpreting and visualizing the data. Hence, a more flexible and efficient solution is required. Consequently, it was decided during this meeting to create an artifact to explore the use of data visualization techniques and dashboards to more efficiently utilize the data at hand.

1.3 Research Methodology

The Design Science Research Methodology (DSRM) was chosen as the research method for this thesis. Design Science Research is primarily a problem-solving paradigm, and according to Brocke et al. [14], DSR "seeks to enhance human knowledge with the creation of innovative artifacts and the generation of design knowledge (DK) via innovative solutions to real-world problems". Considering that the main goal of this thesis is to create a graphical visualization dashboard to aid a specific client with their challenges, we found this research method to be the most relevant to this project.

The methodology is further described in Chapter 3, followed by a description of the design process with the various iterations performed throughout the project in Chapter 4.

1.4 Objectives for a solution

To address some of the challenges identified in Section 1.2, it was decided on a set of objectives for the artifact to be created. This thesis will mainly focus on the issues related to the variability in the number of samples, as well as the fluctuations of available workers. By creating a dashboard that can better utilize the vast amount of data in the LIS, valuable insight might be gained for the different stakeholders that will use the artifact. For laboratory management, gaining knowledge about trends and pitfalls in addition to real-time metrics in the workflow can lead to more informed decisions regarding resource planning. For the operative staff, timely updates on the current status of the preparation process might lead to increased work motivation and better performance. The artifact to be created will not automatize the process of optimization of the workflow as this is considered to be outside the scope of this thesis. The artifact will, however, facilitate for the possibility of manual optimization.

A search for similar dashboards in the literature was conducted using Google Scholar and PubMed. This was done to identify possible solutions and methods of relevance for this project. A few related research studies were found. These studies had all implemented client-specific solutions and were thus not directly transferable to our project. Some learning outcomes from these studies can, however, be used in this project. Relevant findings will be further presented in Section 2.4.

As an overall goal of the WP7, the developed solutions should not necessarily be specific for the pathology lab, as the challenges they face with complex workflow processes is not specific to the field of pathology itself, but can be considered general challenges within healthcare overall. Due to the scope of this thesis, however, the artifact will be tailored to accept data from the relational database used in the project of WP7. The data used in this artifact and related challenges will be presented in Section 4.3.

1.5 Research Questions

The research questions of this thesis relate to the design and implementation of a dashboard to visualize metrics from the workflow at the pathology laboratory at HUS. We have identified the research questions for this project as follows:

- **RQ1:** What are the limitations of existing dashboard solutions in pathology?
- **RQ2:** How can the manual performance of the pathology lab be visualized?
- **RQ3:** How can workflow monitoring through a dashboard impact the people in the lab positively?

1.6 Thesis Outline

- **Chapter one** presents the motivation behind the thesis and the problem identification. The methodology is also presented, along with the research questions that will be addressed.
- **Chapter two** presents the theoretical background and the current status in the field of pathology. Digital pathology and tools to utilize event data will be described. Finally, related work and existing solutions within healthcare and pathology will be discussed.
- **Chapter three** presents the design science research methodology used in this project.
- **Chapter four** describes the iterations performed during the design process, the final design of the artifact, and how the artifact fits in the architecture of the WP7 project.
- **Chapter five** presents the implementation of the dashboard and the technologies used.
- **Chapter six** describes the evaluation process of the dashboard in accordance with the evaluation guidelines from the research methodology.
- **Chapter seven** discusses the findings from the research and the contributions to the knowledge base.
- **Chapter eight** concludes the thesis and presents the remaining work.

Chapter 2

Background

This chapter presents the current status in the field of pathology. Following, tools to utilize event data will be described. Finally, related work and existing solutions within healthcare and pathology will be discussed.

2.1 Current status in the field of pathology

As emphasized in the first chapter, the challenge of increased workload in combination with limited resources is not unique to the Department of Pathology at HUS. This is a challenge that affects pathology labs all around the world. According to studies from the UK [22], Australia [23], the USA [17], and Austria [21], the current and future demand for pathologists is not aligned with the current supply levels. The future trend shows a critical shortage of labor within the field. Pallua et al. [21] argue that one reason for the growing need for pathologists is the increased use of personalized medicine. With patients receiving individually tailored treatments, the number of examinations per cell and/or tissue sample increases, and the examinations become progressively more complex. In addition, Niazi et al. [6] mention an aging population as a cause for the increased sample volume experienced at pathology labs.

Niazi et al. [6] argue that the current pressure that pathologists are facing regarding developing more efficient workflows is trending towards digitalization. Digital Pathology (DP) is currently one of the major topics within the field of pathology [15]. Digital Pathology was initially defined as the transition from viewing pathological images under the microscope to viewing the images on a computer. Today, however, DP embodies all technologies and changes related to this transition, including laboratory management systems, digital dashboards, workflow management, digital image analysis, and more [16], [17]. It is excepted that implementing Digital Pathology in laboratories will improve quality, efficiency, and safety in the diagnosis process [6], [10], [15], [17]. A small number of laboratories worldwide have undertaken the transition to a fully digital workflow, while an increasing number of laboratories have embarked on that journey [18].

2.2 Digital Pathology in Helse Vest

The histology lab at HUS is one of the biggest, public biopsy laboratories in Norway, receiving approximately 50 000 tissue samples yearly [19]. An analysis done on historical numbers shows that this number will continue to rise during the next years. Figure 2.1A shows the increase in samples received from 2000 to 2015. The blue line illustrates the progression of the number of biopsies performed in this time period, and the red line indicates the increased complexity based on the number of immunohistochemical examinations. Based on these numbers, it is estimated that the department will experience a growth of 45% in the number of samples received between 2015 and 2025 (Figure 2.1B). For the region of Helse Vest, the numbers are expected to double. Despite this, the workforce and personnel resources are not increasing in line with the higher workload demand.

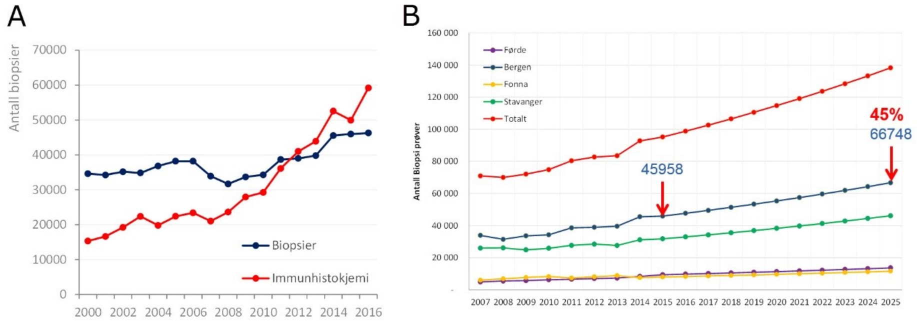

Figure 2.1: (A) Development of the sample volume at the Department of Pathology, HUS. (B) Development of the number of samples at the pathology departments in Helse Vest until 2025 based on the historical increase in the number of samples. From [8]

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Helse Vest is currently undergoing a shift towards Digital Pathology. A goal of implementing Digital Pathology in Helse Vest is to mitigate future increase in the workload at the pathology laboratories in the region. PiV is the main contributor to the process of implementing Digital Pathology in the region. By turning pathology data into meaningful information, PiV aims to make use of next-generation image analysis and optimization algorithms in order to tackle the future increase in workload. As of February 2022, all hospitals in this region have started using digital images instead of viewing images under a microscope. This allows for the images to be available for all pathologists in the region, despite being located at different hospitals. Implementing digital images is an important step in increasing the efficiency of the diagnostic process [20].

Despite this, there is still unused potential in the available expertise and capacity at the pathology departments in the region in terms of workflow efficiency. The Royal College of Pathologists [21] recommends a variety of solutions to tackle the challenges related to workforce inefficiency, including improving the IT infrastructure and implementing a Digital Pathology workflow to work more efficiently and flexibly.

2.3 Tools for utilizing event data from the pathology process

One reason for the need for a tool to better utilize the data from the workflow at the Department of Pathology is the lacking capabilities of the Unilab-700 laboratory information system (U-700). Additionally, WP7 has looked into the possibility of using Process Mining as a tool to improve the workflow. However, prior work done by WP7 has uncovered challenges with this tool as well. The following sections will present the challenges of using both of these tools for workflow optimization and resource planning.

2.3.1 Unilab-700 Laboratory Information System

The Unilab-700 laboratory information system (U-700) used at the Department of Pathology generates a vast amount of data about the work in the lab. Each specimen receives its own barcode when it arrives at the lab. This barcode is scanned and registered at every step that the specimen goes through. By having implemented this routine in the workflow, the LIS creates a list of logged events from every step in the preparation process.

As previously mentioned, the Unilab system offers statistical reports, but these have shown to be insufficient in the resource planning work done by the management and for finding the best possible flow of samples. Moreover, the system does not provide any means of simulation for the ongoing process at the laboratory [8].

Because of this, Excel is currently used in the work for resource planning. This does not allow for flexibility in the planning, as data has to be modified manually and cannot be visualized in real-time. In addition, this is a time-consuming task and not an optimal use of the management's resources.

2.3.2 Process Mining

Process mining is an emerging discipline that utilizes the vast amount of unstructured data that is gathered by information systems around the world. Aalst [22] argues that process mining can be considered as a "means to bridge the gap between data science and process science", as depicted in Figure 2.2. Process mining techniques use event data to discover and improve processes, with the goal of turning information into knowledge and insight. By using these techniques, it is possible to discover the discrepancies between the actual behavior of people and machines and the modeled behavior [22]. Businesses all around the world are currently using process mining to improve both efficiency and compliance within their operations [23].

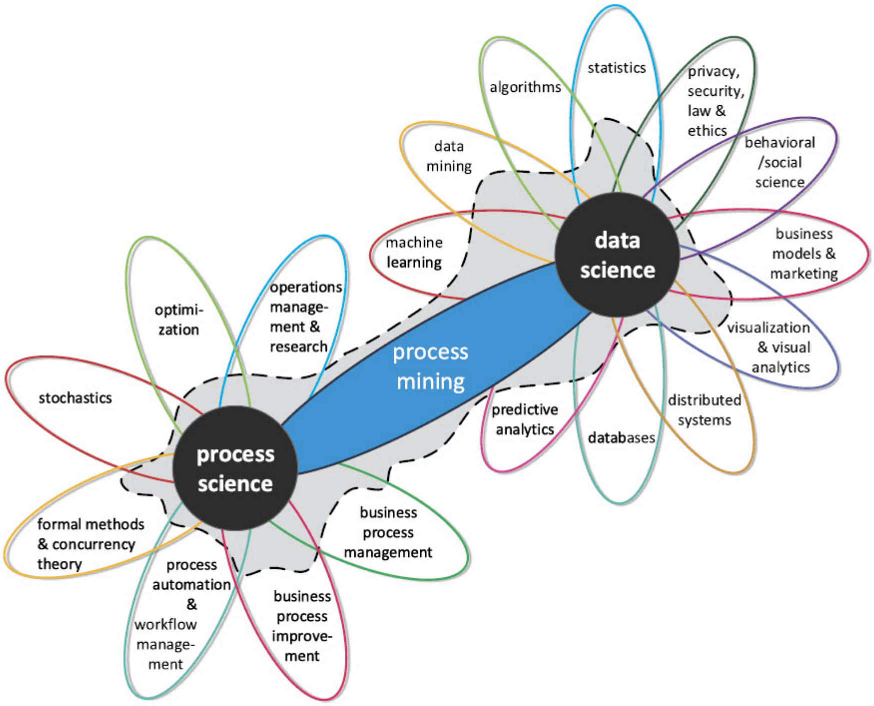

Figure 2.2: Process mining as the bridge between process science and data science, from [22]

Event logs are an essential part of process mining, and it is the data from those logs that are used to extract insight and knowledge about the processes. Event logs are a collection of activities, and it is assumed that each activity is referenced by at least an id and a timestamp. By using process mining techniques on event logs one can create a process model to describe the processes in terms of their key activities [22]. Figure 2.3 shows a process model that is discovered from an event log.

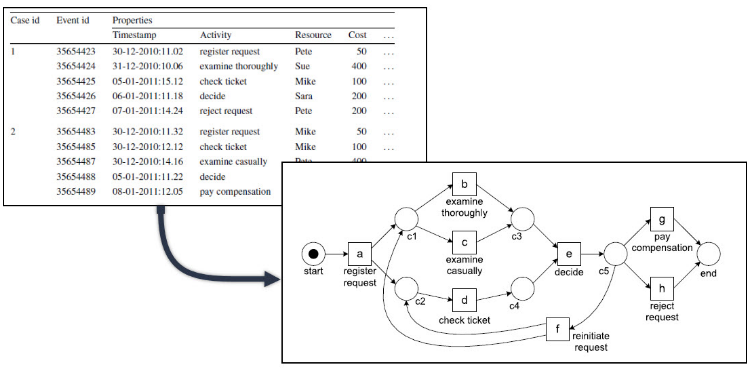

Figure 2.3: Process mining: From an event log to a process model, adapted from [22]

With the increased use of Hospital Information Systems (HIS), there now exists a vast amount of data about the processes in healthcare settings. Because of the great potential of process mining to improve processes and reduce costs, Mans et al. [2] claim that there is a growing acceptance of using these techniques within the healthcare domain.

Stünkel et al. [7] have tried to use process mining techniques in their work to improve the processes at the Department of Pathology. They have, however, met a list of challenges while applying process mining techniques as part of WP7. Some of the technical challenges they have met include:

- The LIS does not record all relevant events
- Not all process steps are always tracked
- The granularity of the logged events varies greatly
- Event names in the database can sometimes be cryptic and ambiguous
- Case meta-information and resource-specific event attributes are sometimes missing.

They conclude that the current process mining techniques that are available are not perfectly suited for the complex specimen preparation process in the pathology laboratory.

2.4 Related work

2.4.1 Dashboards in the health sector

Over the last few decades, there has been a remarkable growth in data. Data is now collected "about anything, at any time, and at any place" [22]. Businesses and organizations around the world are making use of the data produced by their information systems. This also applies in healthcare. However, the extensive amounts of data are of little use if we do not have systems that can extract the information in this data and turn it into valuable insight and knowledge [24].

The abundance of information that is gathered about processes in the health sector can provide meaningful knowledge that can be used to improve these processes. With a greater demand for elderly care around the world due to an aging population, as well as the growing need for precision medicine, a need has occurred to improve productivity and reduce costs in the sector [2].

Using dashboards to track and visualize performance metrics has become increasingly more widespread within healthcare organizations [24]. In this setting, a dashboard is defined as a user interface or a web page that portrays an up-to-date summary of key information, often relating to progress or performance [25].

The benefits of using dashboards in clinical settings have been reported in the literature. A literature review of hospital performance dashboards performed by Buttigieg et al. [26] provides an overview of the benefits that have been reported through the use of dashboards. This list includes advantages such as improved performance, raising awareness of problems, enabled informed decision-making, reduction of costs, improved patient care, and more. In spite of the many advantages found, the dashboards did not come without their challenges and limitations. The authors report a number of obstacles related to the adoption, implementation, and maintenance of these dashboards, such as the resistance to change within healthcare organizations and the significant amount of investment required in financial and human resources.

2.4.2 Dashboards in pathology

A search for scientific literature on dashboards for visualizing workflow processes in the field of pathology reveals a selection of studies done regarding this topic. Dash et al. [27] argue that the archetypal solutions today include creating interfaces to "achieve a fixed set of goals for a single customer". This is consistent with the studies found, as all of them had implemented client-/institution-specific solutions in their research. As a consequence of this, the tools are not available on the market and cannot be used at other laboratories.

Although the studies found present solutions that are specific for their client and use case, the overarching ideas and learning outcomes from those studies can be adapted to the visualization dashboard to be developed in this thesis. This section will introduce studies where the authors have successfully implemented dashboards in their laboratories, and how their results can be used in the design and implementation of the dashboard developed in this thesis.

A real-time dashboard for managing pathology processes

Halwani et al. [10] designed and developed two versions of a dashboard for the Department of Pathology and Laboratory Medicine (DPLM) at The Ottawa Hospital (TOH). In the first phase, a process-level dashboard was created which helped to "monitor and manage the processes at DPLM". During the second phase of the project, the focus was on a case level. This led to the creation of a dashboard using the IBM® Cognos® BI tool. This solution helps the managers at DPLM to uncover and to tackle bottlenecks in the process and increase throughput.

As opposed to that study, where "data did not need to be checked for quality", the quality and the format of the data from the LIS at the pathology department at HUS have shown to be a major challenge in the work of WP7 [7].

While the two dashboards created in this study do address a set of requirements, there is still more work to be done. Although dashboards have shown to be a powerful means to both improve and monitor performance and workflow, there is still more potential that can be gained from the data at hand. Halwani et al conclude that a third version of a dashboard is required in order to attend to the need for workload planning and automatic notifications.

Informatics driven quality improvement in the modern histology lab

Seifert et al. [9] state in their report that the functionalities of the Laboratory Information Systems used in pathology laboratories today do not address all the needs of a modern histology laboratory. However, they argue that data visualization provides a powerful tool to illustrate workflow trends using different charts and diagrams. In their study, they "implemented several custom data analytics dashboards and additional LIS functionalities to monitor and address weaknesses".

Their pathology department uses Beaker as their LIS. In their implementation of dashboards, Seifert et al. were able to utilize built-in modules and reports in Beaker to create customized dashboards. One of the major shortcomings of Beaker was that pending histology work was organized based on cases rather than tasks. This organization of the work list was found to be unintuitive. Additionally, useful information often got concealed behind less useful information. Thus, the authors created a "status board" focusing on pending tasks instead of cases. Furthermore, metrics such as priority grades and time-in-status were also displayed, allowing for the triage of urgent cases. The task-based work list was also more adaptable than the case-based work list regarding changes in the workflow.

Seifert et al. concluded that even though their solution is institution-specific, the technical and functional framework that they present in their research may benefit other institutions as well. In further work, they highlight collaboration between stakeholders, creative problem-solving, and careful and continuous evaluation as important key takeaways.

DB4US: A Decision Support System for Laboratory Information Management

Carmona-Cejudo et al. [28] created an integrated web-based dashboard, DB4US, that automates information related to quality indicators in the laboratory. The application extracts, consolidates, analyses, and visualizes data from the process relating to the use of demographics, reagents, and turn-around times. The aim of their project was to create an application that could easily analyze the performance in the laboratory and detect errors or irregularities. With the application being web-based, it also provided the users with easy access from any computer without needing additional client software.

The use of their application showed improvements in the time usage and optimized use of laboratory resources.

2.4.3 Summary

Table 2.1 offers a comparison of the existing dashboard solutions proposed in the literature. The proposed solutions offer some of the same functionalities, but the main difference between them is on what level the workflow data is presented. The first solution created by Halwani et al. [10] showed information on process level. This was done by aggregating information about processed cases, blocks, and slides. This was deemed as beneficial, however, they found that they needed more information. Thus, the second dashboard was expanded to include information on both processes and on individual cases.

The solutions proposed Both Carmona-Cejudo et al. [28] also included metrics on two levels. They focused on representing aggregated metrics regarding both tasks (tests) and cases (samples). However, compared to Halwani et al, Carmona-Cejudo et al. did not include the option of looking at information about individual cases. Only aggregated metrics were shown.

On the other side, Seifert et al. [9] found that their department would benefit the most from metrics about tasks. Their LIS showed information on a case level, however, they found that this way of presenting the data resulted in information getting buried.

We can also see that none of the dashboards included the option of setting goals. Carmuno-Cejudo et al. had, however, included a configuration to modify the benchmark values (e.g. monitor samples with turn-around times of 10 days instead of 12 days).

When creating dashboards to increase performance, theories have shown that how the feedback is presented is of great importance. Contextual Feedback Intervention Theory (CFIT) [29] states that having realistic and achievable goals is an important contributing factor in order to heighten the value of the feedback. Thus, we can postulate that having both the functionality of comparing metrics to benchmark values and the functionality of setting goals can have the potential to further improve performance and contribute to improving workflow.

	Carmona-Cejudo et al.	**Halwani et al. #1**	**Halwani et al. #2**	**Seifert et al.**
Process-level	No	Yes	Yes	No
Task-level	Yes	No	No	Yes
Case-level	Yes	No	Yes	No
Benchmark comparison	Yes	No	Yes	No
Adjustable goals/KPI	No	No	No	No
Real-time reporting	No	No	Yes	Yes
Built on existing solutions	No	No	Yes	Yes

Table 2.1: Comparison matrix for pathology dashboards

Below, a description of the dashboard functionalities presented in Table 2.1 are provided.

Process-level: monitoring of stages throughout the process. E.g grossing, staining, etc.

Task-level: monitoring of tasks/tests. E.g. sub-category of process (different types of staining, etc)

Case-level: monitoring of individual cases/samples

Benchmark comparison: benchmark values that the workflow is compared against. E.g. are cases being handled within a certain time period (standard turn-around times)

Adjustable goals/KPI: visualizations of metrics in relation to goals that can be adjusted

Real-time reporting: visualizations of metrics in real-time

Built on existing solutions: if the application uses existing tools or is developed from scratch

Chapter 3

Methodology

Due to the solution taking a practical approach in the form of creating an artifact, Design Science Research was chosen as the preferred methodology. Brocke et al. [14] define Design Science Research as a methodology that "seeks to enhance technology and science knowledge bases via the creation of innovative artifacts that solve problems and improve the environment in which they are instantiated". Thus, considering the motivation behind the project and the goals that we set, design science research was deemed the most applicable for this project.

Peffers et al. [30] proposed a methodology for conducting effective design science research in Information Systems (IS). Their Design Science Research Methodology (DSRM) is well grounded in the existing literature about design science in IS and other related disciplines. They argue that Design Science is important in a discipline-oriented to the creation of successful artifacts.

The Design Science Research Methodology proposed by Peffers et al. [30] consists of six activities:

1. **Problem Identification and Motivation:** Define the specific research problem and justify the value of a solution.
2. **Objective of the Solution:** Infer the objectives of a solution from the problem definition and knowledge of what is possible and feasible.
3. **Design and Development:** Create the artifact. Conceptually, a design research artifact can be any designed object in which a research contribution is embedded in the design.
4. **Demonstration:** Demonstrate the use of the artifact to solve one or more instances of the problem.
5. **Evaluation:** Observe and measure how well the artifact supports a solution to the problem.
6. **Communication:** Communicate the problem and its importance, the artifact, its utility and novelty, the rigor of its design, and its effectiveness to

researchers and other relevant audiences such as practicing professionals, when appropriate

Chapter 1 covers the first activity. The motivation behind the artifact is introduced, as well as the artifact's relevance for solving the problems identified in Section 1.2. Due to the increased workload at the Department of Pathology at HUS, there is a need to develop a more efficient workflow and optimize the use of the available labor resources. The Laboratory Information System used at the Department of Pathology provides data that describes the workflow, but there are no tools available that can utilize this data to analyze and visualize the pathology workflow. The artifact is designed to better exploit this data and give valuable, real-time insight to the stakeholders about the progress in the laboratory workflow.

Chapter 2 further strengthens the relevance of creating such an artifact, both as a problem within the field of pathology and as a Software Engineering problem.

Chapter 1 also covers the second activity; objectives for a solution. The objectives were inferred with knowledge of what was both possible and feasible within the context of the problem description and the time constraints of the project. The artifact is created to provide timely updates from the workflow, allowing the laboratory management to monitor the workflow and facilitate the allocation of resources in real time. Additionally, it will provide the operative staff with instant feedback about the progress of their work.

Chapter 4 presents the design and development activity. The artifact is a web-based application that gives real-time updates from the workflow in the laboratory. The design of the artifact was performed in four iterations with varying lengths, with each iteration having its respective goals:

- **First iteration:** Problem identification and defining the objectives for a solution
- **Second iteration:** Creating a design for the artifact
- **Third iteration:** Implementing a prototype with real process data
- **Fourth iteration:** Adding additional functionality

These iterations will be further described in Chapter 4, along with the demonstration and evaluation activities that were performed at the end of each iteration.

Furthermore, an evaluation of the final artifact will be presented in Chapter 6. The evaluation was done from two perspectives. Firstly, a user evaluation was performed with two pathologists from the laboratory. Secondly, a heuristic evaluation was performed to assess how the artifact compares to dashboard design requirements from a meta-study on quality dashboards. Due to time restrictions of incorporating the artifact in the laboratory, the artifact was unfortunately not evaluated in a real setting.

The last activity, communication, is to a large degree presented through this thesis. Additionally, the utility of the artifact was regularly presented to the customer through iterations in the design cycle process.

Chapter 4

Design and Development

In this chapter, the design and development of the artifact will be presented. The first section describes the design process and the various iterations that were performed. The following section will introduce the design of the final artifact. Lastly, the last section will give an account of the preliminary work of WP7 and how the artifact created in this thesis fits in the overall architecture of the project of WP7.

4.1 Design Process

Figure 4.1 shows how the design process performed in this thesis relates to the first five activities of the Design Science Research Methodology proposed by Peffers et al. [30]. The design and development of the artifact were based on a set of requirements defined in each iteration that was performed. For the duration of the development process, regular meetings were held to discuss and evaluate the design and the features of the artifact. Two project members from WP7 (Head of the Histology Lab and a postdoctoral researcher) and the supervisors of this thesis were present at these meetings. The artifact as a whole was presented each time, and both the currently implemented features and new features were discussed. From the demonstration and evaluation performed at the end of each iteration, a new set of requirements were defined. The end of the last iteration resulted in the final pre-evaluation artifact.

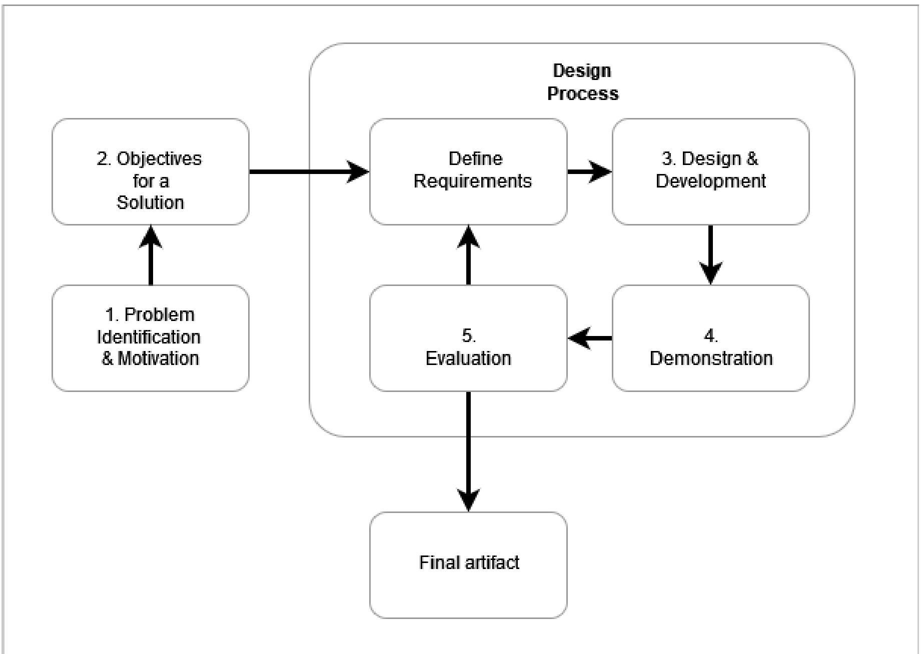

Figure 4.1: Design Process

Altogether, the design process had four iterations with lengths varying from 1-3 weeks depending on the goal of the iteration. The main goals of the iterations were as follows:

- **First iteration:** Problem identification and defining the objectives for a solution
- **Second iteration:** Creating a design for the artifact
- **Third iteration:** Implementing a prototype with real process data
- **Fourth iteration:** Adding additional functionality

4.1.1 First iteration: Defining the objectives for a solution and initial requirements

During the first iteration, the primary concern was defining objectives for a solution based on the initial problem identification. The first meeting was held together with the Head of the Histology lab. As the first step in this process, the stakeholders for the artifact were identified along with objectives for a solution.

Stakeholders:

- Laboratory management
- Operative staff

The main objective was to develop an artifact that can utilize the available process data from the laboratory and visualize the workflow in real-time. Such an artifact will provide timely insight into the current status in the lab for both stakeholder groups.

Figure 4.2 shows the stakeholders' role in the workflow in the laboratory in relation to the process activities. The activities performed by the stakeholders seek to answer a set of questions [31]:

- Report: *What happened?*
- Analyse: *Why did it happen?*
- Predict: *What will happen?*
- Plan: *What is the best that can happen?*

The aim of answering these questions is to assist in turning the data from the workflow into real value. The artifact created in this thesis will primarily contribute to the two last activities - *planning* and *operating*. By being able to monitor real-time progress in the laboratory through a dashboard, both stakeholder groups can make adjustments in their work in order to increase efficiency in the lab.

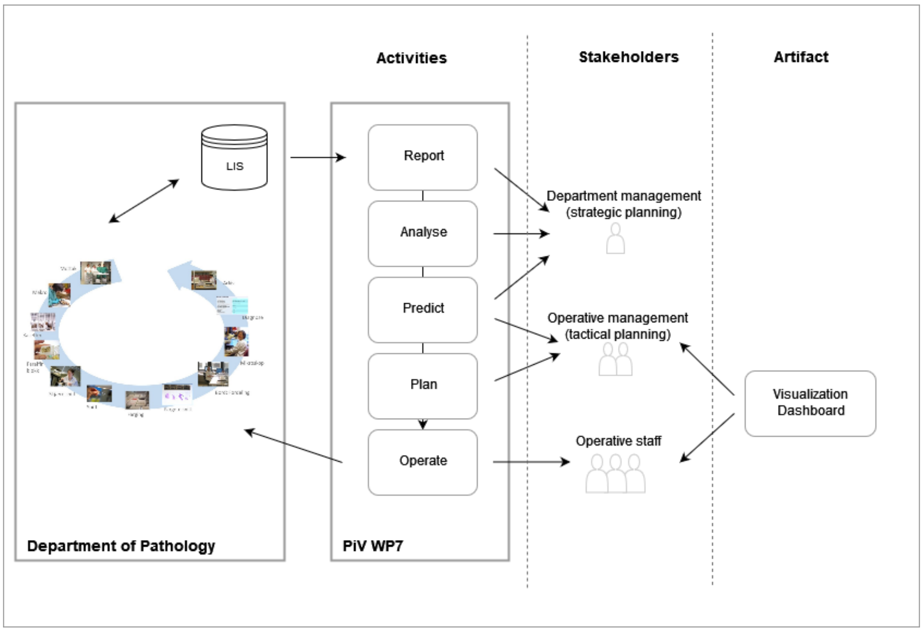

Figure 4.2: Process activities, stakeholders, and the artifact

Further on, a set of requirements for the artifact was defined. For both of these stakeholder groups, the most important functionality of the artifact was to have timely updates of the progress in the laboratory workflow. Due to the complexity of the laboratory workflow and the scope of this thesis, it was decided to limit the visualizations to three stations – grossing, sectioning and staining. The main requirement was to get a live view of the number of samples processed at each station during the day. Additionally, it was deemed important to have this progress status visualized in relation to a goal. This feature was deemed as an important step in increasing the motivation of the staff. Also, due to fluctuations both in the number of samples and in available labor resources, this goal had to be adjustable. These requirements originated due to missing functionalities in the laboratory information system.

Methods to visualize the data were suggested at this meeting. Both bar graphs and line graphs were discussed as possible options, but horizontal bar graphs were chosen as the most appropriate for this particular purpose.

Additionally, a set of non-functional requirements was discussed. In the context of WP7, the dashboard would serve as a frontend connected to a PostgreSQL database. It was considered important that the application was easy to access and it should not require the user to download software. Thus, it was decided that the artifact should be created as a web-based application.

Based on the requests from the customer and the identified gaps in the current functionalities of the LIS, a set of preliminary requirements were made. These requirements would then be the focus of the following iteration.

Preliminary requirements:

- Web-based interface
- Data stored in a relational database
- Data presented in real-time
- Visualization of the number of processed samples from three stations at the laboratory in the form of bar graphs
- Having adjustable daily goals

4.1.2 Second iteration: Creating a design for the artifact

As the first step in this iteration, a set of tools and frameworks for the development of the artifact were decided upon. As these tools were not dependent on the architecture of WP7 and the stakeholder requirements, this was not part of the preliminary requirements. The tools and frameworks used for the artifact will be described in more detail in Chapter 5.

Following, an initial design of the dashboard was created along with a prototype of the main page of the dashboard, the Live View page. The final design of this page is depicted in Figure 4.5. On this page, a progress bar was created for each of the three stations that were decided on in the first iteration – grossing, sectioning and staining. The length of the bar graphs, the x-axis, was set to be the goal of the day for each station. Additionally, if the goal was reached, the color of the bar changed from blue to gold to symbolize successful achievement. Functionality to adjust the goals was also added, in addition to information about how many samples remain in order to reach the goal. As we had not yet gotten access to the real pathology process data, example data was used for this iteration.

Demonstration and Evaluation: The current design and the implemented features were discussed in a meeting with the supervisors of this thesis and the two members from WP7. The first topic of discussion was the design of the bar graphs. Here it was decided that the bars should continue to increment after the daily goal had been reached instead of stopping. Additionally, adding information about the number of workers at each station was requested. Following this, it was decided to add extra pages to the application with graphs visualizing historical trends and patterns in the workflow. As the last requirement, a connection to the database containing real process data was requested.

Requirements for next iteration:

- Improve design and functionality of the progress bars
- Create pages with historical data graphs
- Connect to database with real process data

4.1.3 Third iteration: Implementing a prototype with real process data

During the third iteration, I was granted access to a database with pseudonymized process data from 2021. The data used in this project will be presented in more detail in Section 4.3.

As it was not yet possible to get access to real-time data, a simulation of the real-time updates was created using historical data. This was done by allowing the user to select any date within 2021, and then the progress bars were updated with the number of processed samples according to the status at the same time of day at the selected date.

Additionally, two improvements to the progress bar on the main page were made:

- Allowing the status bars to show the number of processed samples beyond the daily goal
- Added information about the number of workers at each station

Furthermore, extra pages were created providing additional features for laboratory management. This included two pages with visualization options of historic data:

1. The first page showed a comparison of workflow progression at one station during two chosen periods in the form of a line graph.
2. The second page was a view of the average number of samples processed each working hour of the day based on a chosen station and day of the week.

The final design of these pages are presented in Fig. 4.6 and Fig. 4.7.

Demonstration and Evaluation: The demonstration and evaluation activities of this iteration were performed with the same people as before. The discussions during this evaluation were mostly centered around how to improve the progress bars on the main page to increase the information gained from the visualization. From the discussions, it was decided to add a benchmark comparison for each station, allowing the management and the staff to get an overview of the current efficiency and to see if they are on track in order to reach the daily goal. Additionally, a time simulation page was requested in order to view the progress in the lab during a specific time where the user can set the update time interval such that different "playback" speeds could be simulated.

Requirements for next iteration:

- Add benchmark comparison for each station
- Add time simulation page

4.1.4 Fourth iteration: Adding additional functionality

The main requirement in focus during this iteration was adding the benchmark values for comparison at each station. The benchmark was added as an additional bar on top of the current bar in a lighter blue color than the original bar, as shown in Figure 4.3. These bars represent the cumulative average of all processed samples at that specific time of the day in relation to the goal. The purpose of the benchmark is to give an overview of how many samples should have been processed at the current time in order to be on track to reach the daily goal. If the bar is not visible, the staff knows that the current production rate is in line in order to reach the daily goal. If the bar is visible, it shows how many samples should have been processed by that time.

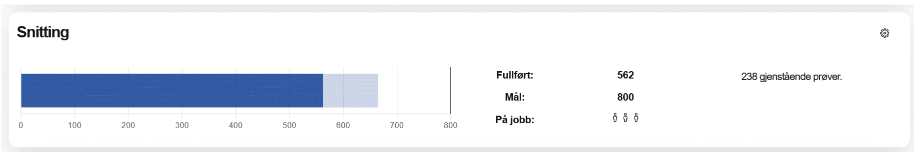

Figure 4.3: Progress bar with benchmark comparison

The cumulative average is calculated from the number of samples processed on each relevant day in 2021. As can be seen in Figure 4.4, the time granularity is set to one minute. The benchmark values are then calculated by multiplying the cumulative value by the daily goal. Thus, one can see how many samples should have been processed at each minute in order to reach the goal.

grossing	on relevant days	cumulative	delta
	42092	0	
08:00:00	949	0,02	0,0225
08:01:00	995	0,02	0,0011
08:02:00	1027	0,02	0,0008
08:03:00	1066	0,03	0,0009
08:04:00	1106	0,03	0,0010
08:05:00	1144	0,03	0,0009
08:06:00	1177	0,03	0,0008
08:07:00	1227	0,03	0,0012
08:08:00	1278	0,03	0,0012
08:09:00	1314	0,03	0,0009
08:10:00	1368	0,03	0,0013
08:11:00	1424	0,03	0,0013
08:12:00	1482	0,04	0,0014
08:13:00	1548	0,04	0,0016
08:14:00	1607	0,04	0,0014
08:15:00	1664	0,04	0,0014
08:16:00	1725	0,04	0,0014
08:17:00	1793	0,04	0,0016
08:18:00	1858	0,04	0,0015
08:19:00	1924	0,05	0,0016
08:20:00	1993	0,05	0,0016

Figure 4.4: Cumulative average values from "grossing" used for comparison

The second requirement for this iteration was adding a page for time simulation. The time simulation shows the same type of bar graphs as are used on the main page of the dashboard. With this simulation, it became possible to see the progress during a specific day in 2021 and a specific time period (e.g. 08.00 to 16.00). The user can also decide the speed of the simulation.

Demonstration and Evaluation: As we were getting closer to having a final prototype of the dashboard, the demonstration, and evaluation of this iteration were mostly focused on updating the queries to the database. One change request was to update the query for the grossing numbers to also include macroscopy samples. Until now, only microscopy samples had been included.

As this was the final iteration of the design process, it was decided that the artifact was ready for external evaluation. As a first step in the evaluation process, a pathologist from the laboratory was invited to take part in a usability testing session. The evaluation and the results from this session will be presented in Section 6.1.1.

4.2 Artifact Description

This section describes the final design of the post-evaluation artifact. A few changes were done after the external evaluation in terms of improved usability. The specific changes that were made after the evaluation are further described in Section 6.1.1. The following description of the artifact includes the last changes that were made, and reflects the current state and design of the artifact.

The artifact is a web-based application, and it was created for two separate groups of stakeholders. The primary purpose of the artifact is to present real-time graphical visualizations from three different stations of the workflow process at the Department of Pathology at HUS. This page will be further on be referred to as the Live-View Page. The secondary purpose of the artifact was to visualize historical trends from the workflow process. These graphical visualizations are separated into three different pages. Those pages will collectively be referred to as the Management Pages.

4.2.1 Live View Page

Live View Page is the main page of the application, shown in Figure 4.5. Here, both the operative staff and the management are presented with the real-time status of three different stations at the laboratory – grossing, sectioning, and staining. The progress bar shows the daily number of processed samples at each station in relation to a daily goal. When the daily goal has been reached, the color of the bar changes from blue to gold, and a vertical line representing the goal will move correspondingly to the left as the number of processed samples increases. The daily goal and the number of workers can be adjusted for each station in accordance with available labor resources at the laboratory for the current day.

For the stations that have not yet reached their goal, the number of remaining samples is displayed on the right.

The light blue bar represents the cumulative average of all samples processed at each station at that time in relation to the daily goal. The number represents how many samples should have been processed by that time of day in order to reach the daily goal.

As the artifact is currently connected to a historical data set, it is displaying a simulation of real-time updates from the year 2021. The date displayed corresponds to the status of the same date in 2021.

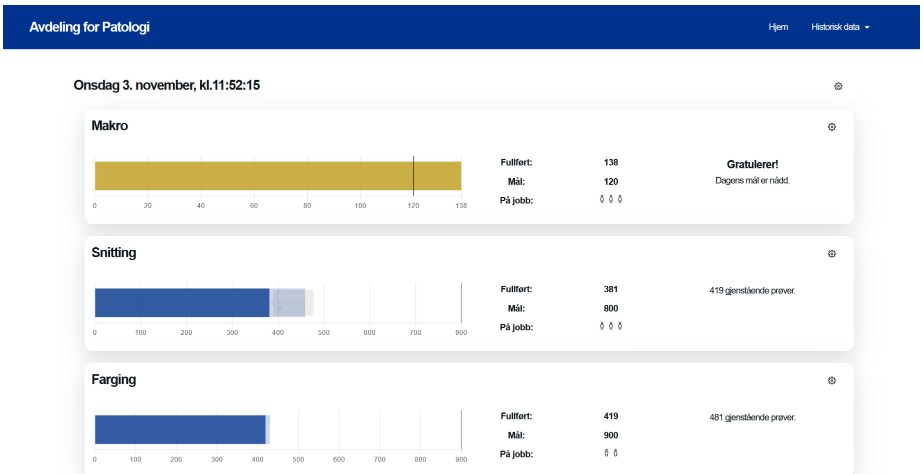

Figure 4.5: Live View Page

4.2.2 Management Pages

The Management Pages are three distinct pages with graphs showing historical trends from the year 2021.

Figure 4.6 shows the first Management page. This page has a line graph visualization where it is possible to compare the total number of progressed samples each day at a station over two periods.

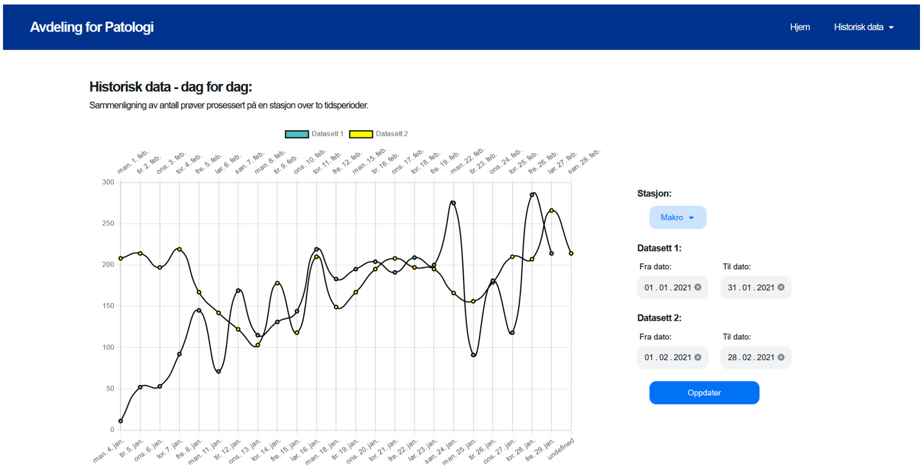

Figure 4.6: Management Page #1

The second page, seen in Figure 4.7, shows the average number of samples processed at each hour at a station divided by weekdays.

Figure 4.7: Management Page #2

Figure 4.8 shows the third Management page which is a time simulation. Here, it is possible to run a simulation of any day in the year 2021. The user can decide on start time and end time, as well as the speed of the simulation

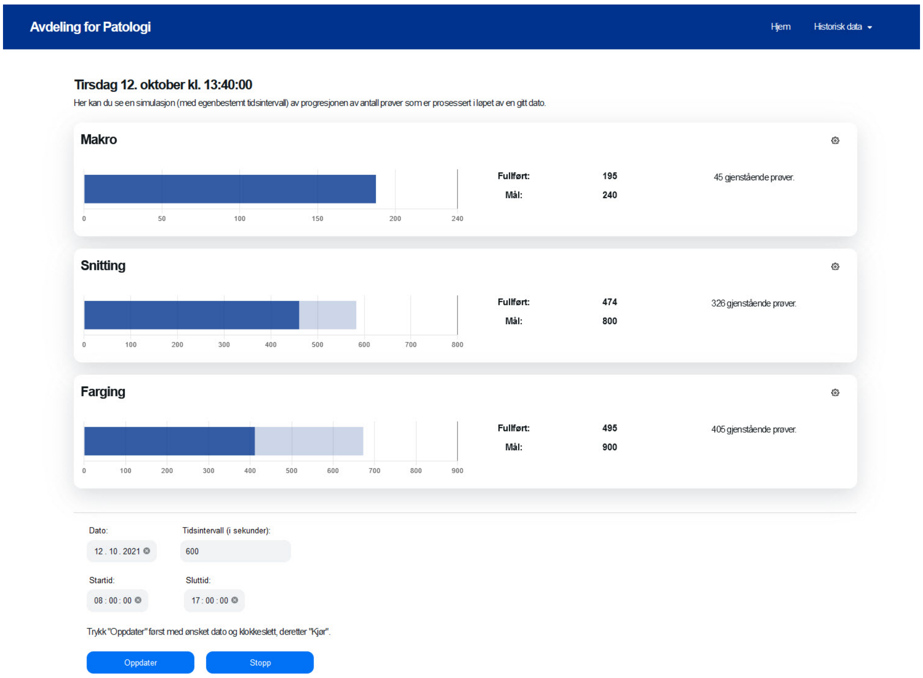

Figure 4.8: Management Page #3

4.3 WP7 Architecture

The artifact created in this thesis is part of the WP7 project. It is the preliminary work done by WP7 that has laid the foundation needed for the development of the artifact.

Following, the preliminary work of WP7 will be presented, in addition to a description of how the artifact fits in the WP7 Cloud Architecture.

4.3.1 Preliminary work of WP7

For the dashboard created in this thesis to have value to the customer, it is essential that it shows real data from the pathology lab. As previously mentioned, the artifact is currently connected to a relational database with historical data from 2021. This data has been extracted from the Unilab database and transformed from raw event data into a viable event log structure. It is the preliminary work of WP7 that has provided this transformation such that the data can be used for this thesis.

The WP7 project group has faced several challenges in the preliminary phase of their project. Some of these challenges include organizational issues with regard to data access and technical issues concerning the transformation of data. Stünkel et al. [7] provide a comprehensive overview of these issues in their status report.

When conducting projects within healthcare, there are particularly strict requirements regarding access to data. Some of these requirements include reporting on what data is extracted and how the privacy of sensitive data is safeguarded. As the Department of Pathology at HUS does not have direct access to the data in the Unilab database, the WP7 had to apply for access in the preliminary phase of their project.

The process of extracting and transforming the data from the Unilab database has been thoroughly described by Stünkel et al. [7]. The main challenge they faced in this process was regarding the data quality in the Unilab database. The three groups of "data quality" issues proposed by Bose et al. [32] all apply to the data from Unilab: "(i) the event log does not contain [all] events that really happened, (ii) the event log contains more events than in reality, and (iii) the real events are concealed in the log." Thus, a data cleansing process had to be done.

The relevant data from the LIS is extracted as comma-separated values (CSV) files. In this process, sensitive data is pseudonymized via hashing. Furthermore, since the LIS used at the laboratory does not offer a viable event log structure, the data had to be transformed so that it can be used for other purposes.

4.3.2 WP7 Cloud

To enable the use of the artifact at the Department of Pathology, the artifact must be incorporated into the WP7 cloud architecture, as seen in Fig. 4.9. WP7 uses Azure Cloud for their project. As the cloud architecture has been created outside of this project, only a brief overview will be given.

In the context of the WP7 project, the artifact, depicted as "dashboard" in Fig. 4.9, serves as its own application. The software of the artifact and all its corresponding dependencies are pulled from GitHub and then containerized using Docker. The Docker container runs as its own application in the Kubernetes Cluster in the WP7 Cloud. With this architecture, the application is isolated from the other applications in the cluster. The only dependency the artifact has is towards the PostgreSQL database.

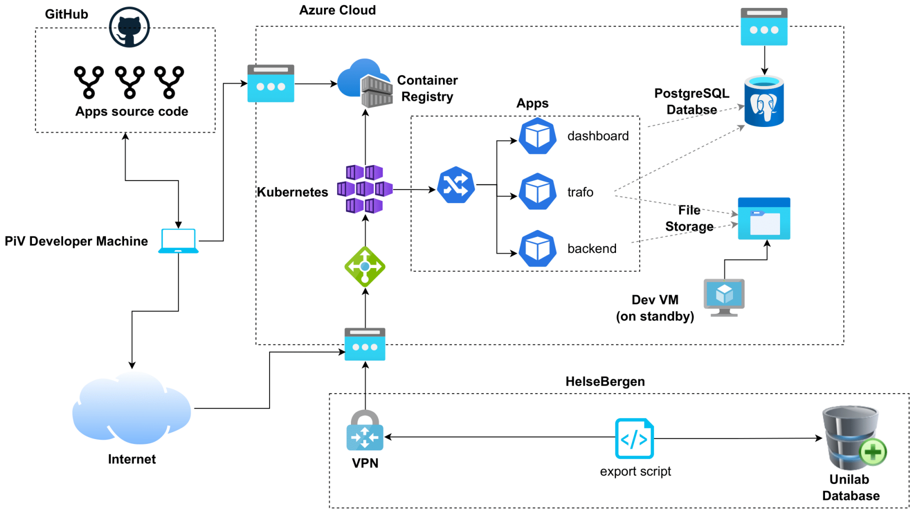

Figure 4.9: WP7 Cloud Architecture

Chapter 5

Implementation

While the previous chapter presented the methodology used in this project and the design of the artifact, this chapter will introduce a more comprehensive description of the technical aspects of the artifact and the tools and frameworks that have been used in the development phase.

5.1 Tools and framework used in the prototype

The technology stack used in this project is as follows:

- Frontend: React together with Next.js
- Backend: Next.js API Routes for server-side API
- Database: PostgreSQL

Each of these will be further introduced in the following sections. In addition, the packages and libraries used for visualizations, data persistence and state management, database connection, and data fetching will also be presented.

5.1.1 Next.js

As the main goal was to create a web-based dashboard, a web development framework was needed. Considering the time constraints in this thesis, it was essential with a flexible and scalable framework that allowed for fast development. Next.js was therefore chosen as the preferred framework to use. Next.js is a flexible React Framework consisting of a set of building blocks enabling developers to create fast web applications. These building blocks consist of tools and configurations such as routing, data fetching and integrations [33]. Next.js can be considered a full-stack framework as it allows both frontend and backend applications in the same codebase. Next.js, therefore, seemed like a natural choice for the purpose of the artifact to be created in this thesis.

Visualizations

The visualizations were created using Chart.js, an open-source JavaScript library. Chart.js is one of the most popular charting libraries, and it is easy to use and offers good documentation. The library supports different types of charts, including bar charts and line charts, and we found it to be a sufficient solution for the purpose of the dashboard [34].

5.1.2 Backend

PostgreSQL and node-postgres

As previously mentioned, the data that is visualized in the database is not fetched directly from the LIS, but from a PostgreSQL database. PostgreSQL is an open-source relational database system [35]. To access this database through the web application, a connection was made using the library *node-postgres* (aka pg). node-Postgres is a collection of modules from node.js for interfacing with a PostgreSQL database. Some of the *node-postgres* configurations used in this project include connection pooling, async/await, and prepared statements. In addition, it allows for using environment variables as default connection parameter values in order to avoid hard-coding database connection information [36].

API Routes

The API of the application was created with Next.js. Next.js offers API Routes, which allowed for the development of a RESTful API with the same framework as the frontend.

In addition, the API Routes can also be created dynamically, allowing for flexibility in the GET requests made to the database. Listing 1 shows an example of this. Thus, the same API routing can be used for different stations and different dates¨[37].

Data Fetching

As the key objective of the main page of the application is to provide a live view of the current situation, frequent update of the data was needed. The client-side data fetching in this application is done with SWR. SWR ("stale-while-revalidate") is a React Hooks library that provides fast and reusable data fetching with just one single line of code [38]. The RESTful API created with API Routes was then used to for the GET requests to the database.

Data persistence and state management

The main aim of the artifact was to visualize the data from the pathology workflow. However, in order to be able to visualize metrics from the workflow, some data was needed that was not included in the database. This included variables such as "goal of the day" and "number of workers" at each station. In order to not interfere with the database structure, it was decided to store this data locally on the client's browser. Since this data is also shared among

```
import pool from "../../../lib/connection";
import pg from "pg";

pg.types.setTypeParser(1082, (value) => value);

export default async function handler(req, res) {
  try {
    const { slug } = req.query;
    var station = slug[0];
    var lifecycle = slug[1];
    var startDate = slug[2];
    var endDate = slug[3];

    let query;

    if (station === "staining") {
      query = {
        text: "select happenedat::date as day, Count(*) as count,
        eventname from public.event where (eventname='automaticStaining')
        and lifecycle=0 and happenedat::date >=$1 and happenedat::date <=$2
        group by 1, eventname order by 1",
        values: [startDate, endDate],
      };
    } else {
      query = {
        text: "select happenedat::date as day, Count(*) as count,
        eventname from public.event where eventname=$1
        and lifecycle=$2 and happenedat::date >=$3 and
        happenedat::date <=$4 group by 1, eventname order by 1",
        values: [station, lifecycle, startDate, endDate],
      };
    }

    const result = await pool.query(query);
    res.status(200).json(result);
  } catch (error) {
    console.log(error);
  }
};
```

Listing 1: Example of a GET request to the database made with API Routes

different pages of the application (Live View page and Management Pages), a state management library was needed.

For this purpose, the state management library Zustand was used [39]. This library allows for easy access to the stored variables wherever needed in the application, and the data is persisted in the browser's localStorage.

5.1.3 Extendibility

The workflow process in the laboratory has several steps, however, only three of them have been included in the artifact. With the flexibility gained from using Next.js and the dynamic API routes, it is possible to expand the artifact to include metrics from other stations as well. Additionally, the frontend has been created using components, thus making it easier to add visualizations from other stations as well.

5.2 System Architecture and Data Flow

The architecture of the prototype and of the final artifact mainly differ in how the application is deployed. For the prototype, Vercel was used for the deployment and hosting of the application. Vercel is a cloud platform created by the same developers as Next.js. Deploying the artifact independently from the WP7 architecture during the design process allowed for more efficient development during the iterations.

With Next.js being a full-stack framework, both the user interface (UI) and the API are integrated in the same codebase. Next.js also allows for easy integration with third-party services. In the case of this artifact, only an integration to the database was needed.

Figure 5.1 shows the architecture of the prototype with Vercel as the hosting and deployment tool. Figure 5.2 show the architecture of the final artifact when it is integrated in the WP7 architecture. For the final artifact, the application is containerized and deployed via Docker in the Kubernetes cluster in the WP7 Cloud Architecture, as seen in Fig. 4.9.

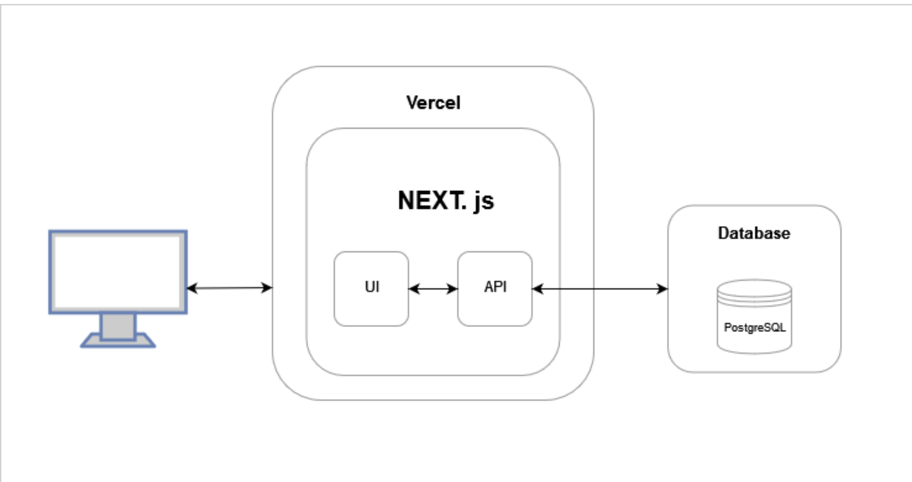

Figure 5.1: System architecture of the prototype, adapted from [33]

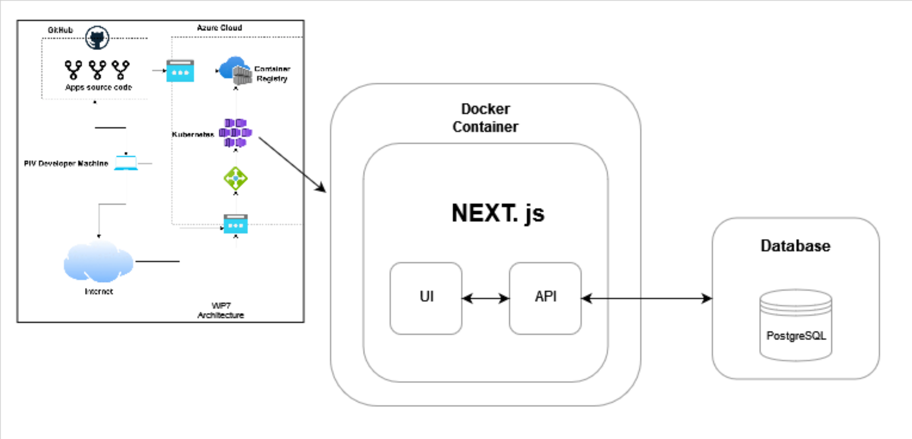

Figure 5.2: System architecture of the final artifact within the WP7 Cloud, adapted from [33]

Figure 5.3 shows the flow of data from the LIS used at the laboratory to the dashboard artifact. The data from the LIS is extracted, transformed, and loaded into a relational database. The developed dashboard then queries the PostgreSQL database in the WP7 cloud.

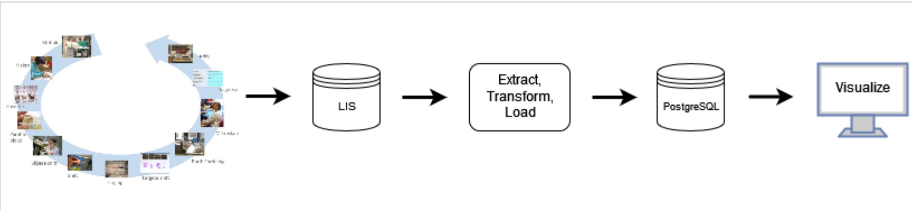

Figure 5.3: Data Flow - from the LIS to the artifact

The prototype of the dashboard can be accessed at `https://patologi-dashboard.vercel.app/`.

Chapter 6

Evaluation

Evaluation is presented as the fifth activity in the Design Science Research Methodology presented by Peffers et al. [30], and it is considered a fundamental part of the Design Science Process.

As the research questions in this thesis are of a qualitative nature, it was deemed appropriate to use qualitative measures for evaluation. The evaluations were done in two parts. The first part was a user evaluation performed with two pathologists from the laboratory. The second part was a heuristic evaluation where the artifact was compared to a set of requirements for a quality dashboard proposed by Randell et al. [40]. Both parts are presented in the following sections.

6.1 User evaluation

The user evaluation was performed in two sessions with two different pathologists. Both of these sessions are described in the following subsections. The first evaluation was performed as a usability testing session with an external pathologist. The second evaluation was performed through a semi-structured interview with the Head of the Histology lab.

6.1.1 Usability testing

After the fourth and final iteration of the design process, an external pathologist from the laboratory was invited to take part in a usability testing session. Two project members from WP7 joined as observers. The purpose of the usability testing was to identify problems in the design and uncover opportunities to improve the artifact.

The usability testing was performed by presenting the dashboard to the pathologist. The pathologist was first shown the application and was then asked to test the functionalities of the artifact while presenting their thoughts underway. At the end, the overall impression of the artifact was summarized.

While the participant's overall impression of both the functionality and the design of the app was positive, improvements regarding usability were identified, as well as possible new ideas for additional features.

During the session, we observed some confusion in regard to navigation within the artifact. This was mainly in regards to how to return to the Live View Page after having been on the Management Pages. In, addition, the participant pointed out inconsistencies in the use of languages. Thus, it was suggested to increase uniformity in the language used in the artifact both in terms of pathology jargon and having everything in Norwegian and not English.

Furthermore, adding an additional visualization graph was discussed. The participant suggested adding a visualization of the number of samples in the queue for each station. This was deemed by the whole evaluation group to be valuable information, but due to time limitations in the project, this suggestion did not result in any changes in the current artifact.

Resulting changes The findings from this evaluation resulted in a few changes to the artifact. A "Home"-button was added to the top bar to increase efficiency in navigation, and all jargon and language were changed to Norwegian to increase the uniformity of the design. Additionally, a vertical line was added to the progress bars on the main page to represent the daily goal and to visualize the movement of the goal after it has been reached. These changes are part of the artifact description presented in Section 4.2.

6.1.2 Semi-structured interview

The second user evaluation was performed with the Head of the Histology lab. As he had been the department representative, we found it beneficial to have him perform a final evaluation of the artifact. As he had taken part in the previous iterations and was familiar with the design, a demonstration was not performed during this evaluation.

The evaluation was performed as a semi-structured interview. This type of interview style is a widely used technique for data collection within the field of software engineering. A semi-structured interview combines specific questions with the aim of gathering foreseen information and open-ended question with aim of obtaining unexpected types of information [41].

The feedback and results from the interview are translated and summarized in Appendix A. The data gained from this interview was used to both evaluate the artifact and to acquire knowledge about further work and research regarding better utilization of the pathology process data.

The interview provided insight into which functionalities were deemed most useful. In this regard, having access to real-time numbers and metrics as immediate feedback was found to be the most desirable aspect of the artifact. As the interviewee already had access to a range of historical data due to his own work of extracting and manipulating the available data from the LIS, the historical graphs in the artifact were not considered equally as important.

Additionally, it was pointed out that the feature of having adjustable goals at each station could potentially improve the work motivation among the operative staff. Today, due to only having retrospective metrics and not being able to measure current productivity, there has not been a common goal to work towards. The interviewee deemed this as a highly desirable feature with great potential opportunities for improvement. Additionally, having the benchmark values for comparison was considered to be of high value in terms of gaining additional insight into the current performance.

With regard to improvements and additional functionalities, several suggestions were made. In terms of short-term future work, incorporating additional metrics from the process was highly coveted. This could for example be adding information about other metrics from other stations not currently included. In the long-term aspect, having a tool that can automate the resource planning work and predict future workload was most wanted.

Overall, the feedback from the interviewee was positive in terms of existing functionalities. Although the artifact does not incorporate every requirement of the laboratory, it was deemed as a solid first prototype that has the potential to improve the workflow in the laboratory.

6.2 Heuristic evaluation with quality dashboard requirements

In the preliminary phase of the project, the literature was reviewed to explore the use of dashboards within healthcare and the field of pathology. The goal of this review was to identify requirements and learning outcomes from previous work. Meta studies on dashboards were also identified, regarding both on the effect of dashboards and requirements for effective design.

Based on data from 54 interviews with personnel at various levels of a healthcare organization, Randell et al. [40] identified five overarching themes that are relevant when designing quality dashboards:

- Choosing performance indicators
- Assessing performance
- Identifying causes
- Communicating from ward to board
- Data quality

The authors found that all these themes have implications for the design of a dashboard. The themes were translated into twelve requirements to be used for future dashboard design. Randell et al. [40] argue that even though the research was conducted in the UK and might be UK-focused, the findings are relevant across healthcare organizations and contexts.

The requirements presented by Randell et al. [40] were used to perform a heuristic evaluation of the dashboard. In this section, we will discuss how the artifact created in the design process conforms to these requirements.

Choosing performance indicators

1. Allow users to select which performance indicators are displayed

Today, the artifact currently shows only one metric – the number of processed samples. This metric was seen as the most informative for the pathology lab to date. This one metric was chosen due to the time constraints of this project. The artifact has, however, been created with extendibility in mind. Thus, it is possible to add other metrics and information in further development.

Assessing performance

2. Where evidence-based standards exist, make it easy to assess how performance compares to that standard

There are no evidence-based standards relating to the metric we chose to visualize. Optimally, to reduce waiting times for patients, all samples waiting to be processed at a given station should be processed during a working day, ending the day with no samples in the queue. Having a visualization of the number of samples in the queue was discussed during one of the iterations of the design cycle as a possible additional feature to add. However, after a discussion with the postdoctoral researcher from WP7, we found that this would require more advanced queries to the database. Because of time limitations, we did not prioritize this. Although it is an important metric of the pathology workflow, it was not considered a necessary metric to add in the first prototype of the artifact, but rather a requirement for future work.

3. Support identification and evaluation of trends over time

The Management Pages of the artifact support visualizations of historical data. With the three views, users can analyze trends over time. The users can analyze the process on various levels – day, hour, and minute. The first page offers a comparison of progress at a station over two time periods. This period is on a day-to-day basis. Furthermore, hourly trends can be analyzed for the three stations as well to evaluate the average productivity during each working day of the week. Lastly, through the time simulation page, the user can analyze the workflow on a specific day down to the minute. These graphical visualizations can currently be shown for three stations – grossing, sectioning, and staining.

4. Allow users to select the time period over which performance indicators are displayed

All three of the Management Pages allow the user to select the wanted time period. On the first page, the user can choose two time periods to compare day-to-day activity. On the second page, the day of the week can be chosen (Monday through Friday), and the data is aggregated on an hour-based level. For the third page, both the date can be changed as well as the time interval of the day down to minutes that want to be looked at.

5. Support comparison against the national average

To our knowledge, there are no national averages available.

6. Allow users to select particular organizations to compare with

The current solution only supports the workflow process at the Department of Pathology at HUS. However, with PIV being a regional project, it might be of interest to include metrics from the other pathology laboratories in the region as well. Nevertheless, there is a set of challenges related to incorporating this requirement in the dashboard. There are both security and privacy considerations to take into account when using data from other departments or laboratories.

Identifying causes

7. Enable users to 'drill down', e.g. to look at particular sub-groups of patients

The Live View Page simultaneously shows all three stations that are currently being supported. The Management Pages, on the other hand, only show visualizations of one station at a time. However, the user has the possibility to choose the station they want to analyze data from. Although, only aggregated is currently visualized. It is not possible to look at samples on an individual level.

8. Provide access to information about other clinical areas within the organization

This requirement was not applicable to our use case as we only focused on the Department of Pathology since we do not have access to data from the other departments.

9. Support simultaneous interaction for discussion at the clinical team level

The artifact supports simultaneous interaction. The data that is presented on the dashboard that does not come from the database (e.g. date, daily goal, number of workers) are stored locally on the users' machines. Thus, another user can use the same application on their machine without interfering with the values that have been set. Thus, the artifact can be used in production at the same is it used for analysis and discussion elsewhere.

Communicating from ward to Board

10. Enable easy identification of when a clinical area is an outlier within a particular audit

This requirement was achieved by adding an extra bar to the graph showing the cumulative average of samples processed in 2021 at that current time. This extra bar gives an indication of how the current performance relates to the daily goal. If the light blue bar is not visible, the performance is on par or above what is needed. However, if the light blue bar is visible, and the divergence between the bars increases, the staff will know that current productivity is not sufficient to reach the goal that has been set. Consequently, if the performance falls below the average, measures can be taken in real-time to mitigate the delays. Thus, this extra indication of the progress allows for easy identification of a station that is not progressing adequately in order to reach the daily goal.

Data quality

11. Provide timely data

As one of the objectives of the artifact was to provide visualization of the current situation at the lab, the data must be up to date. Currently, the artifact supports near real-time updates from the database, with data fetching done at intervals of one second. As the artifact is presently connected to the historical database, only a simulation of real-time updates has been demonstrated.

12. Use sources of data that staff trust

The data used in the artifact has been extracted and transformed from the LIS database by the postdoctoral researcher from WP7. The is currently no knowledge of the operative staff not trusting either the LIS or the WP7 relational database.

6.2.1 Summary

The twelve requirements described by Randell et al. [40] are not provided as a prioritized list. However, through a workshop conducted with representatives from 22 national clinical audits, five of the requirements were highlighted. Requirements 2, 4, and 7 were classified as being essential for a dashboard, and Requirements 1, 4, 7, and 11 were considered top priorities. Although our artifact does not meet all twelve requirements defined by Randell et al., it does to some degree conform to four out of the five requirements identified as being the most important in a quality dashboard, although with requirements 1 and 2 having the greatest potential of improvement out of those five. Requirement 7 is not yet supported, but is a possible addition for future work.

Chapter 7

Findings and Discussion

The definition of Design Science Research provided by Brocke et al. [14] states that the artifact created should "solve problems and improve the environment in which they are instantiated" and "enhance technology and science knowledge bases". This chapter presents and discusses the results from the iterations performed during the design process of creating the artifact, both in regard to the intended environment the artifact was created for and the knowledge base.

7.1 Contributions to the knowledge base and answers to the research questions

The contributions to the knowledge base take into account the information discovered during the course of the design process. To a large extent, this information coincides with the answers to the research questions.

The next section presents the answers to the research questions, followed by a summary of the new knowledge that was discovered.

RQ1: What are the limitations of existing dashboard solutions in pathology?

The answer to this research question is mainly presented in Section 2.4.3. A literature survey was performed to identify existing dashboard solutions in pathology. The survey uncovered three dashboards that had been created for pathology laboratories to assist in workflow management and monitoring of pathology processes. A finding from this survey was that the created solutions were all client-specific, and they were thus not directly transferable to this project.

The objectives and results from the studies were first presented individually. Following, the different functionalities were collectively summarized in a comparison matrix. By doing a comparison of the existing solutions, functionality gaps within the dashboards were uncovered.

The evaluation of the proposed solutions in the literature showed that only two of the dashboards had benchmark comparisons, and none of them had the functionality of setting their own goals.

Thus, we created an artifact that visualizes process-level metrics from the laboratory workflow. Three stations from the workflow were chosen, and aggregated data from these stations were visualized. Benchmark values based on historical data from 2021 were added for comparison. Additionally, the functionality of adjusting the daily goals was added. This supports the daily fluctuations in the laboratory regarding available resources.

Table 7.1 shows an expansion of the figure in Section 2.4.3. with an added column representing the functionalities of the solution created in this thesis.

	Carmona-Cejudo et al.	**Halwani et al. #1**	**Halwani et al. #2**	**Seifert et al.**	**Our solution**
Process-level	No	Yes	Yes	No	Yes
Task-level	No	No	Yes	No	No
Case-level	Yes	No	Yes	No	No
Benchmark comparison	Yes	No	Yes	No	Yes
Adjustable goals/KPI	No	No	No	No	Yes
Real-time reporting	No	No	Yes	Yes	Yes
Built on existing solutions	No	No	Yes	Yes	No

Table 7.1: Updated comparison matrix for pathology dashboards, including the artifact developed in this thesis

RQ2: How can the manual performance of the pathology lab be visualized?

This research question is primarily answered through the design process and iterations that were performed to develop the artifact. The design process started with an initial meeting with the customer in order to identify the needs of the laboratory. The most important requirement for them was to have real-time updates.

The initial work of WP7 extracted, transformed, and loaded process data from the Unilab-700 to a PostgreSQL database within the WP7 Cloud. It was this transformation of the data that laid the foundation for the development of the pathology dashboard created in this thesis. SQL queries are made to this database every second in order to provide the most up-to-date metrics from the process. The Live View Page of the dashboard provides information in the form of numbers of processed samples at three of the stations in the workflow. It was decided to use simple, horizontal bar graphs for the real-time metrics. Additionally, the numbers were visualized in relation to a goal, where the goal was set to be the end of the bar. This goal was made adjustable in order to account for the daily fluctuations in the laboratory regarding resources.

In itself, having real-time numbers was deemed an important requirement. However, through the design process, additional data, in the form of benchmark values, was added to the visualization in order for the staff in the lab to gain more value from the data and further insight into the current progress and performance. The benchmark values were calculated from the cumulative average number of processed samples during all relevant days of 2021 down to a granularity of one minute. Thus, by adding this information, the people in the lab can get a quick overview of their current performance is aligned in order to reach the daily goal.

In addition to the real-time updates, historical graphs were added as well. For this, line graphs and vertical bar graphs were used. One graph allows for the comparisons of data during two time periods. The data shows the fluctuations in the number of samples processed each day during the selected time periods. Thus, the user can for example compare the work done in two different months of the year. Specific visualization features for this graph included a selection of station and date ranges for the two periods. The other historical graphs show aggregated data on how many samples are processed during each hour of a specific weekday. Visualization features for this graph included the selection of station and weekday.

The evaluation of the dashboard showed that the visualizations of real-time metrics were deemed more important and useful than historical visualizations.

RQ3: How can workflow monitoring through a dashboard impact the people in the lab positively?

We were faced with several limitations regarding testing the artifact in a practical setting, both internal project factors and external. To get an answer, the artifact should ideally be tested in its intended environment over the course of several months in order to be able to see an actual effect. However, due to the time scale of this thesis, this was not achievable. Additionally, there were several external factors that restricted us from incorporating the artifact in the laboratory. These included not yet having access to real-time data and the challenges of using the artifact in the laboratory as it had to be approved by several levels within the organization.

Thus, in order to answer this question we had to turn to the literature. Moreover, the answer to this research question can be divided into two answers – one answer for the laboratory management and one answer for the operative staff.

In regards to the impact workflow monitoring can have on laboratory management, we can look to the results from the related work presented in Section

2.4.2. The use of these dashboards in their respective settings all resulted in several positive outcomes for laboratory management. By having access to timely metrics from the workflow, the management was able to quickly get an understanding of the performance status of the workflow and identify pitfalls and bottlenecks in real time, and make changes accordingly. Halwani et al. [10] argue that having graphical views instead of text-based information was key to effective decision support. They concluded that real-time dashboards served as a powerful means for pathology management to identify bottlenecks and analyze data. Carmona-Cejudo et al. [28] also found the use of the dashboard to have a positive impact on the laboratory workflow, both regarding time usage and laboratory resources. Seifert et al. [9] found that the use of visualization techniques and dashboards allowed the management to identify and address the frequent pitfalls. Thus, the quality of care, as well as patient safety, was improved.

From these results, we can conclude that the use of visualization dashboards has the possibility of positively impacting the work of laboratory management in terms of more efficient organization of the sample flow and better resource planning.

These aforementioned studies did not provide specific results in regard to the direct impact the dashboards had on the operative staff. Thus, we expanded the search for literature to not only include dashboards used in pathology laboratories, but in other departments in the health sector as well. Additionally, a search for theories regarding feedback was included.

Contextual Feedback Intervention Theory proposes that feedback has a bigger influence on changing behavior if it is timely, cognitively simple (e.g. graph visualizations), frequent, unambiguous, and offers specific recommendations on how to enhance performance. Regarding feedback in relation to goals, CFIT contends that both goal attractiveness and goal expectancy are important factors. This means that the target goal has to be both desirable and achievable and that the discrepancy between the actual performance and the benchmark values is accurate [29]. Additionally, the literature suggests that the use of dashboards showing individual feedback is more likely to improve performance than those showing collective feedback [12], [29], [42]. The dashboard created in this thesis delivers timely feedback in the form of cognitively simple visualizations of the current performance on a group basis. Thus, even though this dashboard provides aggregated data about overall performance, we can conclude that there is a possibility that the artifact can have a positive impact on the work performance of the operative staff. However, the actual impact on the people at the laboratory will remain speculation until the artifact has been properly tested in its respective environment.

7.1.1 Contributions to the domain

The artifact was created as a tool to better utilize the process data from the pathology workflow at HUS. The design and development of the artifact were motivated by real needs within the Department of Pathology. As pathology laboratories use different LIS to track their processes, and since they also have individual needs, it was not possible to use any existing artifacts or tools.

The evaluations performed identified the visualization as useful for workflow monitoring in the laboratory. Through the design, development, and evaluation of the artifact, a set of problems and solutions were identified:

- Real-time metrics are valuable for both operative staff and management
- Cognitively simple graphs are useful
- Visualizations of metrics in relation to both goals and benchmark values provide more insight into the current state of the workflow
- Additional tools and features, such as predictive analysis, can be beneficial for further resource planning

7.2 Reflections on Design Science Research as a methodology

As the primary goal of this thesis was to create an artifact in order to solve a practical problem, the design science research methodology has proven to be advantageous. The research activities proposed by Peffers et al. [30] were useful guidelines during the project, especially during the iterations of the design process and the evaluation of the artifact. Having the activities as the foundation of the project made the execution of the design and implementation of the artifact easier and more straightforward. Furthermore, the methodology also provided helpful guidelines for the work of presenting the project through this thesis.

Chapter 8

Conclusion and Further Work

This thesis presents an artifact in the form of a dashboard application. The artifact was created to facilitate the progress management of pathology workflows in real-time. This chapter concludes the design process and development of the artifact and presents suggestions for further research regarding utilizing the untapped potential in the process data from the pathology workflow.

8.1 Conclusion

By using the Design Science Research Methodology, we designed, developed, and evaluated an artifact intended to solve identified challenges regarding the utilization of process data from a pathology workflow. The artifact was created as a web-based visualization dashboard with the goal of facilitating real-time progress management of the workflow at the Department of Pathology at HUS.

Design Science Research is a methodology centered around the creation of artifacts to solve problems. Brocke et al. [14] state that the artifacts created should "enhance technology and science knowledge bases [...] and improve the environment in which they are instantiated".

Throughout the iterations performed during the design process, we developed novel ways to visualize the metrics. The graph bar showing the current status of the stations in the workflow was visualized both in relation to a daily adjustable goal and a benchmark value. With the combined use of these functionalities, the visualizations provide an extra layer of insight into the workflow and current progress. Furthermore, according to theories regarding feedback intervention (CFIT), having both target goals and benchmark comparisons increase the positive influence on the performance of the people receiving the feedback. A literature review performed at the start of the design process uncovered that none of the existing solutions provided the same type of visualizations.

The artifact was created with simple visualizations (bar- and line graphs) in order to minimize the cognitive load for the users and to provide insight into the process in an efficient manner. Moreover, the artifact was created with tools and frameworks that facilitate extendibility. As of now, the artifact only utilizes a fraction of the potential that lies in the combined use of data visualization techniques and dashboards. There is still unused potential in the process data from the pathology workflow that can be the focus of future work.

8.2 Further Work

This thesis has been a sub-project of the research done by WP7 as part of the regional project PiV. The goal was to explore the possibilities of data visualization techniques and dashboards to more efficiently utilize the vast amount of data in the LIS at the Department of Pathology at HUS.

This section presents relevant future work which was not part of the scope of this project. Further work can be divided into three main topics – deployment and evaluation, improving existing features, and creating additional features.

8.2.1 Deployment and evaluation

Due to time constraints and difficulties with attaining permission to incorporate the artifact in the laboratory, it has not yet been tested in a real-world setting.

For the artifact to be used in a practical setting, it has to be connected to a database containing real and up-to-date data. Only then can the effect of the artifact be properly tested in the laboratory in order to identify possible flaws and further improvements. Additionally, testing the actual effect on operative staff is important in order to ensure the successful use of the dashboard. When doing this, it can be beneficial to conduct a survey both before and after the implementation. If the dashboard does not prove to motivate the lab technicians as anticipated, adjustments have to be made accordingly.

8.2.2 Improving existing features

As the artifact currently only shows one metric with regards to three different stations, adding the possibility to view additional stations as well could be useful for both stakeholder groups.

In discussion with the head of the histology lab, additional visualizations and features were suggested as being beneficial:

- Visualizations from additional steps (stations) in the workflow
- Status bars showing the number of samples in the queue
- More detailed information about the samples (such as priority grade, type, and size)
- Separate visualizations of samples with different complexity degrees (e.g. macroscopy and microscopy)

8.2.3 Creating additional tools

The current artifact only visualizes existing data. There is, however, still much potential left in the process data at hand. Creating additional tools that can further utilize this data can have great benefits for the laboratory in terms of optimization. This includes individual performance dashboards as well as tools and algorithms for predictive analytics.

Individual dashboards

As mentioned in Section 7.1, prior research has shown that personalized performance dashboards have shown to have a greater effect on individual performance than dashboards showing aggregated data about group performance [42]. Contextual Feedback Intervention Theory [29] contends that individuals are more likely to respond to feedback if it is "timely, frequent, cognitively simple, [..] and provides concrete suggestions of how to improve performance". Horback et al. [12] found that having on-demand access to performance metrics facilitates self-motivation for pathologists to improve performance and efficiency in the lab. Additionally, they discovered that being able to examine both recent performance and trends over time increases personal engagement. Thus, for future work to further optimize the workflow, it could be beneficial to create personalized dashboards for the operative staff working at the laboratory.

Predictive analytics

The current artifact only visualizes data from the process, it does not have the capability of predicting data. Lessard et al. [43] argue that predictive analysis can be incorporated at key points in the pathology workflow with the aim of facilitating workload and resource planning. With predictive analytics, the artifact can assist in resource planning based on the availability and competence of the available staff. As the evaluation of the artifact performed with the Head of the Histology disclosed, having a tool that can predict future workflow is considered to be of great potential regarding future work with optimization of the workflow.

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Appendix A

Semi-structured interview

The questions and answers from the semi-structured with the Head of the Histology lab that was conducted as part of the evaluation of the artifact is included below. Since the interview was performed in Norwegian, it has been translated to English. Additionally, due to the length of the interview, the answers has been paraphrased and summarized.

Questions and Answers

1. What is your role at the Department of Pathology?

- Head of the Histology Lab, working at the department since 2010
- Has a goal of reducing the overall cycle-time (the time it takes between a specimen arriving in the lab until a diagnostic report has been sent in response, Ed.)
- Went from median of 10 days to 3 days. But worse now, due to several factors

2. What data are you most interested in from the work process in the lab?

- Currently only have access to historical data, the LIS is lacking in statistical reports
- Real-time feedback/insight about the workflow would be very useful, in order to be able to have a direct influence in the process
- Feedback on how far we have come in the preparation process and whether we have achieved our goal for the day

3. Which tools do you use to process the workflow data now?

- Unilab provides two statistical reports, but these have never been quality assured
- The reports are imported in Excel and manually corrected

- Only rudimentary statistics is performed
- Previous years are used as benchmark comparison

4. How much time would you estimate you spend on this data processing?

- The actual statistical work is about 10 minutes every day
- It has been operationalized into two reports that can be extracted from the LIS and imported in to Excel. Two Excel macros has been created that are used on the data
- The diagrams are also published on internal sites and made available for other people in the organization
- The most time-consuming activity is analyzing over the numbers and reflecting on why it is like it is

5. What advantages do you get from such a dashboard in your everyday work?

- By being able to get instant feedback, we are able to set productivity goals and hopefully achieve them as well
- It is valuable to know, at say 10 am, whether you are in a good enough position to achieve the daily goals
- Having immediate feedback for the whole group might stimulate a type of competitive instinct

6. Which of the visualizations do you see as most useful for your everyday work?

- The real-time numbers providing immediate feedback of the current status is the most valuable

7. What additional visualizations would you request in the dashboard?

- Information about other steps in the process, e.g. embedding or scanning of slides
- Distinguishing between sample types with different degree of complexity – e.g. having separate visualizations for macroscopy and microscopy
- We have data about the kind of samples we are getting (both in terms of size and from which organ they originate), providing information about this directly to the people working with the samples could be beneficial

8. How do you think the dashboard can affect the working day of the lab personnel?

- I hope it makes their lives more pleasant.
- We are not able to shield our personnel from all the queues we produce. Therefore, narrowing down the work to daily purposes or goals is good
- Having realistic goals, that can be adjusted so that it is correct in relation to reality, can be a factor that increases motivation

- Having the instant feedback will also provide an opportunity to adjust the number of personnel working at the respective stations if there is a need for reorganizing in order to achieve the goals

9. Are there other functionalities (besides the visualizations) that you would like to have in the dashboard?

- A tool that can help with resource planning
- A system that know which samples are in the queue and how much work is associated with the individual steps and which is connected to our current system resource planning system. Thus, the system automatically knows who is available each day and what competence/sub-specializations they have and can organize the samples accordingly

10. Do you have any other comments or feedback?

- We have spent years waiting for data and applications to help us with our workflow
- In principle, we have all possible data available - but it is made unavailable to us because we do not have direct access within our organization.
- There are barriers that shouldn't be there - to using data for good purposes.