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# Indoor Positioning Integrated in EBIM

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# Abstract

This thesis aims to investigate and identify which potentials the use of asset tags, location based services and BIM models hold for the future of hospitals and other large buildings. A prototype of an indoor positioning system integrated in Enterprise Building Information Model (EBIM) was developed during the work on this thesis, in collaboration with Jotne EPM Technology for St. Olav Eiendom. Data gathering was carried out by conducting an interview of a department manager at St. Olav's University Hospital. Additionally, testing and a survey were planned, but could unfortunately not be carried out, and will be explained in Chapter 6. The gathered data reveals that the use of an indoor positioning system, such as the one developed during this project, will be found useful by the potential users. Areas of reduction in costs are identified, and potentials for the future of hospitals and other large buildings are identified together with future development. The findings suggest that implementation of an indoor positioning system integrated in EBIM will provide opportunities, and benefit hospitals and other larger buildings.

# Sammendrag

Intensjonen med denne oppgaven er å undersøke og identifisere potensialer ved bruk av sporingsbrikker, lokasjonsbaserte tjenester og BIM-modeller for fremtiden til sykehus og andre store bygninger. En prototype av et innendørs posisjoneringssystem integrert i Enterprise Building Information Model (EBIM) ble utviklet under arbeidet med denne oppgaven, i samarbeid med Jotne EPM Technology for St. Olav Eiendom. Data ble innsamlet ved å gjennomføre et intervju av en avdelingsleder ved St. Olavs Universitets Sykehus. I tillegg var det planlagt testing og gjennomføring av en spørreundersøkelse, som dessverre ikke kunne gjennomføres, og vil bli forklart i kapittel 6. Innhentet data viser at bruken av et innendørs posisjoneringssystem, slik som det systemet utviklet i løpet av dette prosjektet, vil være nyttig for de potensielle brukerne. Områder hvor kostnader kan reduseres er identifisert, og potensialer for fremtidens sykehus og andre store bygninger er identifisert sammen med videre arbeid. Funnene tyder på at implementeringen av et innendørs posisjoneringssystem integrert i EBIM vil gi muligheter som sykehus og andre større bygninger kan dra nytte av.

# Problem Description

Today's floor plans for buildings, such as DWG, are not suitable for customization and for viewing on smart phones. These floor plans are too detailed and the added data are poorly structured. Next generation floor plans are defined as data models using BIM (Building Information Model). With BIM it is possible to sort out the needed data and present it for the user in different settings, also on a smart phones. This, together with indoor positioning, opens for many applications.

St. Olav's University Hospital is at the forefront internationally in utilizing database technology to describe virtual building models. All buildings (approximately 350 000m$^2$) at St. Olav's University Hospital will by 2015 be modeled according to openBIM. Herein lies a huge potential to look at the organizational management, resource management, and development work. A special focus will be on how the use of BIM models and location technologies can improve the management of buildings, including how rooms and resources are exploited and quality of what comes with.

Supervisor: Professor John Krogstie, IDI, IME, NTNU

# Preface

This thesis concludes my Master of Science at the Norwegian University of Science and Technology (NTNU). The project was supervised by professor John Krogstie, and carried out in collaboration with Jotne EPM Technology and St. Olav Eiendom. The thesis was submitted to the Department of Computer and Information Science (IDI), in the Faculty of Information Technology, Mathematics and Electrical Engineering (IME), at the Norwegian University of Science and Technology (NTNU).

First I would like to thank professor John Krogstie for great guidance during my work on this thesis. A special thanks goes to the project leader Tor Åsmund Evjen at St. Olav Eiendom for all his help, guidance, and inspiring discussions throughout this project. I would also like to thank Jotne EPM Technology for the collaboration, especially Gudbrand Skarseth and Pavelas Zolotariovas. Finally, I would like to Bjørn Henning Hammer, Head of Customer Service Center at Service and Operations at St. Olav's University Hospital, for his interview, and everyone else who has contributed to this project.

Erlend Øgård Aksnes

# Abbreviations

**BIM** - Building Information Model

**CAD** - Computer-Aided Design

**IFD** - International Framework for Dictionaries

**IFC** - Industry Foundation Classes

**IDM** - Information Delivery Manual

**EBIM** - Enterprise Building Information Model

**VDC** - Virtual Design Construction

**FM** - Facility Management

**PM** - Property Management

**IPS** - Indoor Positioning System

**MSM** - Model Server Manager

**TFM** - Tverrfaglig Merkesystem

**WGS** - World Geodetic System

**ETRS** - European Terrestrial Reference System

**EUREF** - European Reference Frame

**ERTS** - European Terrestrial Reference System

**UTM** - Universal Transverse Mercator

**NTM** - Norwegian Transverse Mercator

**GPS** - Global Positioning System

**RTLS** - Real Time Location System

**RFID** - Radio Frequency identification

**AGV** - Automated Guided Vehicle

# Contents

Abstract . . . . . . . . . . i
Sammendrag . . . . . . . . . . iii
Problem Description . . . . . . . . . . v
Preface . . . . . . . . . . vii
Abbreviations . . . . . . . . . . ix
Contents . . . . . . . . . . xiii
List of Figures . . . . . . . . . . xv
List of Tables . . . . . . . . . . xvii
List of Listings . . . . . . . . . . xix

**1 Introduction 1**
1.1 Motivation . . . . . . . . . . 1
1.2 Project Description . . . . . . . . . . 1
1.3 Thesis Structure . . . . . . . . . . 2

**2 Background Theory 3**
2.1 Building Information Modeling (BIM) . . . . . . . . . . 3
2.1.1 History . . . . . . . . . . 4
2.1.2 Benefits . . . . . . . . . . 4
2.1.3 OpenBIM . . . . . . . . . . 5
2.2 Enterprise BIM (EBIM) . . . . . . . . . . 6
2.3 Model Server Manager (MSM) . . . . . . . . . . 7
2.4 TFM . . . . . . . . . . 8
2.5 Coordinate Systems . . . . . . . . . . 9
2.5.1 World Geodetic System . . . . . . . . . . 9
2.5.2 The European Reference Framework . . . . . . . . . . 9
2.5.3 Local BIM Coordinates . . . . . . . . . . 10
2.6 Global Positioning System . . . . . . . . . . 11
2.6.1 How GPS Works . . . . . . . . . . 11
2.6.2 Benefits . . . . . . . . . . 11
2.6.3 Disadvantages . . . . . . . . . . 12
2.7 Indoor Positioning Systems . . . . . . . . . . 12
2.8 Existing Indoor Positioning Systems . . . . . . . . . . 12
2.8.1 MazeMap . . . . . . . . . . 12
2.8.2 AeroScout MobileView . . . . . . . . . . 14

2.9 Location engines . . . . . . . . . . 14
2.9.1 Cisco Mobility Services Engine . . . . . . . . . . 15
2.10 Hardware . . . . . . . . . . 16
2.10.1 WiFi Access Points . . . . . . . . . . 16
2.10.2 Positioning Devices . . . . . . . . . . 16

**3 Research Methodology** **19**
3.1 Research Method . . . . . . . . . . 19
3.2 Research Questions . . . . . . . . . . 20
3.3 Data Gathering . . . . . . . . . . 20
3.3.1 System Usability Scale (SUS) . . . . . . . . . . 20
3.3.2 Survey . . . . . . . . . . 21
3.3.3 Interview . . . . . . . . . . 21
3.4 Usability Testing . . . . . . . . . . 21
3.4.1 Test Environment . . . . . . . . . . 21
3.4.2 Test Location . . . . . . . . . . 22
3.4.3 Test Subjects . . . . . . . . . . 22
3.4.4 Test Execution . . . . . . . . . . 22

**4 Problem Elaboration and Requirements** **23**
4.1 Stakeholders and Users . . . . . . . . . . 23
4.2 Persona . . . . . . . . . . 24
4.2.1 Maintenance Professional Adam . . . . . . . . . . 24
4.2.2 Hospital Porter Siri . . . . . . . . . . 24
4.2.3 Project Leader Ola . . . . . . . . . . 24
4.3 Scenarios and Use Cases . . . . . . . . . . 24
4.3.1 Register Equipment . . . . . . . . . . 25
4.3.2 Locate Equipment . . . . . . . . . . 26
4.3.3 Maintain Equipment . . . . . . . . . . 27
4.3.4 Analyze Tracking Data . . . . . . . . . . 28
4.4 Requirements . . . . . . . . . . 29
4.4.1 Main Requirements . . . . . . . . . . 29
4.4.2 RTLS Tag Configuration . . . . . . . . . . 29
4.4.3 Firewalls . . . . . . . . . . 29
4.4.4 XML Files . . . . . . . . . . 30

**5 Implementation of EBIM IPS** **33**
5.1 Overview of Implementation . . . . . . . . . . 33
5.2 Steps to Implement System . . . . . . . . . . 36
5.3 Acquire and Configure Tags . . . . . . . . . . 36
5.3.1 Configuration of Tags . . . . . . . . . . 37
5.4 Transfer and Store Tracking Data . . . . . . . . . . 42
5.4.1 Cisco MSE REST API . . . . . . . . . . 42
5.4.2 TCP Stream . . . . . . . . . . 42
5.4.3 Issues During Implementation . . . . . . . . . . 43
5.5 Store Data to BIM Database . . . . . . . . . . 44

5.5.1 Tag Object . . . 44
5.5.2 Track Record . . . 45
5.6 Visualization . . . 46

**6 Results from Evaluation 47**
6.1 Survey . . . 47
6.2 Interview . . . 48
6.2.1 Utilizing the IPS . . . 48
6.2.2 Improved Quality of Service . . . 49
6.2.3 Further Development and Use . . . 49
6.3 Accuracy . . . 49

**7 Discussion 51**
7.1 Validity of Results . . . 51
7.2 Costs . . . 51
7.3 Efficiency . . . 52
7.4 Privacy . . . 52
7.5 Accuracy . . . 52

**8 Conclusion and Future Work 53**
8.1 Conclusion . . . 53
8.2 Future Work . . . 54
8.2.1 Accuracy . . . 54
8.2.2 Visualization . . . 56
8.2.3 Maintenance . . . 57
8.2.4 TFMD . . . 57
8.2.5 Emergency Situations . . . 58
8.2.6 Theft of Equipment . . . 59
8.2.7 Wayfinding . . . 59

**Appendix A 61**

**Appendix B 63**

**Appendix C 67**

**Appendix D 69**

**Appendix E 71**

**Appendix F 77**

**Bibliography 79**

# List of Figures


2.1 Building SMART standards [8]. . . . . . . . . . . . . . . . . . . . . . . 5
2.2 St. Olav's University Hospital Enterprise BIM (EBIM) architecture [9]. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 6
2.3 MSM displaying "Kunnskapssenteret" at St. Olav's University Hospital. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 7
2.4 NTM Zones in Norway [13]. . . . . . . . . . . . . . . . . . . . . . . . 10
2.5 Example of MazeMap running on an iPhone 5 [19]. . . . . . . . . . . 13
2.6 Example of MSE in use [22]. . . . . . . . . . . . . . . . . . . . . . . 15
2.7 WiFi access point placement [23]. . . . . . . . . . . . . . . . . . . . 16

4.1 Example of required XML structure. . . . . . . . . . . . . . . . . . . 30

5.1 Information flow in the developed indoor positioning system. . . . . 34
5.2 Stanley Healthcare T2s Tag, used in work of this thesis. . . . . . . . 37
5.3 Tag Configuration - Tag Detection . . . . . . . . . . . . . . . . . . . 37
5.4 Tag Configuration - General . . . . . . . . . . . . . . . . . . . . . . 38
5.5 Tag Configuration - Messages . . . . . . . . . . . . . . . . . . . . . 39
5.6 Tag Configuration - Call Buttons . . . . . . . . . . . . . . . . . . . 40
5.7 Tag Configuration - Tag Activation . . . . . . . . . . . . . . . . . . 41
5.8 Visualization - Web Application . . . . . . . . . . . . . . . . . . . . 46

6.1 Distance between reference point position and system position. . . . 50

8.1 Example of access point placed onto a floor map in Cisco Prime [27]. 55
8.2 Organizational map of the patient flow analysis with a focus on the emergency department at the University Hospital in Bern [28]. . . . 56
8.3 Example of local BIM coordinates. . . . . . . . . . . . . . . . . . . . 74

# List of Tables

4.1 Use Case 1 - Register Equipment . . . . . . . . . . . . . . . . . . . . . 25
4.2 Use Case 2 - Locate Equipment . . . . . . . . . . . . . . . . . . . . . . 26
4.3 Use Case 3 - Maintain Equipment . . . . . . . . . . . . . . . . . . . . 27
4.4 Use Case 4 - Analyze Tracking Data . . . . . . . . . . . . . . . . . . . 28

5.1 Attributes for a Tag object in the database. . . . . . . . . . . . . . . . 45
5.2 Attributes for a Track Record in the database. . . . . . . . . . . . . . 45

# Listings


8.1 Method for Cisco MSE REST API request . . . . . . . . . . . . . . . . 69
8.2 Service start . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 69
8.3 listenToStream() part 1 . . . . . . . . . . . . . . . . . . . . . . . . 70
8.4 listenToStream() part 2 . . . . . . . . . . . . . . . . . . . . . . . . 70
8.5 Conversion of coordinates . . . . . . . . . . . . . . . . . . . . . . . 72
8.6 Conversion from WGS84 to NTM zone 10. . . . . . . . . . . . . . . . . 73
8.7 Class for coordinates and Interpolation method. . . . . . . . . . . . . 73
8.8 Method for conversion from NTM10 to local BIM . . . . . . . . . . . 74
8.9 Method for decoding of messages . . . . . . . . . . . . . . . . . . . . 75

# Chapter 1

# Introduction

This chapter will present the motivation behind this research. A description of the project is then presented before going through the structure of the thesis.

## 1.1 Motivation

The large buildings and campuses of today, such as hospitals and universities, often require detailed building information models (BIM) and efficient workers in order to be constructed. BIM could also be applied for maintenance and the support of core business processes of an organization or company. BIM are often used for construction of buildings, but are hardly used after the construction is complete. In discussions with Tor Åsmund Evjen, Project leader at St. Olav Eiendom, multiple scenarios and areas of use were discussed. By utilizing BIM in combination with indoor positioning; maintenance of equipment could be performed regularly, robots could know where and when to clean the floors in a building, and (re)construction of buildings could be based on patient flow data. These are some of the thoughts on the future areas of use for BIM. As there seems to have been made little research in combining BIM with indoor positioning, this study examines the field during the development of a prototype, and explores the opportunities it might provide.

## 1.2 Project Description

This project has investigated the possible opportunities for hospitals and other large buildings utilizing an indoor positioning system. In the beginning of this project, an extensive literature review was conducted, providing me a greater understanding of relevant technologies and research methodologies. A prototype of an indoor positioning system for St. Olav Eiendom has been developed in collaboration with Jotne EPM Technology in this project, where they unfortunately could not complete their overlaying web application in time.
As a result of this project we were able to continuously collect positioning data, save it in a BIM database, and present the data on two-dimensional maps.

## 1.3 Thesis Structure

This thesis is structured as follows:

**Chapter 2 - Background**
The background chapter describes current knowledge, standards, hardware and technology, in relation to this thesis. Coordinate systems and positioning systems are focused upon, and the current state of the art indoor positioning systems are described.

**Chapter 3 - Research Method**
This chapter describes how the research was conducted, with details of the survey and how the testing was conducted.

**Chapter 4 - Problem Elaboration**
In this chapter the problem area is described through the use of scenarios and use cases, while describing how the implemented solution can solve these issues.

**Chapter 5 - Implementation**
The implementation chapter first gives an overview of the implementation developed through the work on this thesis. Technical details about the components of the system are then described in detail.

**Chapter 6 - Results**
This chapter presents the results from the survey, as well as the interview.

**Chapter 7 - Discussion**
In this chapter the validity of results are discussed together with a general discussion of what comes with an indoor positioning system.

**Chapter 8 - Conclusion and Future Work**
The research questions are assessed in this chapter, before continuing to identify the future work.

# Chapter 2

# Background Theory

This chapter will provide the necessary knowledge in order to understand the core parts in this field of study. General information about BIM will be presented along with some history and information about the benefits BIM bring to the table. Then OpenBIM will be presented, before describing Enterprise BIM (EBIM) and the application utilized for visualization and management of EBIM at St. Olav's University Hospital. A Norwegian interdisciplinary labeling system will be described in detail, before continuing with coordinate systems. An introduction to Global Positioning Systems (GPS) and Indoor Positioning Systems (IPS) will then be given. Existing applications will finally be presented, before ending the chapter with information about location engines, and hardware applicable to this thesis.

## 2.1 Building Information Modeling (BIM)

Building information modeling (BIM) is considered to be both a way to digitally present models of buildings, as well as a process. In this thesis BIM will be considered as a digital representation of a building. BIM is used to share information between stakeholders and all categories of workers, such as electricians, and plumbers. They share information during the whole building process to make sure that everything fits neatly together. For instance, by looking at a BIM, an electrician knows exactly where the plumbing will be, and a plumber knows exactly where the electrical wiring will be. This simplifies the cooperation between workers. As a BIM is a digital representation of a building, it consists of objects such as doors, walls, pipes, wiring, bolts, and windows. Each of these objects is represented with real world specifications. Looking at a door in a BIM, one can find the door's height, depth, width, or detailed measures of the door handle.
The BIM can also be used after the building process, for such as maintenance and renovation of the building.

### 2.1.1 History

The history of BIM starts with Douglas C. Engelbart, who in 1962 presented his vision of the future architect in the paper "Augmenting Human Intellect". Multiple of the visions presented in Engelbarts's paper would be realized in the future, such as object based design, use of relational databases, and parametric manipulation [1].
But it was not until the 1980s that architects started to utilize computers for digital design. Computer-Aided Design (CAD) was the software being used for 2D drawing at this time. The development continued, and object oriented CAD arrived later on. This gave the opportunity to add parametric attributes to objects, which made it possible to achieve more complex modeling of buildings.
In the 2000's, the use of BIM started to become available to commercial businesses, and is still under development to this day [2]. The development of BIM is driven forward by BuildingSMART, with a focus on an open standard BIM.

### 2.1.2 Benefits

As described by Azhar et al., the key benefit of BIM is its accurate geometrical representation of the parts of a building in an integrated data environment [3]. Other important benefits mentioned in the same paper are:

- **Faster and more effective processes:**
  Information is more easily shared and can be value-added and reused.
- **Better design:**
  Building proposals can be rigorously analyzed, simulations performed quickly, and performance benchmarked, enabling improved and innovative solutions.
- **Controlled whole-life costs and environmental data:**
  Environmental performance is more predictable, and life cycle costs are better understood.
- **Better production quality:**
  Documentation output is flexible and exploits automation.
- **Automated assembly:**
  Digital product data can be exploited in downstream processes and used for manufacturing and assembly of structural systems.
- **Better customer service:**
  Proposals are better understood through accurate visualization.
- **Life cycle data:**
  Requirements, design, construction, and operational information can be used in facilities management.

### 2.1.3 OpenBIM

OpenBIM is based on open standards and workflows which are used to achieve collaborative design, realization and operation of buildings. OpenBIM is an initiative of buildingSMART and several leading software vendors using the open buildingSMART Data Model [4]. By sharing all information between all actors in one open format, everyone can work more efficiently with less errors. In order to share all the information, an open format called Industry Foundation Classes (IFC) is used. IFC uses a plain text file and is both a data representation standard and a file format. The details of each object in the BIM are stored, such as color, dimensions of the object, and coherent objects. This simplifies the building process, as well as maintenance during the buildings life cycle.

The standards of openBIM are the following; Terms (ISO 12006-3 (IFD)), Process (ISO29481 (IDM)), Data (ISO 16739 (IFC)).

- BuildingSMART data models, also known as Industry Foundation Classes (IFC), are based on ISO 16739 [5].
- BuildingSMART data dictionaries, also known as International Framework for Dictionaries (IFD) libraries, are based on ISO 12006-3 [6].
- BuildingSMART Process, also known as Information Delivery Manual(IDM), is based on ISO29481 [7].

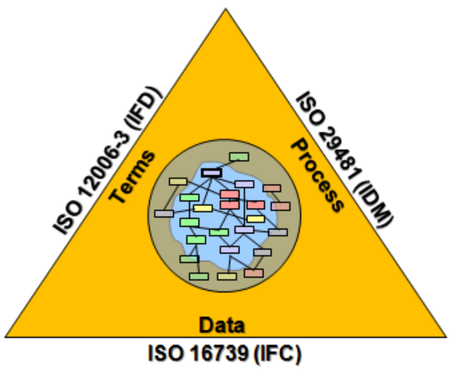


Figure 2.1: Building SMART standards [8].

## 2.2 Enterprise BIM (EBIM)

St. Olav's University Hospital consists of many buildings, both old and new, which has to be maintained throughout their decades of life spans. With this issue at hand, they identified the need of a homogeneous standardized open platform in order to develop and maintain their facilities. Together with St. Olav's University Hospital, Central Norway Health Authority established the a project called LifeCycle BIM in 2012, in order to establish a life-cycle BIM- based Facility Management platform. The solution was to implement an EBIM philosophy, where each old, new, and future building is an integral unit in the entire portfolio of buildings. Using such a solution, makes it possible to incorporate processes and the core business of the hospital.

EBIM is a discrete information database at St. Olav's University Hospital, which targets important user aspects, such as Virtual Design Construction (VDC), Facility Management, and Property Management. As illustrated in Figure 2.2, the EBIM will support important functions in the core business area and be an important source for strategic management analysis in the near future [9]. Through the work on this thesis, an indoor positioning system is being implemented along with other features, which will assist in realizing the goals of EBIM.

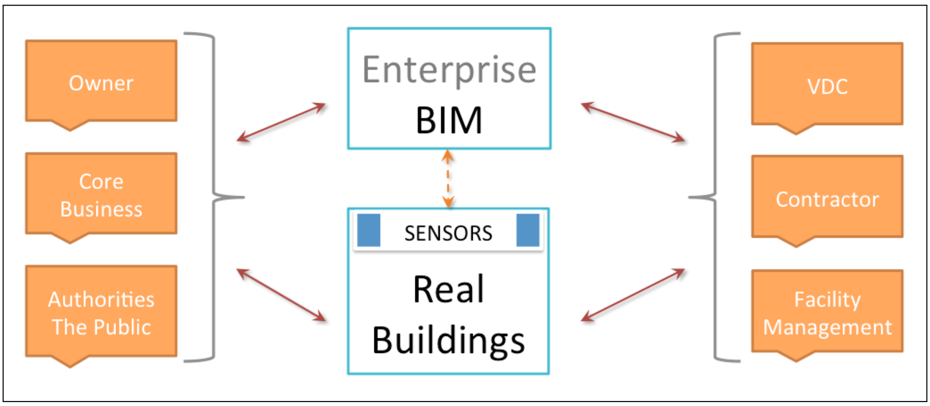


Figure 2.2: St. Olav's University Hospital Enterprise BIM (EBIM) architecture [9].

## 2.3 Model Server Manager (MSM)

For the visualization and management of St. Olav's University Hospitals EBIM, an application developed by Jotne EPM Technology is utilized. The application is called MSM (Model Server Manager), and is installed on computers. MSM retrieves the building models and all data connected to them, from a database installed on a model server. All of St. Olav's University Hospitals building models are stored in this database, enabling the users to view multiple buildings at the same time.

All objects in the models have a number of attributes, depending on which type of object. Figure 2.3, a window in the building "Kunnskapssenteret" has been selected, and many of its properties are shown in the right hand pane. The objects properties first of all has to contain measurements for the object, as well as a placement in the building it belongs to. When some objects, such as ventilation pipes, are part of a ventilation system, it has to be defined which of the systems the pipe is connected to.

In these models, multiple classification systems are used to to define owners, location, and the discipline related to the object. TFM (Tverfaglig Merkesystem) is one of these systems and will be explained in Section 2.4.

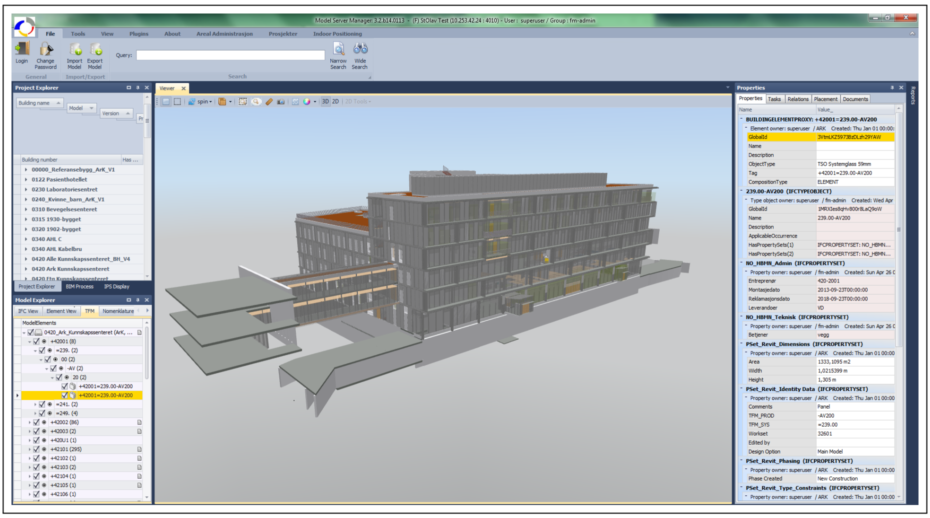

Figure 2.3: MSM displaying "Kunnskapssenteret" at St. Olav's University Hospital.

## 2.4 TFM

TFM ("Tverrfaglig Merkesystem") is a Norwegian interdisciplinary labeling system. TFM is used in BIM at St. Olav's University Hospital to categorize building components, based on such as disciplines, buildings, systems, and type of object. The TFM codes can be divided into three main parts, which are described underneath, using an example of a building components TFM label at St. Olav's University Hospital.

Example TFM label:
`+042201=542.01-RY0628`

- `+042201` - The first part of the label describes the location, which is defined by the contractor. The `+` symbol indicates that it refers to a location. The location is usually the number of a building and can be more detailed including spaces inside the building.
  The numbers refers to locations at St. Olav's University Hospital and the numbers represents spaces like this:
  - `042` - Building number 042, which is the "Kunnskapssenteret" building.
  - `2` - Wing number 2 in "Kunnskapssenteret".
  - `01` - Floor number 01 in "Kunnskapssenteret".
- `=542.01` - The second part of the label indicates what discipline the object associates with, indicated by the `=` symbol. The numbers before the punctuation represents a kind of object in a discipline. There are six series being used for the involved disciplines, such as 200 for architectural components, 300 for plumbing/gas/sanitary components, and 400 for electrical components. The numbers after the punctuation indicates which system the components are connected to, such as ventilation systems or plumbing systems.
  The numbers in this example refers to the following:
  - `5` - Telecommunications and automation, which is the 500 series.
  - `4` - Alarm- and signal-systems, underlying the 500 series.
  - `2` - Fire alarm, underlying the 540 series.
  - `.01` - Fire alarm system 01, the example component is connected to this system.
- `-RY0628` - The third and last part of the label describes what kind of component it is and what its serial number is.
  - `RY` - Smoke detector.
  - `0628` - Serial number.

## 2.5 Coordinate Systems

Multiple coordinate systems are used in this thesis, and a description of them is necessary to understand them and differentiate between them.

### 2.5.1 World Geodetic System

The World Geodetic System (WGS) is a reference frame for the Earth, and is used for navigation, cartography and geodesy. It was first in the 1950's that a unified WGS became essential. It was the start of international space science and astronautics, while there also arose a need for global maps for aviation, navigation, and geography. The WGS has later been revised multiple times, where WGS 84 is the latest revision, established in 1984 and revised again in 2004 [10]. WGS 84 is defined and maintained by the United States National Geospatial-Intelligence Agency (NGA), and is used as reference coordinate system for GPS.

### 2.5.2 The European Reference Framework

The European Reference Framework (EUREF89), also known as European Terrestrial Reference System (ERTS 89), is a regional frame of reference for the tectonic earth plate Eurasia. The official map projection of EUREF89 is UTM (Universal Transverse Mercator), where the zones has a width of 6°[11]. The UTM-projection has a scale factor of 0.9996 in the central meridian. This results in measurements made in the terrain having to be corrected with up to 4 centimeters per 100 meters, depending on the distance to the central meridian, to be converted to a distance in UTM. While there are no issues with this correction for construction of roads and such, it has larger consequences when it comes to construction of buildings. Building parts can be prefabricated and might not fit perfectly, which can potentially result in fatalities, or just buildings that needs to be fixed later on. It was therefore necessary to introduce a new map projection NTM (Norwegian Transverse Mercator), with zones 5 to 30 covering Norway. The zones in NTM has a width of 1°, and the scale correction needed is significantly less, compared to UTM. In the southern parts of Norway the maximum scale correction needed is 0.11 centimeters per 100 meters, while the maximum scale correction needed in northern Norway is 0.05 centimeters per 100 meters [12].

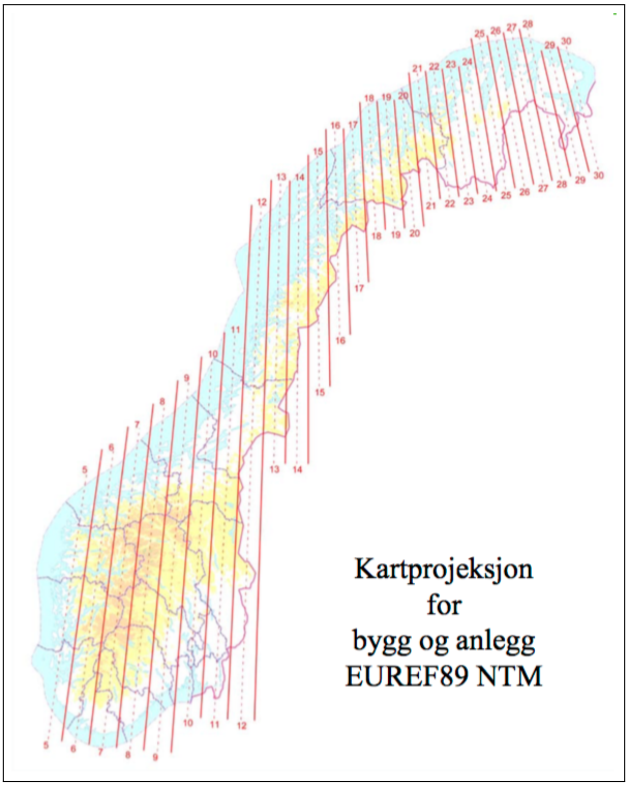


Figure 2.4: NTM Zones in Norway [13].

### 2.5.3 Local BIM Coordinates

Local coordinates in a BIM model are set according to one reference point for the building. This reference point can then be used to represent the location of objects in the building or the building itself, relative to the rest of the NTM zone 10. At St. Olav's University Hospital they use a point close to the river "Nidelva" as a reference point in NTM zone 10. The reference point is the origin in the local BIM coordinate system, while still having its position in NTM zone 10. If an object inside a building is placed 50 meters north and 35 meters west from the reference point, the objects local BIM coordinates will be $x$ = *-35* and $y$ = *50*.

## 2.6 Global Positioning System

The GPS (Global Positioning System) assists us when navigating all over the world, and is utilized by navigation systems in cars, boats, airplanes, and smart phones. The GPS is a network made up of the three segments; space, control and user. These segments will be used to describe GPS below [14].

**Space Segment**
24 solar powered satellites orbit the Earth at speeds over 7000 miles per hour. Of the 24 satellites, at least 4 of them is visible from any point on Earth at any given time. The satellites beams down signals to anyone on Earth with a GPS receiver. These signals carry a time code and geographical data point that allows the user to pinpoint their exact position, speed and time anywhere on the planet [15].

**Control Segment**
A ground master control center in Colorado Springs consists of unmanned monitor stations and ground antennas. These work together to assure that the GPS data is accurate, and that the satellites are working properly.

**User Segment**
This segment consists of the users devices with GPS receivers, such as smart phones and navigation systems in cars.

### 2.6.1 How GPS Works

These five points will in simplicity describe how GPS works.

1. All satellites have a clock set to exactly the same time as the other satellites.
2. All satellites know their exact position.
3. Each satellite transmits its position and a time signal, which is received by a GPS-receiver.
4. GPS-receivers down at Earth receive signals from multiple satellites before calculating the distance to each satellite
5. Finally the GPS-receivers calculate their positions using the distances from the different satellites.

### 2.6.2 Benefits

Most smart phones today have a GPS receiver, which makes it highly accessible. The U.S. government has claimed a worst case pseudo range accuracy of 7.8 meters in space with a confidence factor of 95%. However, real-world data presented by the FAA (Federal Aviation Administration) shows that the accuracy actually is better than 3.5 meters horizontally [16].

### 2.6.3 Disadvantages

Once a person using a GPS receiver moves inside a building, GPS tracking does not work very well, or at all. The accuracy is not adequate for indoor positioning and it is likely that the user might look like its placed in a room next door, or outside even.

## 2.7 Indoor Positioning Systems

While GPS tracking works very well outside, this does not apply for the use of GPS inside buildings. It is therefore necessary to utilize other technologies, or combine multiple technologies to calculate indoor positions. Common technologies used for indoor tracking are such as WiFi and radio-frequency identification (RFID). The use of WiFi localization was used in the paper "Visualizing a City Within a City" [17] to visualize mobility on the campus of NTNU. In this case they created and studied heat maps of movement on the campus, using floor plans and WiFi tracking.
Most people today carry a smart phone which provides a possibility to connect to WiFi networks, and most buildings have a WiFi Network, at least larger buildings for such as businesses, hospitals, and universities. This is why, when looking at the cost of implementing an indoor positioning system (IPS), WiFi makes an excellent choice.

## 2.8 Existing Indoor Positioning Systems

In this section currently existing applications utilizing indoor positioning and other useful techniques and technologies will be presented. It should be mentioned that most, if not all, available solutions for indoor positioning depend on the use of two dimensional floor plans.

### 2.8.1 MazeMap

MazeMap started as a research and development project between Trådløse Trondheim and NTNU. It is an indoor positioning navigation service mainly for large buildings, such as hospitals, universities, and shopping malls. MazeMap extracts information from DWG-files in order to build new indoor maps, making it possible to link and search through the information. By using MazeMap the users can see all rooms, floors, and buildings, while having the ability to locate themselves inside the buildings. It is also possible to search for rooms and get turn by turn navigation inside buildings. All of the features of MazeMap is avaliable on any device such as smart phones, tablets, and laptops. It has been stated that the MazeMap positioning service has an accuracy of 5-10 meters, using the Wi-Fi network at NTNU [18]. This of course might differ in other buildings, depending on the placement of Wi-Fi access points, and their density.
Given that the device being used has a GPS receiver, it is also possible to use

MazeMap outdoors, which is useful when a campus or similar consists of multiple buildings. If both GPS and WiFi signals are avaliable, MazeMap is able to combine them, thus increasing the accuracy. MazeMap utilize data from Cisco MSE location engines at St. Olav's University Hospital and NTNU in Trondheim.

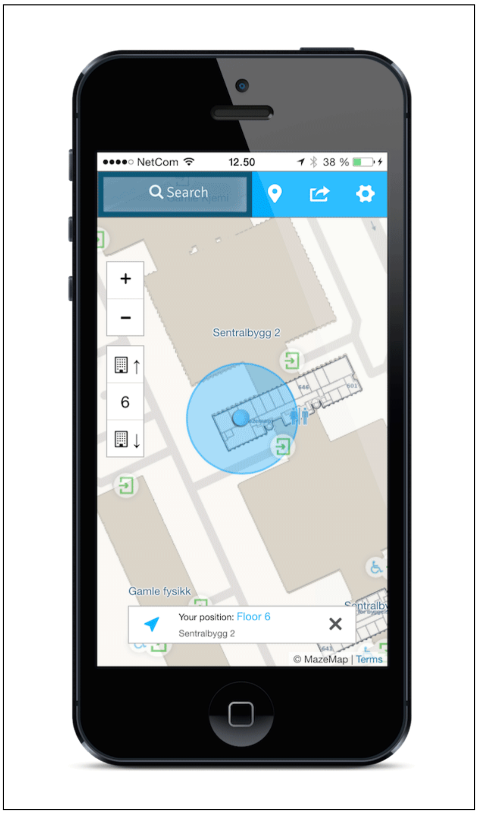


Figure 2.5: Example of MazeMap running on an iPhone 5 [19].

### Benefits

- MazeMap is a great application for navigation in larger buildings or campus like NTNU. It is available for use on smart phones, tablets, computers, and basically any other device with a web browser.
- MazeMap can easily be integrated with multiple beneficial features, such as timetables, SMS notification, and room reservation.

### Disadvantages

- MazeMap normally has an accuracy of 5-10 meters, and some places down to the meter, depending on the placement and density of WiFi-access points [20].

- It is not intended to be used for tracking of equipment, which larger organizations and businesses, e.g. St. Olav's University Hospital, might greatly benefit from.

### 2.8.2 AeroScout MobileView

AeroScout MobileView is a web application which also takes advantage of the positioning data calculated by a Cisco MSE location engine. A pilot project was conducted at St. Olav's University Hospital during the work on this thesis, where this product was tested as a solution to track medical equipment. MobileView is a web application where the users can maintain the real-time location system (RTLS) tags used for tracking of equipment. The RTLS tags can be assigned to equipment types, and given an identifier. Buildings and all floors in the buildings can also be listed, in order to see what equipment is located there.

**Benefits**

- The system is ready for deployment, and can be implemented right away.
- Has a possibility to define walls for 2D drawings, which improves the accuracy of the positioning.

**Disadvantages**

- High cost to acquire, plus yearly licensing fees.
- Not possible to change, optimize, and add features. For a large organization or business such as St. Olav's University Hospital, having the possibility to modify, optimize, and create new features for an IPS, would be beneficial.
- Utilizes DWG-file format for maps in order to visualize the positioning.
- Proprietary cloud solution, where sharing of data with third party systems is controlled through the use of API.

## 2.9 Location engines

Location engines are used to calculate the best possible estimate for the object being tracked. A position can be calculated using a combination of topography, geometry, and filtering algorithms. It is possible to take different approaches when developing a location engine, but all modern location engines are based on some, or a combination of, the following calculations; triangulation, multilateration, and the method of least squares.

Triangulation is a method of determining the location of an object by measuring angles to it from fixed points that already forms a line. The two angles will then give away the position of the object, and makes up a triangle.

Multilateration is a method commonly used in navigation, where Time Difference Of Arrival (TDOA) is used to measure and plot points of possible locations, which forms a line or curve, known as a hyperbolic curve. To find the exact location of the object, it is necessary to have at least two of these lines in order to compare them and provide a smaller number of possible positions.

The method of least squares can be used to correct errors in positioning data, by fitting the data. For instance, when driving a car and stopping on a shoulder of a road, the GPS will most likely illustrate that the car is still on the road, as the data has been fitted for the purpose of cars driving on roads.

### 2.9.1 Cisco Mobility Services Engine

In the implementation presented in this thesis, a Cisco MSE (Mobility Service Engine) was utilized to gather tracking data. It is in fact the same location engine being used for the Mazemap solution at St. Olav's University Hospital, and it was additionally used for a pilot project for a test implementation of AeroScout MobileView.
Cisco MSE is a location engine, which can either be run as a virtual or physical appliance. The Cisco MSE receives information from clients and RTLS tags connected to the WiFi network. The clients and RTLS tags beacons are "picked up" by one or more WiFi access points, and this information is used to calculate the client or tags position. The positions of each client or tag can then be forwarded to a third party application, or grabbed using their REST (Representational State Transfer) API (Application Program Interface) [21].

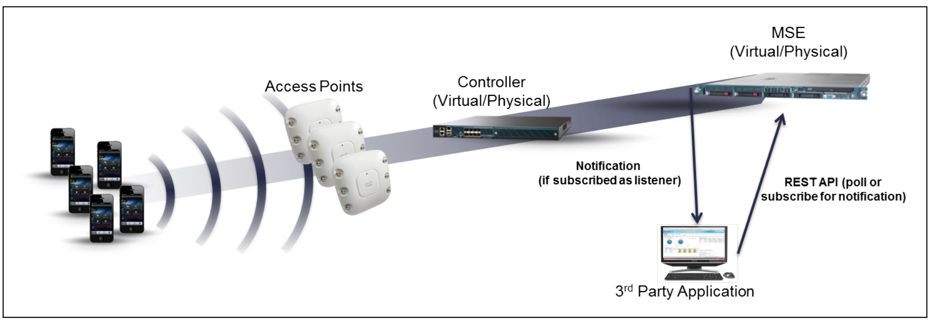


Figure 2.6: Example of MSE in use [22].

Figure 2.6 gives an overview of how an indoor positioning system fits together with the Cisco MSE on top. Mazemap, AeroScout MobileView, and the implementation developed during the work on this thesis are examples of third party applications shown in this figure. The implementation in this thesis differs in how the data is retrieved, as the Cisco MSE REST API was not utilized.

## 2.10 Hardware

In order to track object's in a building, hardware is needed to send and receive information about the objects position. Hardware used to create an indoor positioning system will therefore be described in this section.

### 2.10.1 WiFi Access Points

By utilizing the WiFi access points in a building for indoor positioning, one will get multiple uses for the WiFi network. When placing the access points in a building and considering utilizing them for indoor tracking, it is important to place them in a way that improves the accuracy of measurement. WiFi access points should be placed near walls, and add access points in the middle of the room if it is a large space. All access points should not be placed in a straight line in the middle of the corridor, as they often tend to be placed [23].
Figure 2.7 displays an example from Cisco, where they express recommended and not recommended placement of WiFi access points. When placing a point inside one of these drawings, it should be easy to see which of the drawings it is easiest to draw triangles in using two access points and an additional placed point. Thus facilitating the triangulation of a position in a room, when placing the access points in a zigzag pattern.

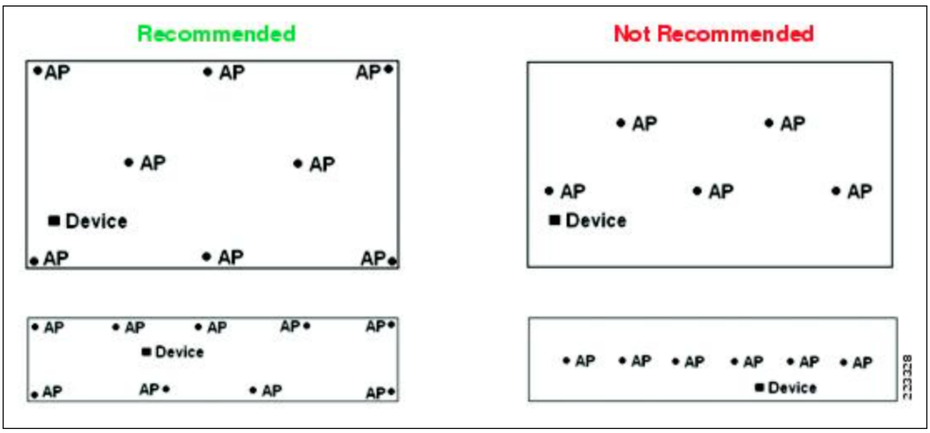


Figure 2.7: WiFi access point placement [23].

### 2.10.2 Positioning Devices

Positioning devices might be considered a vague term, however it is here used to describe devices being tracked while carried by a person or mounted on an object. Positioning devices may be active or passive devices. An active positioning device has its own power source, batteries, and is able to send information. A passive positioning device has no power source, and needs help from other devices in order to send their position.

### Active Positioning Devices

Laptops, tablets and mobile phones are very common, and most people carry their smart phones everywhere they go. These active positioning devices are useful to further utilize in an IPS, as people do not have to buy a new device for indoor positioning. For all other objects one might wish to track, such as beds, medical equipment, and AGV's (Automated Guided Vehicles) in a hospital, some sort of RTLS tag has to be mounted. Positioning devices like these RTLS tags come in different variants, but most of them have a battery and the ability to transmit their position on a WiFi network.
Examples of active positioning devices:

- Smart Phone
- Computer / Laptop
- Tablet
- RTLS Tag

### Passive Positioning Devices

RFID is a common technology, which most people have experienced or seen in action, as a security measure to prevent theft in stores. Products such as clothes are equipped with a RFID chips, and at the entrance of a store there are large electromagnetic transmitters, which can read the chips. When RFID chips passes these transmitters they are powered by an electromagnetic induction from a magnetic field the reader produce. When powered like this, RFID chips send their information, and the reader can start the alarm if the chip has not been deactivated. The same technology is used for lock systems, were users position their card in front of a reader in order to unlock a door.
Examples of passive positioning devices:

- RFID
- Barcode

# Chapter 3

# Research Methodology

This chapter will describe how the research for this thesis was conducted, starting with a description of the research method, explaining how the research was guided. The research questions are then laid out, before ending with an elaboration on the data gathering.

## 3.1 Research Method

The chosen research method for the work of this thesis is based on "Design and Creation" [24], a method focusing on design and development in information technology. For projects such as the one in this research where development of a product is key, there are important factors that should be present in order for the project to be considered as research. The project should not only demonstrate technical skills, but also academic qualities such as analysis, explanation, argument, justification, and critical evaluation. This also means that a project like this should contribute to knowledge in some way. This research method describes an iterative process "The design and creation process: Leaning via Making", where five steps are used for development and research [24].

- **Awareness** - Recognition and articulation of a problem.
- **Suggestion** - Offering a tentative idea of how the problem might be addressed.
- **Development** - Implementation of the tentative idea.
- **Evaluation** - Evaluation of the developed artifact, with a focus on its value and deviations from expectations.
- **Conclusion** - Results from the design process are consolidated and written down, together with the gained knowledge, and any loose ends. Any unexpected or anomalous results that cannot yet be explained, could be subject of further research.

## 3.2 Research Questions

This research investigates the utilization of indoor positioning services combined with BIM. The main research question is therefore the following:

- Which potentials do the use of asset tags, location-based services and BIM models hold for the future of hospitals and other large buildings?

In order to answer this broad research question, the following questions were applied to guide the research:

1. Is it possible to combine indoor positioning services with an EBIM and present it in a clear and comprehensible way?
   (a) Will users, such as porters and maintenance workers, find it useful?
   (b) Will administration find it useful?
2. Will utilization of the indoor positioning system help to reduce the hospital costs?
   (a) Which costs could be reduced?
   (b) How much could the costs be reduced?

## 3.3 Data Gathering

In order to answer the research questions, data gathering was required. Employees at St. Olav's University Hospital would use a prototype of the system, developed through the work on this thesis in collaboration with Jotne EPM Technology. After using the system for a period of one week, they would take a survey regarding their experience. In addition to the survey, an interview with a department manager at St. Olav's University Hospital was conducted to obtaining detailed information from an administrators point of view.

### 3.3.1 System Usability Scale (SUS)

In the survey conducted, System Usability Scale (SUS) was used as a reliable tool to measure the usability of the system. SUS was originally created by John Brooke in 1986, and allows for evaluation of a wide variety of products and services, such as hardware, software, mobile devices, websites, and applications. The survey consists of 10 statements in relation to the system being tested. The user responds to the statements using a scale from 1 to 5, where 1 represents "I strongly disagree" and five represents "I strongly agree". SUS has become an industry standard and is easily scalable to administer participants. It can also be used on small sample sizes with reliable results. The most important benefit is its possibility to effectively differentiate between usable and unusable systems [25].

The complete SUS form is included in the survey, which can be found in Appendix B.

### 3.3.2 Survey

The SUS form was translated to Norwegian, since all test subjects are Norwegian. The first statement in the SUS form has been slightly altered in order to receive more applicable data.

Standard version: *I think that I would like to use this system frequently.*

Altered version: *I think that I would like to use this system for the relevant tasks.*

This alteration was made because employees will have to do this task often, with or without this system. With the alteration it should be possible to see if they would like to use the system, regardless of whether they perform the task often or not.

In addition to the SUS form, the test subjects will answer a few demographic questions, and application specific questions. The demographics will reveal any differences in relation to such as age or profession. The application specific questions will give information about time saving, and the possibility to use the system on a smart phone.

The complete survey can be found in Appendix B.

### 3.3.3 Interview

An interview of a department manager at the hospital was conducted. This will give insight to how management at the hospital envision the future at the hospital, given the availability of an indoor positioning system. The main focus was on reduction in costs and time spent. Additionally, the future possibilities of the indoor positioning system was an important topic.

The complete interview can be found in Appendix C.

## 3.4 Usability Testing

Usability testing of the indoor positioning system will be performed by employees at St. Olavs Hospital. They will utilize the system in their every day work at the hospital for a period of one week before taking the survey.

### 3.4.1 Test Environment

During this test, there is ongoing work to develop a user interface for the system, which will be a web application, available when connected to the hospital's WiFi. The system will in the near future be included in a larger system at the hospital, where they have already implemented a secure login method. This unfortunately means that during this test, the users will have to use a computer connected with a cable to the network at the hospital. Once the system is available when connected to the WiFi network at the hospital, it will also be possible to use the system on smart phones or tablets.

### 3.4.2 Test Location

The testing will take place at St. Olav's University Hospital in Trondheim. Which of the buildings will be included will depend on the movement of equipment with RTLS tags mounted on them. The users will have to locate the equipment regardless of which building they are located in.

### 3.4.3 Test Subjects

The test subjects will be employees at the St. Olav's University Hospital, such as hospital porters and maintenance professionals.

### 3.4.4 Test Execution

Over the period of one week, the test subjects will perform the following task a number of times, depending on how often equipment is used. Each time the test subjects needs to locate equipment they will perform the following steps:

1. Navigate to the web application for indoor positioning.
2. Log on to the application, using given credentials for this test.
3. Search for an object that has to be located.
4. Identify where the object is located at the hospital.
5. Retrieve the object, based on the location displayed.

# Chapter 4

# Problem Elaboration and Requirements

This chapter will give insight to the everyday life of various types of employees at a hospital. First the different stakeholders and potential users will be presented. Then three persona are described, which are fictitious characters used together with scenarios to describe problem areas. For each scenario there will also be presented coherent use cases with more technical details. Finally the requirements for the Windows service developed are described in detail.

## 4.1 Stakeholders and Users

Maintenance professionals and hospital porters are employees who have to locate equipment at the hospital on a daily basis. Hospital porters need to find beds and wheelchairs in order to transport patients. Maintenance professionals need to find miscellaneous equipment that needs to be repaired. These users will most likely be frequent users of an indoor positioning system, with a need for simple positioning data for beds, wheelchairs, and other types of equipment. This means that the data should be easily accessible and comprehensible for every employee at the hospital. A web application for smart phones, together with a way finding option, would be most preferable in this case.

Owners of equipment and department managers might wish to look at either detailed or historical data. In order to look at historical or detailed positioning data, an advanced application running on a computer would make most sense. The reason for this is that a larger screen is necessary in order to work with more complex data like this.
The historical data could be displayed in different ways for analysis, such as pie charts and node trees, which will be discussed in Section 8.2.2.

## 4.2 Persona

In order to give a better understanding of the users of a system, it is common to create a persona for each scenario. The persona is a fictive character with attributes and skills, contributing to simulate a real situation [26]. A template was used in order to guide the description of the three persona [26].

### 4.2.1 Maintenance Professional Adam

Adam works as a maintenance professional at St. Olav's University Hospital, and is 39 years old. He has 15 years of experience with maintenance of such as beds, wheelchairs, and various medical equipment at the hospital. In his daily work, tasks require him to locate various types of equipment which has to be fixed or replaced. He considers himself slightly above average in terms of computer skills.

### 4.2.2 Hospital Porter Siri

Siri is 29 years old, and is employed as a porter at St. Olav's University Hospital. Her main task at work is to transport patients around the hospital. This sometimes include finding an available bed, or the person that she is supposed to transport. She has been working at the hospital for 2 years, and knows her way around the hospital to some degree. She considers her computer skills to be basic, although easily understands new features on her smart phone.

### 4.2.3 Project Leader Ola

Ola is a 48 year old project leader at St. Olav Eiendom. Ola is educated in the field of building engineering, and has 20 years of experience as a project leader for building projects at St. Olav's University Hospital. The projects Ola is in charge of range from new construction of buildings, to refurbishing and remodeling of older buildings. He analyses data in order to plan buildings that support effective treatment of patients. To obtain more useful data, he would like to know the paths of patients in each patient group. This would make it easier for Ola to give departments and rooms a more logical placement, based on real patient flow data. He has a lot of experience with analysis and considers himself as competent in the use of computers.

## 4.3 Scenarios and Use Cases

This section will describe how the system can be used now, and how it could be used in the future, depending on further development. A scenario for a given task will first be presented, simply describing how the system would be used by employees. After each scenario a coherent Use Case follows, with a more technical description of the system in relation to the task.
Of these scenarios, only "Locate Equipment" will be relevant for the usability test. The scenario "Register Equipment" is used to describe an administrators task when

registering new equipment. The last scenario ”Analyze tracking data” describes a future scenario, which most likely will be available as a feature in the near future at St. Olav’s University Hospital. The abbreviation IPS, used in the use cases, stands for indoor positioning system.

### 4.3.1 Register Equipment

Adam is an employee at St. Olav’s University Hospital and works as a maintenance professional. His main tasks are maintenance and deployment of equipment at the hospital, such as beds, wheelchairs, and other medical equipment. One day new beds arrive at the hospital and they need to be prepared for deployment. Adam starts preparing the first bed for deployment by selecting an appropriate RTLS tag using a document. In the document it has been defined which RTLS tag each category of equipment should have. He brings the RTLS tag over to a computer, where he connects a tag activator to the computer. He then continues by starting the Tag Manager software on the computer, in order to configure and activate the tag. When the tag has been configured and activated, he proceeds to mount the RTLS tag on the bed together with a label. The label describes that it is of equipment type ”bed”, together with a serial number to identify the specific bed. Finally he launches the MSM to give the bed a virtual identifier identical to the physical label.

| | |
|---|---|
| **ID** | 1 |
| **Name** | Register Equipment |
| **Brief Description** | Activate and configure a RTLS tag before mounting it on a piece of equipment. Assign the equipment with an identifier, both physically and virtually. |
| **Actors** | Maintenance Professionals |
| **Preconditions** | 1. Reports of existing equipment is available.<br>2. WiFi network and Location Engine is working<br>3. Model server is working. |
| **Basic Flow** | 1. Activate and configure an RTLS tag.<br>2. Mount the RTLS tag on the equipment.<br>3. Assign an identifier to the equipment in MSM.<br>4. Place a label with an identical identifier on the equipment. |
| **Post Conditions** | The equipment is registered with a RTLS tag, and can be located using the EBIM IPS. |

Table 4.1: Use Case 1 - Register Equipment

### 4.3.2 Locate Equipment

Siri, the hospital porter, is at work when she receives the task to retrieve a specific bed and bring it to a department in the building called "Nevrosenteret". Siri does not know where the bed is located, and she therefore logs on to a computer. On the computer she launches a web browser, and navigates to the web application for indoor positioning. In the web application she continues to search for the specific bed. The web application displays the beds position, 3. floor in the building called "Gastrosenteret". She continues to note down its location before walking over to "Gastrosenteret", where she finds the bed. Siri finally brings the bed back to "Nevrosenteret".

As a side note, it should be mentioned that the web application will be available on smart phones in the near future. This would make the application more accessible to its users, and give them the possibility to search for equipment on the fly.

| | |
|---|---|
| **ID** | 2 |
| **Name** | Locate equipment |
| **Brief Description** | Search for equipment in the IPS web application and retrieve the equipment. |
| **Actors** | Hospital Porters and Maintenance Professionals |
| **Preconditions** | 1. Apache server is working.<br>2. WiFi network and Location Engine is working<br>3. Model server is working. |
| **Basic Flow** | 1. Login to the IPS web application.<br>2. Search for equipment<br>3. View its location in a building(s).<br>4. Retrieve the equipment |
| **Post Conditions** | None |

Table 4.2: Use Case 2 - Locate Equipment

### 4.3.3 Maintain Equipment

Adam the maintenance professional at St. Olav's University Hospital opens the MSM software on a computer, where he generates a report of equipment that has to be maintained. Some equipment might be broken or have little to no battery life left on the RTLS tag. Regardless of the error he has to change the battery on the RTLS tag, as it is more efficient to do while he has the equipment in for maintenance.
In the report he can see three pieces of equipment that is in need of maintenance, of which he chooses a wheelchair located somewhere at the hospital. When selecting the wheelchair he can view all available information about it, including its location. With that information, Adam proceeds to the location of the wheelchair, only to find out it is not there.
He then picks up his smart phone and logs in to the indoor positioning web application, where he searches for the wheelchair again. The wheelchair has been moved and Adam tracks it down in the adjacent room.
After bringing back the wheelchair, he continues to remove the RTLS tag from the wheel chair and replaces the battery. Finally he mounts the RTLS tag back on the wheelchair and redeploys it in the hospital.

| | |
|---|---|
| **ID** | 3 |
| **Name** | Maintain equipment |
| **Brief Description** | Get report of equipment that should be taken in for service, locate the equipment, retrieve and repair equipment, redeploy equipment. |
| **Actors** | Maintenance Professionals |
| **Preconditions** | 1. Reports of existing equipment is available.<br>2. WiFi network and Location Engine is working<br>3. Model server is working.<br>3. Battery data is correct. |
| **Basic Flow** | 1. Open EBIM IPS plugin in MSM.<br>2. Choose maintenance and get report.<br>3. Locate the equipment.<br>4. Retrieve and repair the equipment.<br>5. Redeploy the equipment. |
| **Post Conditions** | Equipment repaired and possible to locate. |

Table 4.3: Use Case 3 - Maintain Equipment

### 4.3.4 Analyze Tracking Data

Ola works at St. Olav Eiendom and is in charge of a new project at the St. Olav's University Hospital. The project involves remodeling a building where patients are being treated for miscellaneous illnesses. As the building is today, patients have to move around a lot to find the department they have been directed to. Sometimes the patients cannot find the department easily, and precious time is wasted. Ola wants to simplify the process for the patients, while a streamlining of the process would also make it possible to treat more patients.
In order to remodel the building according to the patient flow, he needs to know where all the types of patients in the building moves. He acquires some RTLS tags in order to track the patients willing to participate in the research. He continues to track patients for a period of one month, and now has data on the various patient flows.
Ola continues to design and plan the remodeling of the building, using the patient flow data to further improve the patient flows and efficiency of the hospital.

| | |
|---|---|
| **ID** | 4 |
| **Name** | Historical data |
| **Brief Description** | Get historic data for one or more tags. |
| **Actors** | Maintenance Professionals, Owners, and Dept. Managers |
| **Preconditions** | 1. Reports of existing equipment is available.<br>2. WiFi network and Location Engine is working<br>3. Model server is working. |
| **Basic Flow** | 1. Open EBIM IPS plugin in MSM.<br>2. Right click on one or more tags, and select "History".<br>3. View the default view of historic data. |
| **Post Conditions** | None |

Table 4.4: Use Case 4 - Analyze Tracking Data

## 4.4 Requirements

In order for the Windows service to acquire data, it is necessary for certain requirements to be met. In this section all necessary requirements will be addressed and described. This information is important for further development and configuration of the Windows service, as well as further development of the system as a whole.

### 4.4.1 Main Requirements

In order for the Windows service to work, multiple requirements must be met, where these are the main requirements:

- WiFi RTLS Tags must be active.
- WiFi RTLS Tags must be located inside a building at St. Olav's University Hospital.
- WiFi network at St. Olav's University Hospital must be up and running.
- The location engine (Cisco MSE) at St. Olav's University Hospital must be up and running.
- The location engine (Cisco MSE) at St. Olav's University Hospital must be dumping data in XML-files.

More detailed information about required configurations will be described in the next sections of this chapter.

### 4.4.2 RTLS Tag Configuration

- The channels used by the tags should be set to 1, 6, and 11, because non-overlapping channels prevents interference.
- Beacon interval must be set, based on the type of equipment to be tracked.

*A detailed guide for RTLS tag configuration can be found in Appendix A.*

### 4.4.3 Firewalls

Although the Cisco MSE dumps the data to the model server at St. Olav Eiendom, it is necessary for the model server to reply to the Cisco MSE in order to accept the connection. The firewalls on the model server, Cisco MSE server, and in the St. Olavs Hospital network must thus be set to allow communication between the model server and the Cisco MSE server on port 55200.

### 4.4.4 XML Files

The files received by the Windows service from Cisco MSE have to be parsed and imported to the EBIM database. It is therefore necessary that all attributes and values are present in every XML received. The Cisco MSE has been configured to dump clean XML files, but occasionally files arrive with http headers. All files should start with an XML deceleration, followed by a tag called "StreamingNotification". It is therefore also required that the files end with an identical closing tag. Any additional text above, such as http headers, or under the XML will be removed before saving the XML, unless if it is another XML in the same file. If multiple XML's lies within a file, they will be saved as separate files by the Windows service. The XML's need to have the same structure every time. Below is an example of how the XML files should be structured.

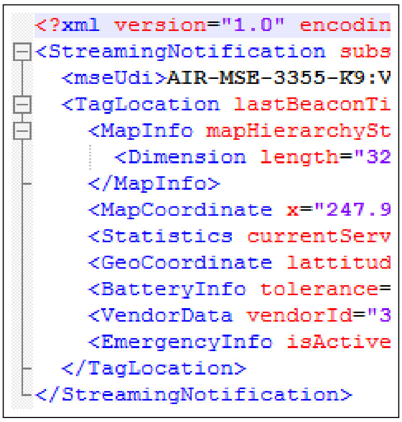


Figure 4.1: Example of required XML structure.

While it is of high importance that the XML-files have the correct structure, it is equally important that certain attributes are present. The relevant and required attributes for this system are listed on the next page.

Required Attributes

- StreamingNotification
  - Entity
- TagLocation
  - macAddress
  - confidenceFactor
- MapInfo
  - mapHierarchyString
  - floorRefID
- Statistics
  - lastLocatedTime
- GeoCoordinate
  - lattitude
  - longitude
- BatteryInfo
  - tolerance
  - percentRemaining
  - daysRemaining
  - batteryAge
- VendorData
  - data

## Chapter 5

# Implementation of EBIM IPS

In this chapter the implementation of indoor positioning integrated in EBIM will be presented. An overview of the implementation will be given before further elaboration on the details of the implementation. The main focus in this chapter will be directed towards my work in the development of this implementation, while still explaining the parts developed by Jotne EPM Technology in less detail.

## 5.1 Overview of Implementation

In this section an overview of the system will be presented, from the hardware to the visualization of data for end users. Figure 5.1 displays which components the system consists of, and how the information flows from the WiFi RTLS Tag to the end user. These components and their communication will be described here in order to get an overview of the implementation.

**WiFi-Tags**
WiFi RTLS tags transmits beacons based on a set interval during configuration of the individual RTLS tags. When an RTLS tag sends a beacon inside a building at St. Olav's University Hospital, the beacon is picked up by the access points in the Wi-Fi network.

**Wi-Fi Network**
Multiple access points at the hospital communicate and receive beacons from WiFi RTLS tags. The data is forwarded together with time of arrival and signal strength to the location engine, which in this case is a Cisco MSE.

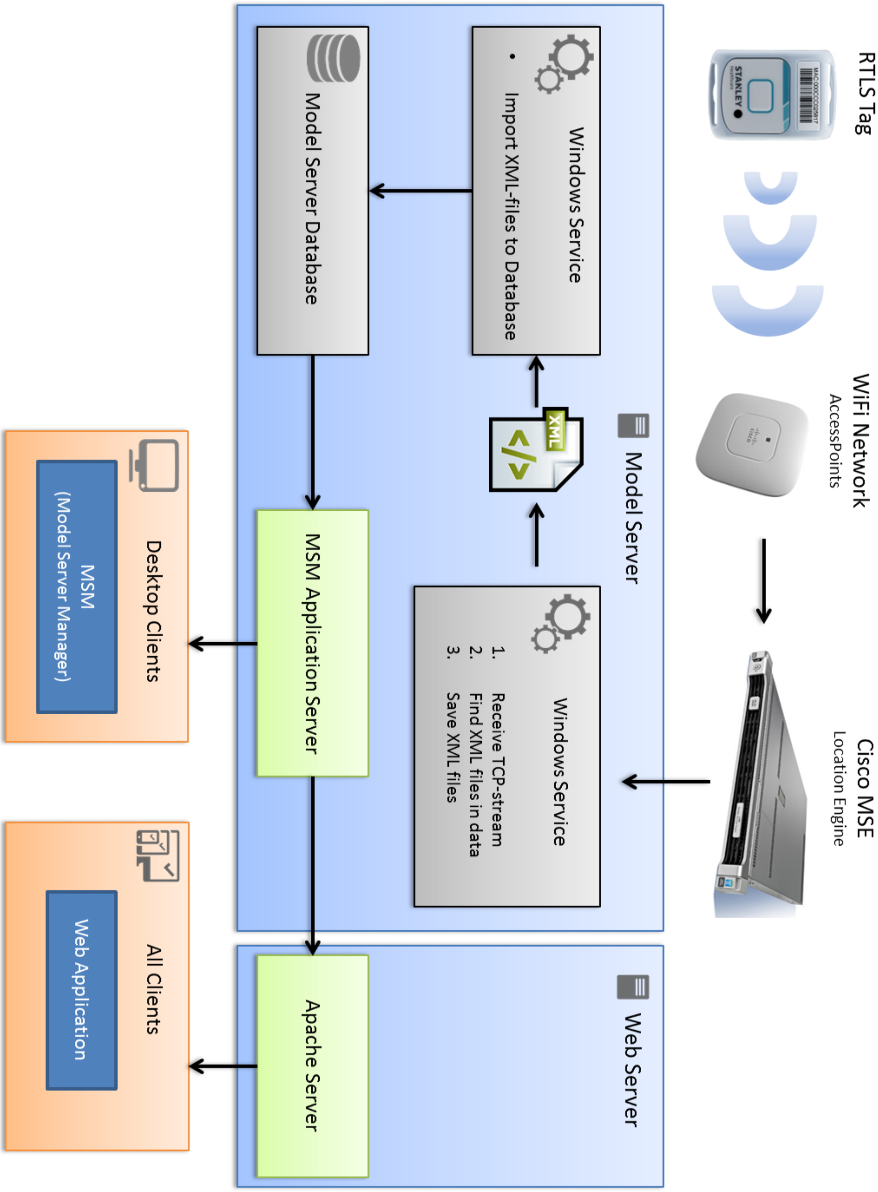


Figure 5.1: Information flow in the developed indoor positioning system.

**Cisco MSE Location Engine**

The Cisco MSE receives the communication data from access points in the WiFi network, and uses time difference of arrival (TDOA) and received signal strength indication (RSSI) to calculate the clients/tags position.

HEMIT (Helse Midt-Norge IT) has configured at least 3 GPS markers for each floor plan, which are used as references to the GPS Coordinate system. The Cisco MSE calculates local floor plan coordinates for the tag, based on TDOA (time Difference of arrival) and RSSI (Received Signal Strength Indication). This coordinate is then converted into a GPS coordinate, in WGS 84 format, based on the GPS reference points for the floor plan the tag is located in. The detailed positioning data for the tag is finally forwarded using a TCP-stream from the Cisco MSE server to the model server, where the Windows service is running.

**Windows Service**

The Windows service is installed on the model server which receives the positioning data as a TCP-stream from the Cisco MSE server. The service continuously loops and waits for data to arrive. When data arrives, it tries to process data and save any XML-files, before waiting for more data.

Other features were developed for this service during this project, but were not included in the final implementation. These features are described in Appendix E, together with an explanation of why they were not included in the final implementation.

**Import to Database**

The XML files have been saved on the model server and need to be imported into the model database. Jotne EPM Technology created a Windows service that imports data from the files into the database continuously.

**Visualization**

The positioning data will finally be visualized for the end user through a web application developed by Jotne EPM Technology. This application allows the users to search and find equipment on the hospital.

## 5.2 Steps to Implement System

Multiple steps were necessary in order to implement this system. Some of the steps were performed by me, while others were carried out by Jotne EPM Technology. Thus there will be a slight variation in the level of detail in the description of the steps taken to implement the system.

1. A description of how the tags were acquired and configured will first be presented.
2. The next step in the implementation was to transfer the tracking data calculated by the Cisco MSE to the BIM-server.
3. Jotne EPM Technology then imports the data into a database on the model server.
4. There are two main options for visualization of the data.
   (a) **MSM -** Until recently Jotne EPM Technology and St. Olavs Hospital used the MSM (Model Server Manager) to visualize the data in a 3D environment, with an option of 2D visualization together with a map of the surroundings.
   (b) **Web Application -** During the work on this thesis Jotne EPM Technology started to work on a web application to handle work orders. The same application can be used for the IPS, and will be explained at the end of this chapter.

## 5.3 Acquire and Configure Tags

The first step in implementing this system, was to acquire positioning data for the objects we wanted to track. The objects needed to be equipped with active WiFi RTLS tags, thus we first had to acquire some tags. After browsing the Internet for all sorts of WiFi RTLS tags, it was decided that we should order T2s 802.11 active Wi-Fi tags from Stanley Healthcare. These tags are compatible with the Cisco MSE location engine at St. Olav's University Hospital, marked as CCX (Cisco Compatible Extensions). It was also necessary to order a Stanley Health Care Tag Activator, in order to configure the tags.

As a side note, it is worth mentioning the difficulty of ordering just tags, and not a complete solution for two dimensional floor plans, such as AeroScout MobileView. At first tried we tried to order from some web shops, but were finally able to buy the tags and a tag activator from a Stanley Healthcare retailer in Norway.
When we got the tag activator, it did not come with any software, just a serial number to activate the software. After a lot of back and forth we finally acquired the software from Stanley Healthcare in Denmark.


Figure 5.2: Stanley Healthcare T2s Tag, used in work of this thesis.

## 5.3.1 Configuration of Tags

There are multiple possible tag features to configure the tags, depending on which tags are being used. Not all features will be described, as only some of them are available when using the T2s tags. Only those features that are available and used in this system will be described here. Connecting to the tag activator was done using a regular CAT-6 network cable, and setting an IPv4-address for the computer in the range 192.168.1.*. The computer was therefore set with IPv4-address 192.168.1.134 and Subnet Mask 255.255.255.0, which also was necessary. The Tag activator uses 192.168.1.235 as default IP-address.

### Tag Configuration - Detection

Before it is possible to configure tags, they have to be detected by the tag activator. In this case "Wireless" was selected to detect tags, which makes it possible to configure and activate up to 50 tags at the same time wireless. If there is a specific tag or a range of tags one wish to configure, it is possible to input a specific MAC-address, or a range, if one leaves some of the last values empty.

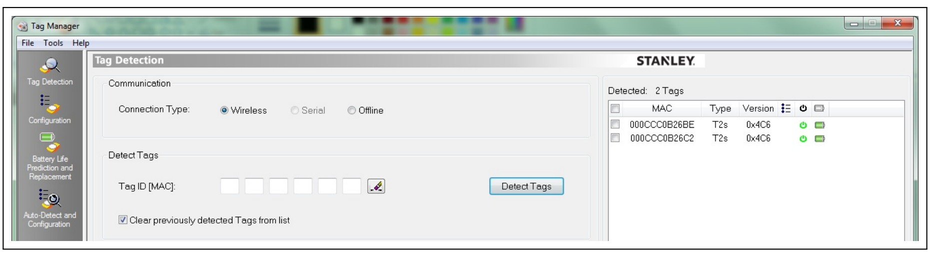


Figure 5.3: Tag Configuration - Tag Detection

### Tag Configuration - General

When the tags has been detected, tags have to be selected in order to be configured, activated, or deactivated. By navigating to "Configuration" in the left pane, all the available configuration options becomes visible. Cisco recommends using non-overlapping 802.11b channels, which is why all tags were configured with channels 1, 6, and 11. The T2s tags have a led light, which can be used to see when the tag is sending beacons. The use of led lights can be configured under the tab "General". Depending on type of equipment the tags are placed on, tag transmission interval can also be set accordingly under "General".

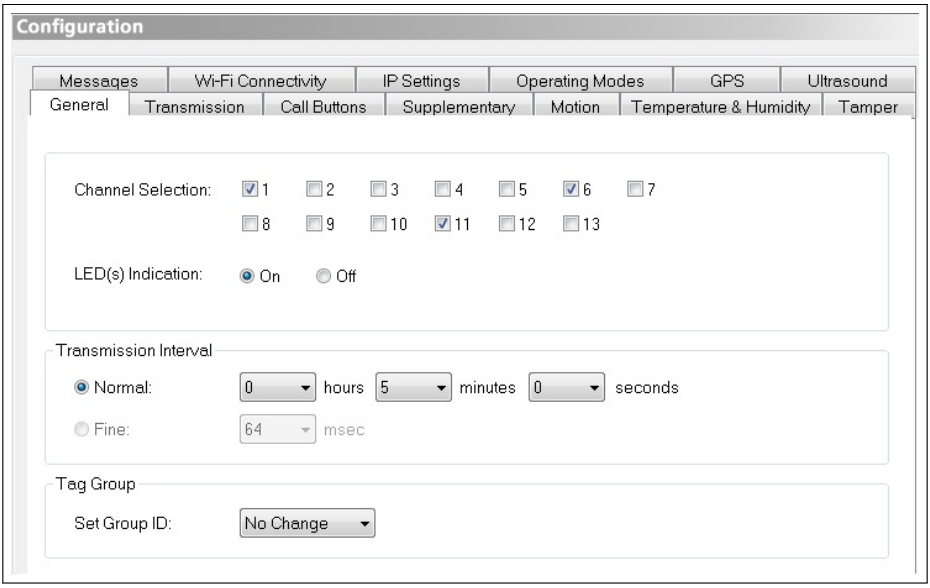


Figure 5.4: Tag Configuration - General

### Tag Configuration - Messages

The tags have a possibility to store messages, either in HEX or ASCII, where latter was chosen, as it is possible to write normal characters in ASCII. Using ASCII, the messages are limited to 15 characters. The messages can be used for multiple scenarios as they can be sent either by such as clicking the tag button a specific way, or every time the tag sends a beacon. In this system it was used to describe the object, such as a bed, which could have an identification "SE001". Similar to normal objects in BIM, you would have two characters describing the object, and a serial number to identify the specific instance of the object.

When the messages arrive at the model server, they seem to be encoded in Base64 with some additional characters. The number of additional characters may vary, and messages were thus not used in this implementation after all. A code snippet for the decoding of these messages can be found in Appendix E.

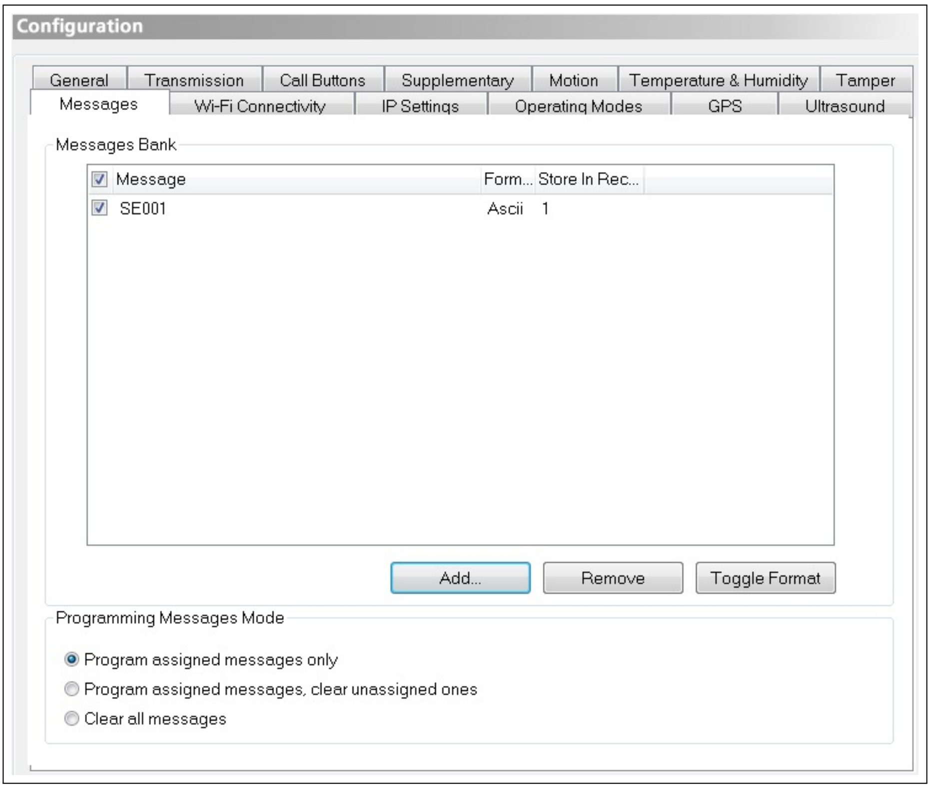


Figure 5.5: Tag Configuration - Messages

### Tag Configuration - Call Buttons

On the T2s tags there are Call Buttons which can be configured to send messages when pressed. Depending on configuration, a chosen message can be sent using one or multiple short clicks, or a click with a longer duration. With a custom implementation like this IPS, call buttons could be used for multiple purposes, which will be discussed in Section 8.2.3.

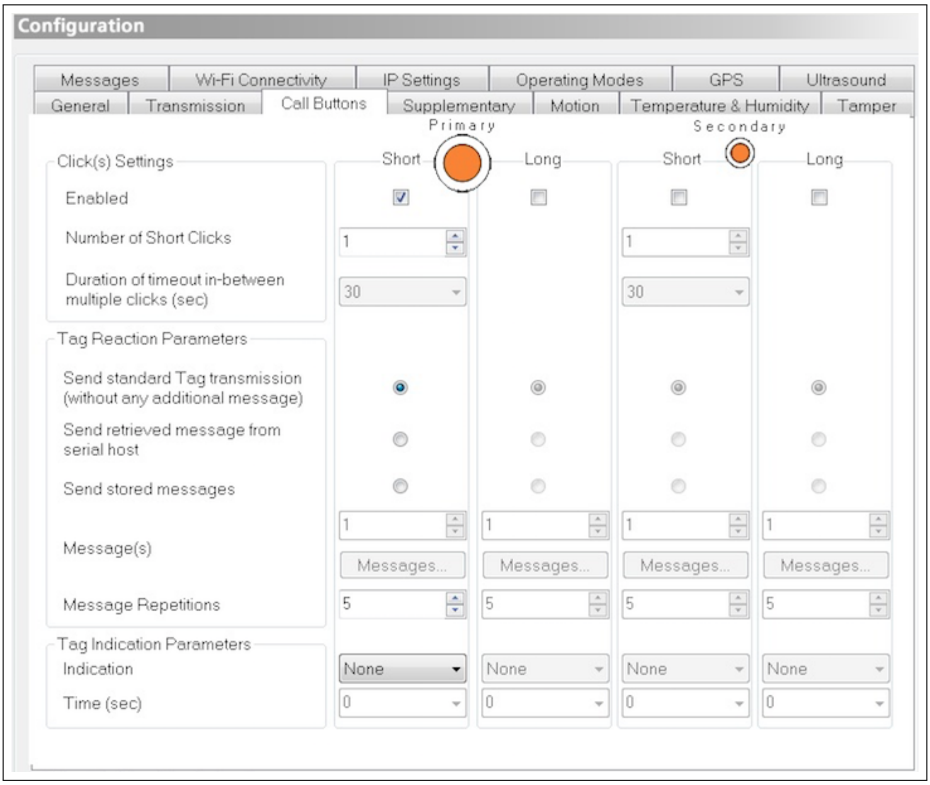


Figure 5.6: Tag Configuration - Call Buttons

### Tag Configuration - Tag Activation

After going through all configurations, the configurations have to be applied to one or multiple tags. The configurations have to be checked off as displayed in Figure 5.7, together with the box that says "Activate". By clicking the "Apply" button the tags are set with the chosen configurations and activated. The tags are now ready for use, and can be mounted on an object one wish to track.

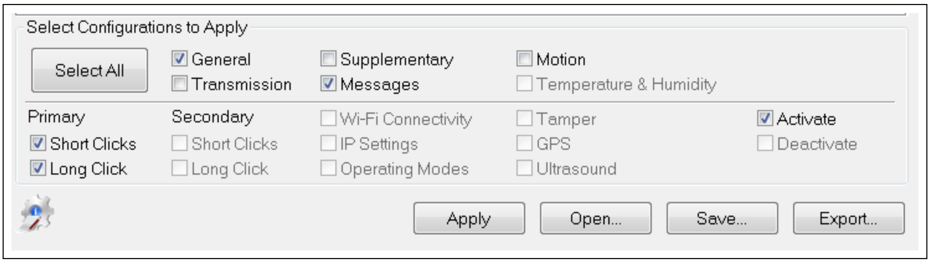


Figure 5.7: Tag Configuration - Tag Activation

## 5.4 Transfer and Store Tracking Data

The Windows service created through the work on this thesis receives and saves all the positioning data from the Cisco MSE location engine at St. Olav's University Hospital. It is worth mentioning that a lot of features were created to alter and optimize the data, even though many of them were not used in the final implementation. The service works faster with less methods to process, and as incoming data can arrive fast consecutively the service needs to be ready at all times. The other methods created while working on this thesis are still relevant to the implementation of the system, as they can be implemented in other parts of the system, such as the MSM (Model Server Manager). Those additional methods will thus be explained in Appendix E.

### 5.4.1 Cisco MSE REST API

When first looking to retrieve positioning data from Cisco MSE, it seemed that using Cisco MSE REST API to grab the data would be the easiest way of doing it. The work to retrieve positioning data therefore started by writing a Windows service that made a request such as the one in Listing 8.1 in Appendix D. In this code a request is being made towards a Cisco MSE Sandbox Server, in order to retrieve positioning data.
In order to make such a request, a user name and password had to be specified, in order to securely access the Cisco MSE and the tracking data. As there is no option to create additional user accounts on the Cisco MSE, only the administrator account could be used. This would not have been an issue if St. Olav Eiendom was the owner of the Cisco MSE server, but HEMIT is the owner of that server. And because of regulations, HEMIT would not offer administrator access to others outside their organization to that server. This meant that other ways of transferring the data would have to be further investigated.

An employee at HEMIT found an option in the user interface of the Cisco MSE, which was to forward positioning data from the Cisco MSE using a TCP-stream. In order to receive this data, a server would need to be able to accept data continuously at any time. The development of a Windows service that could receive the TCP-stream was therefore started.

### 5.4.2 TCP Stream

The Windows service developed during the work of this thesis was written in C#, using Visual Studio IDE (Integrated Development Environment). The service starts as displayed in Listing 8.2 in Appendix D, by creating a thread for the method "listenToStream()", before continuing to start the thread and thereby running the method.
The method "listenToStream()" starts running and begins with setting a buffer size variable, as shown in Listing 8.3 in Appendix D. A TCP-Listener, called "listener" is then created, using an IP address from the method "getIP()" and port number

55200. The method "getIP()" grabs the IP address of the server this service is running on. Since the IP address of the server could be changed in the future, it has to be grabbed like this. Port 55200 is the port the positioning data is being forwarded to, from the Cisco MSE server. The TCP-Listener is then configured with "ReuseAddress", which allows the socket to be bound to an address that is already in use. This setting ensures that it is possible to listen on this port even if an other application already has it open. A TCP-client is created, which will be the client sending data to this server, in this case the Cisco MSE server. Finally the TCP-listener is started and the service is ready for incoming connections to the specified IP-address and port.

When the listener has started, it continues into an endless loop, as displayed in Listing 8.4 in Appendix D, because this service should always run. The loop starts by waiting for an incoming connection it can accept. Since the server the service is running on is in a restricted network, it is safe to allow all incoming connections.
When a connection has been established, the service continues to grab the TCP-stream the client is sending. A variable for a byte buffer is set using the buffer size variable set earlier. A string variable is used to store the incoming data after it has been encoded from the byte buffer. After reading the stream and encoding the bytes to a string, the service tries to process the data if any bytes has been received. Finally a try-catch statement checks the data for XML-files and saves them if they exist.

### 5.4.3 Issues During Implementation

During the development of this service multiple issues arose before reaching the final solution, and the main issues will be described here.

**Issues with URL**
First the MSE server was configured by HEMIT to forward the positioning data to the model server using an URL starting with "http://". The service on the model server on the other hand were expecting a TCP connection, and it only sent TCP-accept responses. This resulted in no data being sent to the model server, where the service was installed, because the MSE server never received the HTTP accept response. With no access to the MSE server, development was paused until HEMIT, the owner of the MSE server, found and corrected the error. The URL was then corrected to start with "tcp://", which enabled the two servers to connect, and data to be sent.

**Issues with speed**
By looking at the network traffic on the server, it was possible to see that the service did not receive and save all data that was being sent. The service spent too much time on processing the data, and were not always ready to receive when files were being sent to the server. The issue was resolved by simplifying the service, meaning less processing of the data.

## 5.5 Store Data to BIM Database

When starting with the development of the Windows service, the possibility of saving the positioning data to the database through the use of queries in the service was discussed. However, Jotne EPM Technology already had a procedure for importing XML files, which could easily be altered to fit the need. The importing of files runs continuously as a service, similar to the Windows service developed for retrieval of positioning data.

When the data is stored as objects in the database, the objects need to be connected to the building model it is located in. As the objects in this case are tags with a possibility to move between the different buildings at the hospital, it had to be possible for these objects to switch between which building models they belong to. This had not been done before, as all objects in building models like this usually are static and not moving around.

### 5.5.1 Tag Object

When a tag has been imported as an object to the database it comes with multiple attributes. More attributes can then be assigned to the tags, such as an identifier for the equipment they are mounted on.
The tags are saved as devices, with tracking records connected to each tag. Table 5.1 displays the most important attributes for the tags in this implementation, along with a description of each attribute.

| Attribute | Value | Description |
|---|---|---|
| **deviceId** | String | MAC-address. |
| **objectType** | String | Tracked device classification from Cisco MSE. |
| **IFCEntity** | String | Related IFC Object, the building the tag is located in. |
| **IFCGUID** | String | Unique identifier for the building the tag is located in. |
| **currentIFCInstanceId** | Integer | Unique identifier for the instance of IFCGUID the tag is located in. |
| **currentFloor** | Floor | Floor in the building the tag is located on. |
| **trackingHistory** | ListOfTrackRecords | List of all tracking records for a tag. |
| **lastTrackRecord** | TrackRecord | Last track record for a tag. |
| **batPercentRemaining** | Integer | Remaining battery percent on the tag. |
| **batDaysRemaining** | Integer | Remaining days of battery life on the tag. |
| **batAge** | Integer | Number of days since the tag battery has been changed |

Table 5.1: Attributes for a Tag object in the database.

### 5.5.2 Track Record

Each time a tag sends a beacon revealing its position, the tracking data is stored for each tag as a track record. The track records are added to a list for the appropriate tag, providing the opportunity to see where the tag has been located. The most important attributes in these track records are time, floor, longitude, and latitude, as displayed in Table 5.2. The time stamp provides information about when the tag sent its position. The floor attribute is linked to an entity called ”Floor”, which links the values of ”floorRefID” from the XML files, to the actual floors in the building models. Finally the latitude and longitude provides x and y coordinates for the tag.

| Attribute | Value | Description |
|---|---|---|
| **timeLocated** | timeStamp | Time of last beacon from tag. |
| **floor** | Floor | The floor the tag is located in, linking to a building. |
| **latitude** | Real | Latitude for the tag location in WGS 84 format. |
| **longitude** | Real | Longitude for the tag location in WGS 84 format. |

Table 5.2: Attributes for a Track Record in the database.

## 5.6 Visualization

The visualization of this implementation was first thought to be carried out in MSM, with the possibility to view the moving objects in both 3D and 2D. It turned out that it would be too time consuming to implement such a solution during the work on this thesis. Fortunately, Jotne EPM Technology had also been working on a web application, which could be utilized for this implementation.
The web application retrieves a map from kartverket.no and the buildings are placed on top of the map. The tracked objects can then be placed in this map on top of the building floors of the models. With this application users can easily search for equipment with a mounted tag, and locate its position at St. Olav's University Hospital.

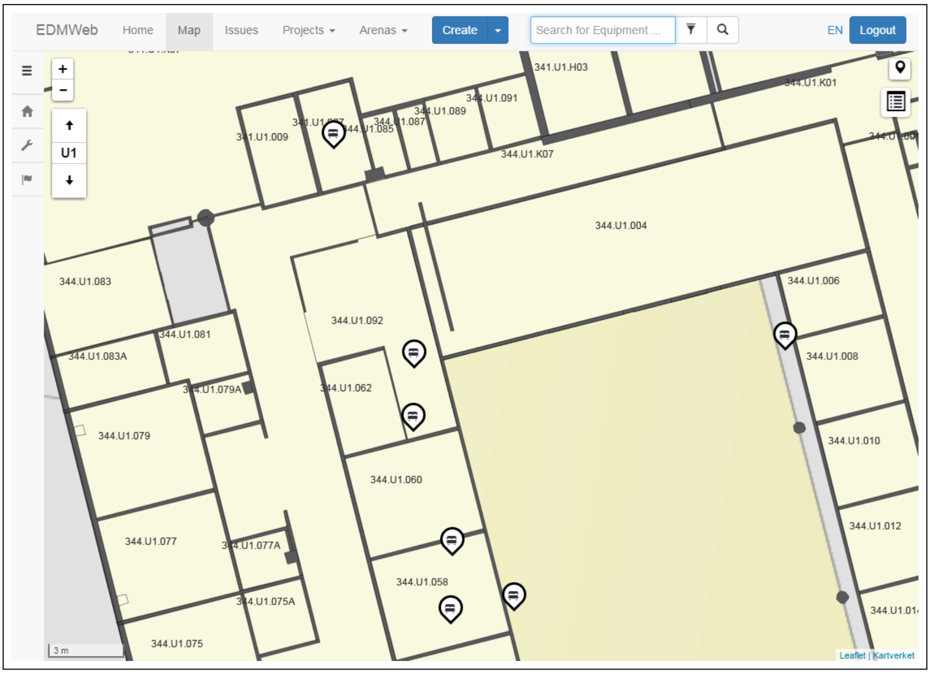


Figure 5.8: Visualization - Web Application

# Chapter 6

# Results from Evaluation

Unfortunately the web application developed by Jotne EPM Technology could not be completed in time for testing to be carried out during the work on this thesis. By the time it was decided to test the system ”as is”, most of the people who had agreed to participate in the testing had gone on vacation, with an exception of one person. The testing was initially planned to be carried out about a month earlier, but were delayed multiple times, as Jotne EPM Technology had not finished their web application. The testing was thus not carried out, but assumed outcomes will be presented here, before presenting the interview which was carried out as planned.

## 6.1 Survey

The testing and survey was meant to give an indication of whether the employees at the hospital could benefit from the use of an indoor positioning system. During the work on this thesis, I presented a temporary solution to the department manager at the Customer Service Center at St. Olav's University Hospital and other managers. I described how it could be used when development is completed, and they said that they would be the ones utilizing the system first. They would use the system to track objects that needs to be retrieved, and request employees to retrieve the equipment, such as beds and wheelchairs. By having discussed with the potential users, I hopefully have some understanding of their opinion and view of the new indoor positioning system.

The managers at St. Olav's University Hospital were eager to put the indoor positioning system into operation, and clearly talked about needs that the system could meet. First they wanted to track beds and wheelchairs, before continuing with mattresses at a later time. The survey would also have given an indication of whether the indoor positioning system with its web application on top is user friendly and easily comprehensible. When presenting an uncompleted solution to the managers, they seemed to easily understand how the system would be applied.

The web application displayed the hospital buildings on top of a normal map, with the tracked objects on top. The tracked objects were ten beds and ten wheelchairs mounted with Stanley Health Care T2s tags. The beds and wheelchairs had equal physical and virtual labels, such as "SE001", where "SE" indicated that it was a bed, and "001" indicated that it was bed number one. During testing the managers were supposed to be able to search for equipment, such as "SE005", bed number five. When finding the position of bed number five at the hospital, they would inform an employee who would retrieve the bed.

The graphical user interface of the web application mainly consisted of a map displaying the tracked objects, and a search bar with the possibility to search for tracked objects. Given that the development of the web application was completed, this simple interface would most likely have resulted in positive feedback regarding the usability of the system.

## 6.2 Interview

The interview was conducted at St. Olav Eiendom, where Bjørn Henning Hammer, Head of Customer Service Center at Service and Operations at St. Olav's University Hospital, was interviewed. The interview was held in Norwegian, but has been translated to English for this thesis. Hammer gave detailed insight into the employee's and administration's difficulties at the Hospital, in relation to the use of an indoor positioning system. In this section the contents of the interview is presented, while the complete interview can be found in Appendix C.

### 6.2.1 Utilizing the IPS

Hammer envisions that the employees first and foremost will utilize the indoor positioning system for tracking and retrieving equipment such as bed, wheelchairs, and mattresses. Because mattresses have an average lifespan of 5 years at the hospital, it is important to know how old they are, in order to know when to replace the mattresses.
Wheelchairs are used multiple times every day at the hospital, and they are usually left in hallways around the hospital. As of today there is no routine at the hospital for collection of wheelchairs, employees simply retrieve wheelchairs that have been used, when they see them. With an indoor positioning system it would be possible to establish a routine where wheelchairs could be retrieved and placed at the information desks at the entrances of the buildings. A routine such as this could be performed in the morning at 06.00 and again at noon, 12.00, to ensure the availability of wheelchairs throughout the day.

Hospital beds have a lifespan of 15 years as of today, which could probably be extended through the use of an indoor positioning system. A routine for maintenance and cleaning of beds should also be possible to implement when having information about the beds' locations, the time of their last maintenance, and the time since they were properly cleaned. A routine utilizing this information could ensure regular maintenance and clean beds, which would potentially extend the lifespan of the beds.

### 6.2.2 Improved Quality of Service

When asking the following questions about time saving at the hospital, Hammer spoke of a more important aspect of the matter:

*Do you think that this system will reduce the time it takes for your employees to perform tasks involving tracking of various types of equipment?*

Hammer informs that the hospital, as of today, does not have any procedures for retrieval of equipment. This makes it difficult to estimate time saved when utilizing the indoor positioning system. Hammer continues: "By making wheelchairs more accessible to patients, together with regular maintenance and cleaning of wheelchairs, it will lead to an improved quality of service for patients. And an improved quality of service is considered more important than any possible reduction in costs.

### 6.2.3 Further Development and Use

When asking if further development of this system could benefit his department in other ways than tracking of equipment, Hammer sees that there is a possibility for that, which would probably be easier to see when one has been using the system over a longer period of time.
At the end of the interview Hammer continues to inform that a system such as this, has been missed at the hospital, as many have the need for tracking of different kinds of equipment. He had recently visited a hospital in Sweden where they had a similar wish for an indoor positioning system. Some of the issues with procurement of such a system is the price of implementation and continuous license costs. It is therefore great that this system is being developed internally at St. Olav's University Hospital, providing its value in use, while not having to pay the marked price. Other than that he thinks that the system is brilliant in terms of costs, as the system utilizes the existing WiFi infrastructure at the hospital.

## 6.3 Accuracy

In this implementation, accuracy was tested with tags mounted at fixed positions at St. Olav's University Hospital. The tags' positions given by the indoor positioning system were compared against reference points of objects the tags were mounted on, or closest to, such as doors. A door's reference point might be up to 2 meters away from the mounted tags actual position, and unfortunately contributes to low accuracy in the measurements. Aside from this, the testing was primarily performed to ensure that the indoor positioning system was getting data from the tags.

Figure 8.1 displays results from two tests, where the euclidean distance between reference points and system position were measured. The formula below expresses how the calculations was performed.

$$d = \sqrt{(ReferencePoint_x - SystemPosition_x)^2 + (ReferencePoint_y - SystemPosition_y)^2}$$

By looking at the distances between the reference points and the values given by the system in Figure 8.1, we can see that values are between 4-10 meters. These values are as expected, considering the approximately up to 2 meter inaccuracy in the reference points. And when considering that the required accuracy in a recent pilot project for indoor positioning at St. Olav's University Hospital were 5 to 10 meters deviation, these measurements are as they should be. The measurements are actually within the same accuracy as Mazemaps measurements at the campus of NTNU [18].

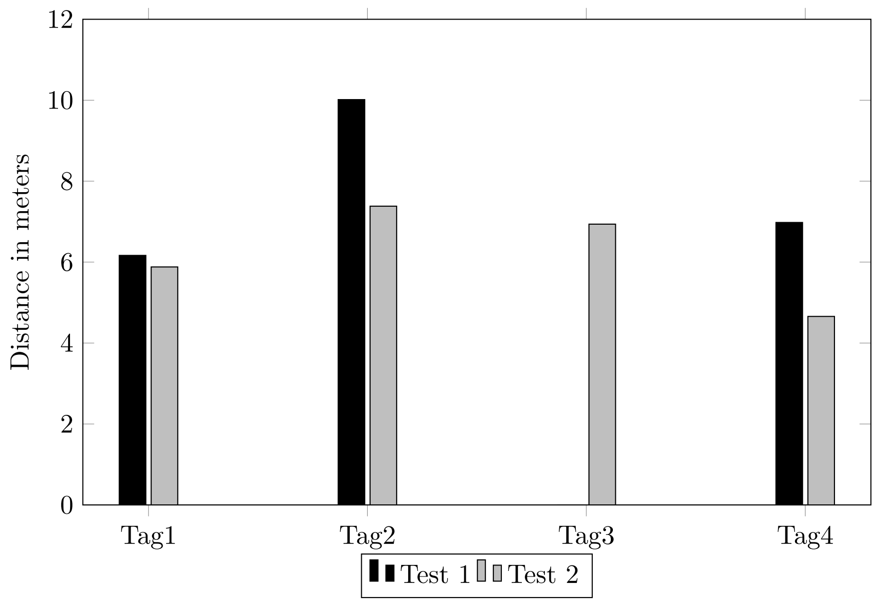


Figure 6.1: Distance between reference point position and system position.

# Chapter 7

# Discussion

Because the planned testing and survey was not carried out, the interview with Hammer, Head of Customer Service Center, will be discussed combined with a general discussion of the introduction of an indoor positioning system at the St. Olav's University Hospital.

## 7.1 Validity of Results

The validity of results from the survey are not great, as the testing and survey was never carried out. While having discussed with the potential users, one could say that less data, but more qualitative data has been collected. Combined with the interview of Head of Customer Service Center, the data can be considered as good qualitative data.

## 7.2 Costs

The reduction in costs at the hospital was an important topic in the interview with Hammer, Head Of Customer Service Center. Although all costs should be considered in an organization such as a hospital, it became clear that the patients' experienced quality of service is considered more important than any possible reduction in costs. Even so, Hammer saw potentials for lowering costs at the hospital when utilizing an indoor positioning system. He focused on how regular maintenance of equipment could extend the life spans of equipment. As of today, departments at the hospital also need to have redundant equipment, because they lose track of it and do not have time to search for it. Regular maintenance combined with more efficient utilization of equipment would surely lower some costs at the hospital. They could buy lower amounts of equipment, and the equipment could potentially last longer with regular maintenance.

## 7.3 Efficiency

Tracking of equipment at the hospital, would most likely lead to better efficiency, as the employees spend less time looking for equipment. Knowing how much better efficiency and saved time an indoor positioning system could provide, would possibly be more interesting. Unfortunately they do not as of today have any routines at St. Olav's University Hospital for regular retrieval of equipment. It was therefore not possible to compare time spent on retrieval of equipment earlier compared with retrieval using the new indoor positioning system.

## 7.4 Privacy

When tracking equipment and possibly people, it is only natural that some will be skeptical and afraid of invasion of their privacy. Even in this project an employee at St. Olav's University Hospital dismounted an RTLS tag from a bike he was using, as he did not wish to be tracked. The tag was merely mounted on the bike in order to receive a larger amount of data, as a bike travels greater distances at the hospital than many other types of equipment. However, for this employee, it might have felt like an invasion of privacy, which can be understandable. At the hospital everything is centered around the patients, making even the tracking of such as beds and wheelchairs a topic of privacy. It is therefore important to always consider the privacy of people when developing a system which could potentially be used to track individuals. Privacy could be regarded as the greatest obstacle when developing an indoor positioning system, and should therefore be taken into deep consideration.

## 7.5 Accuracy

The accuracy results in Section 6.3 describes an accuracy within 4 to 10 meters, which was to be expected when using the same network and location engine as Mazemap. The accuracy of this implementation is thus not better than MazeMap's implementation at St. Olav's University Hospital. The testing was merely performed to ensure that the data received directly from the Cisco MSE location engine would be sufficient for the implementation. For this solution, as any other, there will still be inaccurate data, depending on density and placement of WiFi access points, as well as the building's structure and materials.

The improvement of accuracy in indoor positioning can first be carried out when the system is implemented. Then it could be possible to experiment with utilization of the static building structure and BIM, in order to calibrate the indoor positioning system. The improvement of accuracy is further elaborated on in Section 8.2.1.

# Chapter 8

# Conclusion and Future Work

In this chapter the research questions are assessed in relation to the results, before stating a conclusion and identifying the future work.

## 8.1 Conclusion

This research has investigated which potentials the use of asset tags, location-based services and BIM holds for the future of hospitals and other large buildings. In order to answer the research question, the following questions were applied to guide the research:

1. Is it possible to combine indoor positioning services with an EBIM and present it in a clear and comprehensible way?
   (a) Will users, such as porters and maintenance workers, find it useful?
   (b) Will administration find it useful?
2. Will utilization of the indoor positioning system help to reduce the hospital costs?
   (a) Which costs could be reduced?
   (b) How much could the costs be reduced?

The first questions, 1(a) and 1(b), were thought out to be answered through user testing and the survey in Appendix B. Unfortunately this could not be carried out, as mentioned in Chapter 6. Having discussed with managers in the administration at the hospital, it is safe to say that they found the indoor positioning system useful, at least the idea of it. This would thus most likely be the case for other users as well, such as hospital porters and maintenance workers.

Looking at questions 2(a) and 2(b), the potential areas of reduction in costs at the hospital were identified through the interview with Hammer, Head of Customer

Service Center. Regular maintenance and more efficient utilization of equipment could reduce the costs of procurement of equipment. Unfortunately it was not possible to get detailed information about how much the costs could be reduced.

About a year ago, I had little to no knowledge about BIM and indoor positioning systems. This project and the work on this thesis has provided me with great insight into the core business at the hospital, BIM, and positioning systems. The opportunities an indoor positioning system provides for organizations such as St. Olav's University Hospital seems to be immense. Some of the possible opportunities are described in Section 8.2, while others will probably be revealed during the use and future development of the indoor positioning system.

## 8.2 Future Work

This section describes how this indoor positioning system could be utilized in the future, given the necessary development. Improvement of accuracy is first presented as an important topic, because it could possibly be greatly improved upon. Visualizing the data in different ways could give new meaning to data, and future possibilities are presented. Continuing, the use of call buttons for maintenance and a new classification system for moving objects are described. Finally the use of an indoor positioning system in case of emergency situations, and theft of equipment are presented.

### 8.2.1 Accuracy

In any positioning system, the accuracy is an important factor in determining if the system is good, or how good the system is. Ideally, an indoor positioning system should be able to have such an accuracy that it provides enough information to find a pair of scissors on a desk. This would require an accuracy of under 1 meter deviation. Some testing of accuracy was performed during the work on this thesis, the results however will mostly be used as an example to explain how the accuracy can be improved upon in the future. Calibration and accuracy of map reference points will be of high importance when attempting to improve the accuracy of the positioning, as well as placement and positioning of Wi-Fi access points.

#### Calibration Using Static Building Structure

The structure of the buildings affects the WiFi signal strength and can result in further inaccuracy when tracking tags indoors. Because the building is a static structure and having the positioning data connected to the BIM, it could be possible to calibrate the indoor positioning system. You could stand in a corridor with your smart phone and open the indoor positioning web application. In this application you could mark your actual position, click on a "calibrate" button, and the position given by the system would then be saved together with the actual position.

### Access Points

For the triangulation, the access points have to be added to floor maps in Cisco Prime, a software used together with Cisco MSE appliances. When adding access points to the floor maps, they are used as reference points for the triangulation. This means that any difference in the placement of access points on the floor maps, compared to the actual placements of the access points will influence the final position of the tag being tracked by the system. Improving the accuracy of the placements of the access points in Cisco Prime at St. Olav's University Hospital would therefore improve the accuracy of the indoor positioning system.

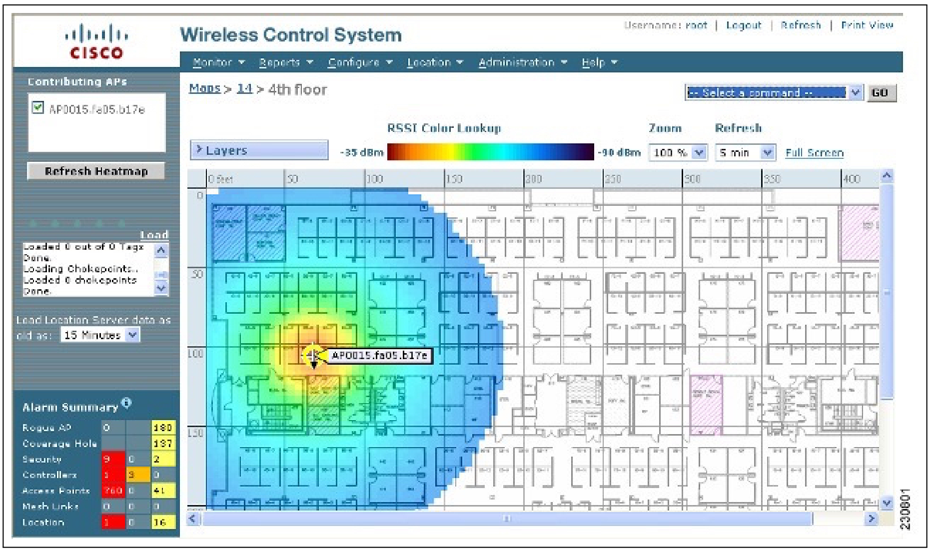


Figure 8.1: Example of access point placed onto a floor map in Cisco Prime [27].

In addition to the access points having equal positions both virtually in Cisco Prime and physically at the hospital, there are more improvements that could be carried out to improve accuracy when considering access points. Looking back at Section 2.10.1, where the importance of placement of access points are described, Figure 2.7 clearly displays how access points should be placed and not placed. During the work on this thesis, I have walked through a large portion of the corridors and rooms at the hospital, where unfortunately all access points I saw have been placed as displayed in the lower right hand side of Figure 2.7. All the access points have been mounted in a straight line in the middle of the corridors, making it harder to triangulate a position for objects being tracked.

### 8.2.2 Visualization

Presenting positioning data on a two-dimensional map is sufficient for certain tasks, making it possible to find an object inside a building. Other ways of presenting positioning data could give new meaning to data and give new insight to the information collected by an indoor positioning system. If we choose to track all devices connected to the WiFi network at St. Olav's University Hospital, patterns of peoples' movement will start to emerge. In order to see these patterns, we would most likely need to present the data in another way than two dimensional maps. Although it could be interesting to view the traffic on one floor of one or more buildings in a two dimensional map, it could be even more interesting to include all floors in all buildings at the hospital. This could be done using BIM with transparent walls and floors, leaving the traffic pattern of peoples movement in focus.

Dominique Brodbeck presented in a TED talk a software called xPlan, developed in order to present and analyze patient flow at the University Hospital in Bern, Switzerland. As displayed in Figure 8.3, patient transfers from the emergency department are presented. With this software it is possible to select departments and underlying departments in order to analyze the flow to and from the departments. This representation of patient flows provides a comprehensible way of looking at the data, giving an opportunity to plan construction of new buildings or remodeling of old building according to the patient flows.

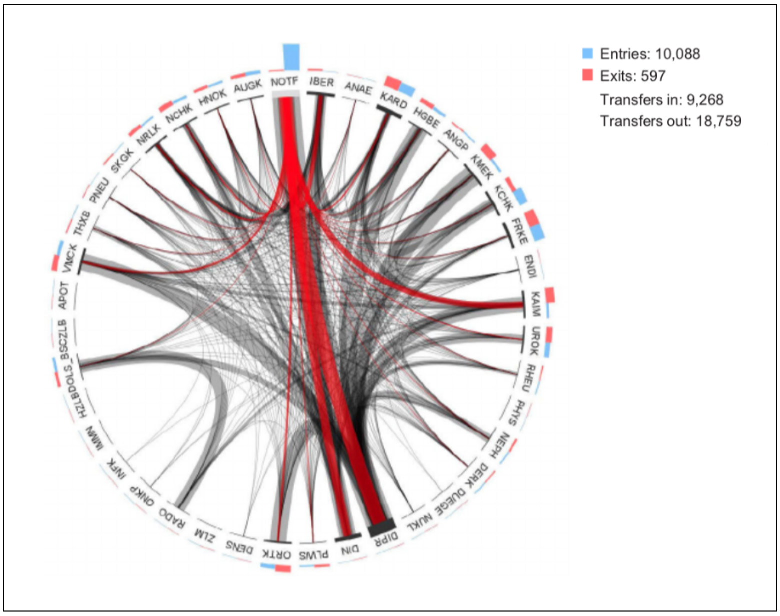


Figure 8.2: Organizational map of the patient flow analysis with a focus on the emergency department at the University Hospital in Bern [28].

The representation of data in this software, or a similar representation could be created and utilized to present the indoor positioning data at St. Olav's University Hospital. It could present the patient flow clearly for administrators, with a possibility to drill down or aggregate the data. The granularity of the data would depend on beacon intervals on the applied RTLS tags, and how well the departments and underlying departments at the hospital are defined.

### 8.2.3 Maintenance

Maintenance professionals working at places such as St. Olav's University Hospital, with its approximately 350.000 square meters, encounter many challenges, as it can be difficult to find the equipment that is in need of repair. It is safe to say that an indoor positioning system could be greatly beneficial when trying to locate damaged equipment. In addition it could actually reduce the time employees spend reporting the damaged equipment.

Equipment fitted with RTLS tags could utilize a button, such as the button on the Stanley Health Care T2s tag. When an employee at the hospital notice damaged equipment, this button could be pressed. Depending on how the employee presses the button, different messages could be transmitted to the indoor positioning system. A single button click with a duration of more than three seconds could indicate that the equipment is damaged and in need of repair. While two button clicks within a time frame of three seconds, could indicate that the equipment is damaged and is in need of urgent repair. How the button is pressed would thus indicate which message the tag should send. These messages needs to be decoded and are described in Appendix E.

### 8.2.4 TFMD

The data for moving objects is stored in the same database as static building objects, and it is possible to use existing methods for such as traversing through the data, and searching for objects. All static objects in a regular BIM at St Olavs University Hospital are categorized by a Norwegian standard "Tverrfaglig merkesystem" (TFM), which translates into "interdisciplinary marking system". The TFM standard could be used as a basis for a new standard classification system for moving objects. In contrast to static building objects classified by TFM, moving objects could be classified by a new classification system, TFMD, where "D" stands for dynamic. The moving objects' locations are dynamic, as they move around the buildings, and their location would have to be updated dynamically. An example of a moving object classified using TFMD is described here, similar to the example of TFM presented in Section 2.4.

Example TFMD label:
+042201=210.00-DY001

- +042201 - The first part of the label would still describe the location of the object. This part of the label would be dynamic, as moving objects should be able to transfer between rooms, floors and buildings. The values described here are thus equal to the ones in the example in Section 2.4.
  - 042 - Building number 042, which is the ”Kunnskapssenteret” building.
  - 2 - Wing number 2 in ”Kunnskapssenteret”.
  - 01 - Floor number 01 in ”Kunnskapssenteret”.
- =210.00 - The second part of the label could indicate whether the object is a person, or which department the object is connected to. The example below illustrates an example of numbers and corresponding departments.
  - 200 - People.
  - 300 - Core business, including such as cleaning carts.
  - 400 - Maintenance equipment.
  - 500 - Medical equipment.
  - 700 - External equipment.
- DY001 - The third and last part of the label would still describe what kind of object it is and what serial number the object has. DY could represent a type of person, such as a patient group or type of employee. Below is an example of what DY001 could represent.
  - DY - Doctor.
  - 001 - Serial number.

A classification system such as this could possibly make it easier to keep track of all moving objects at the hospital. Objects could have defined owners, and read/write access to the different objects could easily be controlled by administrators to avoid people abusing the system.

### 8.2.5 Emergency Situations

With an indoor positioning system, it could be possible for firemen or similar personnel to track people carrying devices connected to the WiFi network inside buildings in emergency situations. In case of fire, it could be greatly beneficial for firemen to know where people are located, or in which direction they have moved since the fire started. From this data they could possibly get more information about where the fire is spreading, and where they should search for people that needs to be rescued.

During a breach at the hospital resulting in a biological hazard, it could be possible to track the hazardous object or patient, giving the opportunity to delineate and lock down the contaminated areas. These are examples of how an indoor positioning system could possibly be utilized to save lives.

### 8.2.6 Theft of Equipment

Hospitals and other large organizations often have some more expensive equipment, which has a higher risk of being stolen. In addition to the normal RTLS tags for an indoor positioning system, expensive equipment could be mounted with GPS receivers communicating over 4G with a server connected to the indoor positioning system. When a thief then steals the equipment the GPS receiver could, by a set interval, transmit the position of the equipment even when it is not located at the hospital. When the equipments position then is updated with a location outside the hospital, an alarm could go of at the workstation of administrators of the indoor positioning system. They could contact the police and provide directions to the stolen equipment.

### 8.2.7 Wayfinding

When employing new hospital porters and maintenance professionals at the hospital, it might still be hard to navigate when utilizing the indoor positioning system, as St. Olav's University Hospital has 350.000 square meters of space. Incorporation of a wayfinding feature could extend the usability of the indoor positioning system, making it even easier for employees to find equipment at the hospital.

When "drawing lines" in a BIM model for wayfinding, it also opens a possibility for more accurate tracking histories. When the lines for wayfinding have to be drawn through doors and hallways in the models, not just across the models, the distance traveled by a tracked object could easily be estimated more accurately. The level of accuracy when tracking patient flows could be improved by the use of such wayfinding methods. Maintenance of AGV's could also be performed when they have traveled a certain distance, to extend the AGV's life spans, when using wayfinding methods.

# Appendix A

**Prepare tags for deployment**

1. Connect power to the tag activator.
2. Connect the tag activator to computer using the network cable.
3. Configure the local network connection on the computer to use an IP-address in the range 192.168.1.*, Subnet Mask 255.255.255.0, and leave Standard gateway and DNS server empty.
4. Locate and start the Tag Manager software on the computer.
5. Select connection type ”Wireless”.
6. Place the tags near the activator and click ”Detect Tags” in the Tag Manager.
7. Select the tags you wish to configure/active and select ”Configure” in the left pane.
8. Under ”General” the settings should be set to the following:
   (a) Channel selection should be set to only 1, 6, and 11.
   (b) Transmission interval should stay on ”Normal”, and a transmission interval has to be set. The transmission interval will depend on what kind of equipment the tag will be placed on.
9. Under ”Select Configurations to Apply”, select ”General” and ”Activate”, before clicking ”Apply”.
10. Mount the tag on equipment and deploy for use.

# Appendix B

Survey in Norwegian.

# Spørreskjema for innendørs posisjonerings system

I dette skjemaet presenteres først noen generelle spørsmål om brukeren.
Deretter presenteres flere utsagn om systemet for innendørs posisjonering.
For hvert utsagn svarer man hvor enig man er på en skala fra 1 til 5, hvor 1 betyr "Veldig uenig" og 5 betyr "Veldig enig".

Eventuelle spørsmål kan rettes til erlendoa@stud.ntnu.no

*Må fylles ut

1. **Kjønn** *
   *Merk av for alt som passer*
   - [ ] Mann
   - [ ] Kvinne
2. **Alder** *
   *Markér bare én oval.*
   - ( ) 18 - 30
   - ( ) 30 - 40
   - ( ) 40 - 50
   - ( ) 50 - 60
   - ( ) 60+
3. **Hva arbeider du som/med?** *
   *Markér bare én oval.*
   - ( ) Portør
   - ( ) Vedlikehold
   - ( ) Andre: ..........
4. **Kunne du tenkt deg å et slik system tilgjengelig på smart telefon til en hver tid?** *
   *Markér bare én oval.*
   - ( ) Ja
   - ( ) Nei
   - ( ) Andre: ..........

# Utsagn om systemet

5. **Jeg kunne tenke meg å bruke systemet til aktuelle arbeidsoppgaver.** *
*Markér bare én oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Veldig uenig | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | Veldig enig |

6. **Jeg synes systemet var unødvendig komplisert.** *
*Markér bare én oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Veldig uenig | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | Veldig enig |

7. **Jeg synes systemet var lett å bruke.** *
*Markér bare én oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Veldig uenig | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | Veldig enig |

8. **Jeg tror jeg vil måtte trenge hjelp fra en person med teknisk kunnskap for å kunne bruke dette systemet.** *
*Markér bare én oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Veldig uenig | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | Veldig enig |

9. **Jeg syntes at de forskjellige delene av systemet hang godt sammen.** *
*Markér bare én oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Veldig uenig | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | Veldig enig |

10. **Jeg syntes systemet virket ulogisk.** *
*Markér bare én oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Veldig uenig | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | Veldig enig |

11. **Jeg vil anta at folk flest kan lære seg dette systemet veldig raskt.** *
*Markér bare én oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Veldig uenig | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | Veldig enig |

12. **Jeg synes systemet var veldig vanskelig å bruke.** *
*Markér bare én oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Veldig uenig | ◯ | ◯ | ◯ | ◯ | ◯ | Veldig enig |

13. **Jeg følte meg sikker da jeg brukte systemet.** *
*Markér bare én oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Veldig uenig | ◯ | ◯ | ◯ | ◯ | ◯ | Veldig enig |

14. **Jeg trenger å lære meg mye før jeg kan komme i gang med å bruke dette systemet på egen hånd.** *
*Markér bare én oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Veldig uenig | ◯ | ◯ | ◯ | ◯ | ◯ | Veldig enig |

15. **Har du noen andre kommentarer til systemet? Eventuelle forbedringer?**

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# Appendix C

Interview with Bjørn Henning Hammer, Head of Customer Service Center at Service and Operations, at St. Olav's University Hospital.

- How long have you worked (as department manager) at St. Olav's University Hospital?

  **Answer:**

  I have worked as department manager at St. Olav's University Hospital for 7 months.

- How do you envision your employees utilizing the indoor positioning system?

  **Answer:**

  Employees first and foremost have a need to track beds, wheelchairs, and mattresses. Mattresses has an approximate lifespan of 5 years, and this system can help us to know how old a bed is, so that we know when it should be disposed. The wheelchairs needs to be tracked daily, as they move around a lot, and needs to be available for new patients. Beds has of today an approximate lifespan of 15 years, which might be possible to extend, given the opportunity to perform maintenance and cleaning regularly.

- How often do employees perform task that requires locating equipment, such as beds, wheelchairs, and other medical equipment?

  **Answer:**

  Hospital porters and security staff daily performs tasks with a need of such a system. Wheelchairs should be retrieved, collected and placed at building entrances at least two times in day for the wheelchairs to be ready for new patients.

- Do you think that this system will reduce the time it takes for your employees to perform tasks involving tracking of various types of equipment?

  **Answer:**

  As of today the hospital has no procedures for retrieval of wheelchairs, employees grabs wheelchairs that are not in use when they see them, and place them at the building entrances. By making wheelchairs more accessible to patients, together with regular maintenance and cleaning of wheelchairs, it will lead to an improved quality of service for patients. And an improved quality of service for the patients is considered more important than any possible reduction in costs.

- If it is possible to save time by utilizing this system, thereby also reducing costs, what could a rough estimate of reduced cost be?

  **Answer:**

  The hospital will be able to save money by utilizing the system for tracking of beds that has a need of maintenance. This system will be able to contribute to frequent maintenance and cleaning of beds, which can lead to longer lifespans for the beds.

- Do you think an indoor positioning system could lead to more optimized use of equipment? And would that lower the need for the amount of equipment?

  **Answer:**

  Absolutely.

- Do you think further development of this system could benefit your department in other ways than tracking of equipment?

  **Answer:**

  There is a possibility for that, and it will probably be easier to see when one has been using the system over a longer period of time.

- Do you have any other comments regarding indoor positioning at the hospital?

  **Answer:**

  A system such as this has been missed at the hospital, as many have the need for tracking of different kinds of equipment. I have recently visited a hospital in Sweden, where they had a similar wish for an indoor positioning system. Some of the issues with procurement of such a system is the price of implementation, and continuous license costs. It is therefore great that this system is being developed internally at St. Olav's University Hospital, giving us its value in use, and not having to pay the marked price. Other than that, the system is brilliant in terms of costs, as the system uses the existing infrastructure (WiFi).

# Appendix D - Code Snippets

```
public static XmlDocument RequestXml()
{
   try
   {
      //Set user name and password variables.
      String username = "learning";
      String password = "learning";
      //Encode user name and password using base64 encoding.
      String encoded = System.Convert.ToBase64String(System.Text.Encoding.GetEncoding
           ("ISO-8859-1").GetBytes(username + ":" + password));
      //Create a HTTP request, based on which data one wish to retrieve.
      HttpWebRequest request = WebRequest.Create("https://64.103.26.61:443/api/
           contextaware/v1/location/clients") as HttpWebRequest;

      //Use the encoded user name and password when creating the HTTP header.
      request.Headers.Add(HttpRequestHeader.Authorization, "Basic " + encoded);
      //Set option to validate server certificate.
      request.ServerCertificateValidationCallback += (sender, cert, chain,
           sslPolicyErrors) => true;
      //Load the HTTP response into a variable.
      HttpWebResponse response = request.GetResponse() as HttpWebResponse;

      //Create an XML document where the data can be saved.
      XmlDocument xmlDoc = new XmlDocument();
      //Save the data to the XML document.
      xmlDoc.Load(response.GetResponseStream());

      //Return the data as XML document.
      return (xmlDoc);
   }
```

Listing 8.1: Method for Cisco MSE REST API request

```
   //Method that runs when the service receives a "start" command.
   protected override void OnStart(string[] args)
   {
      //A thread is created and started, running the method "listenToStream()".
      System.Threading.Thread t = new System.Threading.Thread(listenToStream);
      t.Start();
   }
```

Listing 8.2: Service start

```
public static void listenToStream()
{
   //A buffer is set for the data comming through the TCP-stream.
   int BufferSize = 10000;
   //A TcpListener listening to IP of server this service is running on.
   //The port has been set to 55200, which MSE is sending to.
   TcpListener listener = new TcpListener(IPAddress.Parse(Program.getIP()), 55200);
   //"ReuseAddress" ensures that the possibility to listen to a port even if another
        application already has it open.
   listener.Server.SetSocketOption(SocketOptionLevel.Socket, SocketOptionName.
        ReuseAddress, true);
   //Variable for the client sending data.
   TcpClient client;
   //Service start listening for incoming connections to the IP and port specified
        for the TcpListener.
   listener.Start();
```

Listing 8.3: listenToStream() part 1

```
while (true)
{
   //Accept any client trying to send data.
   client = listener.AcceptTcpClient();
   //Grab the clients stream.
   NetworkStream tcpStream = client.GetStream();
   //Set a byte buffer for the incomming data.
   byte[] buffer = new byte[BufferSize];
   //String variable to save converted data.
   string message = "";
   //Count the number of bytes received.
   int bytesReceived;

   //Get and convert the incoming data.
   do
   {
      bytesReceived = tcpStream.Read(buffer, 0, client.ReceiveBufferSize);
      message += Encoding.ASCII.GetString(buffer, 0, bytesReceived);
   }
   while (bytesReceived > 0);

   //Try to process the data
   try {
```

Listing 8.4: listenToStream() part 2

# Appendix E - Additional Features

Through the work on this thesis and development of the Windows service, multiple features were created and tested. The features described here were not part of the final implementation, as the service had to be simple in order to work efficiently enough in order to process all the data in time. Some features are still relevant to the system, as they can be applied elsewhere in the solution, and will thus be explained here.

**Converting Coordinates**
The positioning data for tracked equipment are given in GPS (WGS 84) coordinates. These coordinates have to be converted in order to place the equipment in a BIM model. The conversion was carried out in these two steps:

1. Convert GPS (WGS 84) coordinates to NTM zone 10 coordinates.
2. Convert NTM zone 10 coordinates to local BIM coordinates.

Listing 8.5 displays the code for the main conversion method. That method converts the coordinates using two other methods, displayed in Listing 8.6 and Listing 8.8, and saved to the XML-files.

```
//Converts GPS (WGS 84) coordinates to local BIM coordinates.
public static void processCoordinates(string file)
{
   try
   {
      //Load the XML from a file and select the nodes for coordinates.
      XmlDocument xml = new XmlDocument();
      xml.Load(file);
      XmlNodeList xnl = xml.SelectNodes("/StreamingNotification/TagLocation/
           GeoCoordinate");

      //Loop through the nodes and replace coordinates with BIM coordinates.
      foreach (XmlNode xn in xnl)
      {
         double GeoLat = double.Parse(xn.Attributes["lattitude"].Value, System.
              Globalization.CultureInfo.InvariantCulture);
         double GeoLong = double.Parse(xn.Attributes["longitude"].Value, System.
              Globalization.CultureInfo.InvariantCulture);

         xn.Attributes["lattitude"].Value = Convert.ToString(ntmToBim(degreesToNtm(
              new Point2D(GeoLong, GeoLat))).y);

         xn.Attributes["longitude"].Value = Convert.ToString(ntmToBim(degreesToNtm(
              new Point2D(GeoLong, GeoLat))).x);
      }
      //Delete the old file, and save the new file with updated coordinates
      File.Delete(file);
      xml.Save(file);
   }
```

Listing 8.5: Conversion of coordinates

Listing number 8.6 displays how GPS coordinates are converted to NTM zone 10 coordinates. A coordinate pair is created as an object of "Point2D". The x coordinate in WGS 84 format is converted using interpolation between longitude 63°and 64°. Interpolation between latitude 9°and 10°was performed to convert the y coordinate, before returning the coordinates in NTM zone 10 format.
In the interpolation method it was also used a constant for the length of a degree, which was calculated for the relevant degrees. The values for the WGS 84 degrees in NTM zone 10 format was narrow down to create a smaller box, in order for the interpolation method to give more exact values.

```
//Converts coordinates from WGS84 to NTM zone 10
public static Point2D degreesToNtm(Point2D degrees)
{
   try
   {
      Point2D coordinates = new Point2D(degrees.x, degrees.y);

      //Interpolate between Longtitude 63 and 64, and convert x coordinate to NTM
           zone 10
      coordinates.x = Point2D.Lerp(ntmEastingsOffset - Point2D.Lerp(
           lengthOfADegreeOfLatitude63, lengthOfADegreeOfLatitude64, degrees.y -
           latitudeLowerBound) / 2.0, ntmEastingsOffset + Point2D.Lerp(
           lengthOfADegreeOfLatitude63, lengthOfADegreeOfLatitude64, degrees.y -
           latitudeLowerBound) / 2.0, degrees.x - longitudeLowerBound);

      //Interpolate between Longtitude 63 and 64, and convert y coordinate to NTM
           zone 10
      coordinates.y = Point2D.Lerp(ntmNorthingsOffset + ntmNorthingsFor63DegreesNorth
           , ntmNorthingsOffset + ntmNorthingsFor64DegreesNorth, degrees.y -
           latitudeLowerBound);

      return coordinates;
   }
```

Listing 8.6: Conversion from WGS84 to NTM zone 10.

A class was made for the coordinates together with a method for interpolation, displayed in Listing number 7.

```
//Class for coordinates
public class Point2D : object
{
   public double x, y;
   public Point2D(double x, double y)
   {
      this.x = x;
      this.y = y;
   }

   //Interpolation Method
   public static double Lerp(double a, double b, double w)
   {
      return (1.0 - w) * a + w * b;
   }
}
```

Listing 8.7: Class for coordinates and Interpolation method.

During the development there were inconsistencies in the buildings NTM zone 10 reference points at St. Olav's University Hospital. This issue was fixed by setting a common reference point in NTM zone 10 for all buildings at the hospital. Listing number 8 shows the simple conversion of coordinates from NTM zone 10 to BIM coordinates. The reference point is subtracted from the coordinate, before converting them from meters to millimeters.

```
//Converts coordinates from NTM zone 10 to local BIM coordinates
public static Point2D ntmToBim(Point2D ntmCoordinates)
{
   try
   {
      //Subtract reference coordinates for St. Olav's University Hospital
      ntmCoordinates.x -= 94100;
      ntmCoordinates.y -= 1603600;
      //Convert from meters to millimeters
      ntmCoordinates.x = ntmCoordinates.x * 1000;
      ntmCoordinates.y = ntmCoordinates.y * 1000;

      return ntmCoordinates;
   }
```

Listing 8.8: Method for conversion from NTM10 to local BIM

In order to a better understand the coordinates, Figure 5.11 displays the reference point and a example object position at the hospital. The object position in local BIM coordinates is converted from NTM zone 10 coordinates for x and y as follows:

$$x = (\textit{Object Position Easting - Reference Point Easting}) \times \textit{1000}$$

$$y = (\textit{Object Position Northing - Reference Point Northing}) \times \textit{1000}$$

Finally the objects local BIM coordinates (x, y) needs to be placed on a floor in a building at the hospital. Each floor has a reference point, based on the reference point for the whole hospital. The floor reference point have to be subtracted from the object's local BIM coordinates, in order to place the object in a specific floor of a building.

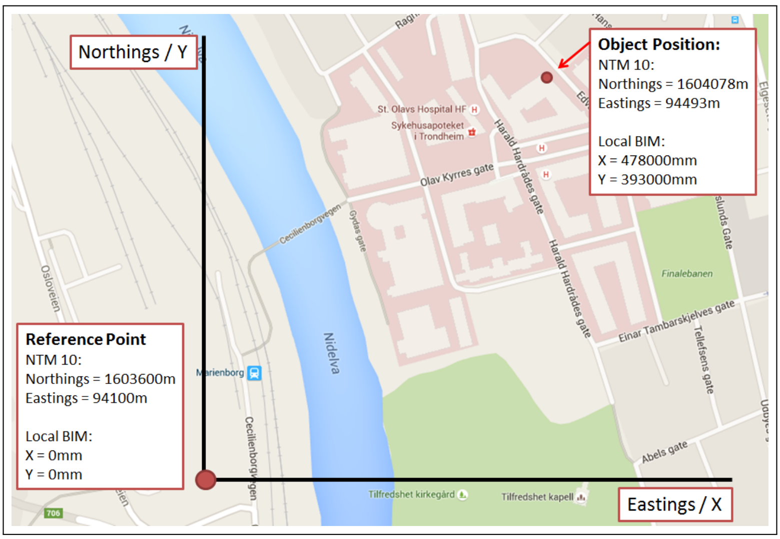


Figure 8.3: Example of local BIM coordinates.

### Decoding Messages

The Stanley Health Care T2s tags have an option for messages to be assigned to them, thus messages was considered to be used in the implementation. The method in Listing 8.9 starts by loading an XML document from a file. The nodes containing messages are then selected before looping through the nodes in the XML document. When a node containing a message is reached, the message is converted and saved to the XML document. In this example the ten first characters in the message was removed, which seemed to be appropriate for messages of five characters. In other words, ten characters were added during the encoding, when initially configuring a tag with a five character long message.

As mentioned in Section 5.3, messages are being encoded in base64 encoding, with some added characters. The number of added characters seems to differ, depending on the length of the message. And because of uncertainties in how the messages are encoded, it was decided that it should not be included in this implementation. However, the messages could be used in a future implementation, when the encoding has been properly defined. Thus a method for the conversion of messages was explained here, and displayed in Listing 8.9.

```
//This method decodes the messages on the tags.
public static void decodeMessages(string file, string output)
{
   try
   {
      //Create an XML document and load a file into it.
      XmlDocument xml = new XmlDocument();
      xml.Load(file);
      //Select the nodes in the XML where the messages are being stored.
      XmlNodeList xnl = xml.SelectNodes("/StreamingNotification/TagLocation/
           VendorData");

      //Loops through all messages and decodes them.
      foreach (XmlNode xn in xnl)
      {
         //Decode the message.
         byte[] encodedMessage = Convert.FromBase64String(xn.Attributes["data"].Value
              );
         string decodedMessage = Encoding.UTF8.GetString(encodedMessage);

         //Remove an appropriate amount of characters.
         string cleanstring = decodedMessage.Remove(0, 10);

         //Save the converted message to XML document.
         xn.Attributes["data"].Value = cleanstring;
      }
      //Save the XML document as a file.
      xml.Save(output);
   }
```

Listing 8.9: Method for decoding of messages

# Appendix F

The source code for the developed Windows service was delivered as a compressed folder, "Code - Master Thesis (Erlend Øgård Aksnes)", together with this thesis.

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