Can Surface Scanning Improve the Workflow of Elekta Linac Treatments?

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Can Surface Scanning Improve the Workflow of Elekta Linac Treatments?

Kan ytskanning förbättra arbetsflödet för behandlingar med Elekta Linac?

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Abstract

The aim of the project was to compare the workflow for an Elekta Linac with and without the surface scanning system Catalyst and describe pros and cons with both workflows. The findings in the report can be used as decision support in development of Elekta products and workflow improvements.

The method for the project was to do interviews, observations and time measurements at Södersjukhuset (not using Catalyst) and Sundsvalls sjukhus (using Catalyst). The workflows were graded in an assessment protocol covering time efficiency, comfort, noise, resources, reliability, cost, dosage and side effects. Different workflow scenarios were simulated in AnyLogic.

The result of the project was that, according to our protocol, the workflow with Catalyst was rated higher than without it. The simulations in AnyLogic showed that minimizing gaps in the treatment schedule generated the same number of patients treated per day, if the positioning could not be done faster. The simulations also showed that removing position verification with cone beam computer tomography (CBCT), an imaging system which is used in addition to the Catalyst system, would increase the number of treated patients with approximately 33%.

The conclusion was that there were no great differences in time efficiency between the workflows. However, considering the higher reliability and comfort for the patient, optical surface scanning can improve the positioning for Elekta Linac and is therefore worth implementing. Minimizing treatment gaps would not improve the workflow. Removing the use of CBCT would increase the number of treated patients per day.

Keywords: Elekta Linac, Elekta VersaHD, Elekta Infinity, C-RAD, Catalyst, radiotherapy, surface scanning, workflow analysis
Sammanfattning

Målet med projektet var att jämföra arbetsflödet för en Elekta Linac med och utan ytskanningssystemet Catalyst och att beskriva för- och nackdelar med respektive flöde. Upptäckterna i rapporten kan användas som beslutsstöd i framtida utveckling av Elektaprodukter och arbetsflödesförbättringar.

Metoden för projektet var att göra intervjuer, observationer och tidsmätningar på Södersjukhuset (utan Catalyst) och Sundsvalls sjukhus (med Catalyst). Flödena graderades i ett bedömningsprotokoll med avseende på tidseffektivitet, komfort, ljusnivå, resurser, pålitlighet, kostnad, dos och biverkningar. Olika flödes scenario simulerades i AnyLogic.

Resultatet visade att flödet med Catalyst fick högre poäng i bedömningsprotokollet. Simuleringen i AnyLogic visade att minimering av glapp i behandlingsschemat gav samma antal behandlade patienter. Behandling utan bildtagning med konformad datortomografi (CBCT), som idag används tillsammans med Catalyst-systemet för verifikation av patientens position, skulle öka antalet behandlade patienter med cirka 33%.

Slutsatsen var att det inte är någon större skillnad i tidseffektivitet mellan flödena. Tar man hänsyn till den högre pålitligheten och komforten för patienten, kan optisk ytskanning förbättra positioneringen för Elekta Linac och är därför värt att implementera. Att minimera glapp i behandlingsschemat skulle inte förbättra flödet. Att ta bort CBCT-kontrollen skulle öka antalet behandlade patienter per dag.

Nyckelord: Elekta Linac, Elekta VersaHD, Elekta Infinity, C-RAD, Catalyst, strålbehandling, ytskanning, arbetsflödesanalys
Acknowledgement

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Without all of your assistance the writing of this report would not have been possible.
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**Abbreviations**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>RT</td>
<td>Radio Therapy</td>
</tr>
<tr>
<td>SR</td>
<td>Stereotactic Radiosurgery</td>
</tr>
<tr>
<td>MR/RT</td>
<td>Magnetic Resonance Radiation Therapy</td>
</tr>
<tr>
<td>MRI</td>
<td>Magnetic Resonance Imaging</td>
</tr>
<tr>
<td>IGRT</td>
<td>Image Guided Radiation Therapy</td>
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<tr>
<td>SIGRT</td>
<td>Surface Image Guided Radiation Therapy</td>
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<tr>
<td>Linac</td>
<td>Linear Accelerator</td>
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<tr>
<td>CT</td>
<td>Computer Tomography</td>
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<tr>
<td>CBCT</td>
<td>Cone Beam Computer Tomography</td>
</tr>
<tr>
<td>ABC</td>
<td>Active Breathing Coordinator</td>
</tr>
<tr>
<td>DIBH</td>
<td>Deep Inhalation Breath Hold</td>
</tr>
<tr>
<td>SÖS</td>
<td>Södersjukhuset</td>
</tr>
<tr>
<td>PPD</td>
<td>Patient Positioning Device</td>
</tr>
<tr>
<td>Gy</td>
<td>Gray</td>
</tr>
<tr>
<td>Sv</td>
<td>Sievert</td>
</tr>
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</table>
1 Introduction

In today’s cancer care there is a great need for treating patients with high precision in a time efficient way. By making the workflow more efficient it is possible to decrease the cost of each treatment, treat more patients per machine and thereby make the treatment available for more people. With refinement of the patient positioning workflow there is also a possible gain in higher precision.

A prominent company in the field of cancer care is Elekta Instrument AB, working with several different solutions for cancer treatment. The company was founded in 1972 and their first product, the Leksell Gamma Knife®, was a huge step forward in the field of precision radiation therapy. Since then, Elekta has developed new products and branched out within the field. Today Elekta is working with the future solutions for radiotherapy, Stereotactic Radiosurgery, Magnetic Resonance Radio Therapy, Oncology Informatics, Brachytherapy, Neurotherapy and Particle Therapy. An important group of products are the Linear Accelerators (Linacs), machines used for treatment delivery in radiotherapy [1]. In this report the workflow for an Elekta VersaHD and an Elekta Infinity are analyzed. These specific machines are most commonly used for treating breast and prostate cancer.

In 2004, a company called C-RAD was formed by researchers at the Royal Institute of Technology and Karolinska Institutet [2]. C-RAD focuses on positioning and scanning-products. Through these products, they aim to reach their goal of curing more cancer patients and improve their quality of life. They are convinced that this can be done using Surface Image Guided Radiation Therapy (SIGRT) [3].

The problem C-RAD is looking to solve is movements caused by the patient during radiation therapy. Movements can cause less accurate treatment, for example by missing targets or distributing extra dose to healthy tissue. C-RAD’s products are supposed to counteract just that. One of their products is called CatalystHD, a three camera real-time tracking system. The system allows online patient tracking before and during treatment, which will provide the best possible therapeutic and palliative treatment outcome, according to C-RAD [3]. Together, the Catalyst system and Elekta’s Linac systems can possibly give cancer patients a better treatment.

1.1 Aim

The aim for this project was to compare the two workflows (with and without Catalyst) and describe pros and cons with both workflows, to be used as decision support when developing future products of Elekta.

1.2 Limitation

This project was limited to only study the Linac workflows of breast and prostate cancer treatment performed at Södersjukhuset and Sundsvall’s sjukhus.


2 Background

Tumour cells are more sensitive to radiation than healthy cells, which makes it possible to treat several types of cell mutations with radiotherapy. However, the use of radiation can also harm surrounding tissue making it essential to develop technologies to maximize the dose delivered to the tumour while minimizing radiation to the healthy tissue. The Elekta Linear Accelerators (Linacs) are designed to fulfill this purpose. Even though the development of the design might be considered the most important aspect in the improvement of radiotherapy, other areas of the treatment could also be optimized. Such areas are different steps in the workflow of the treatment, for example examinations, treatment planning and patient positioning.

2.1 Elekta VersaHD and Elekta Infinity

There are many different types of treatment delivery systems in the Linac family, but they are all based on the same technology for creating the radiation beam. The VersaHD and the Infinity have the benefit of versatility in the selection of treatment technique [4, 5]. Instead of specializing in one specific type of treatment, these machines are designed to meet the need of flexibility whilst assuring high quality therapy. Both VersaHD and Infinity are equipped with a rotating gantry, making it possible to decrease the treatment time by not only using fixed treatment angles. In Figure 1 the radiation source is circled in red.

![Figure 1: The VersaHD in bunker 3 at SÖS. Color coding: pink marks the Catalyst system, red marks the radiation source, blue marks the CBCT-arm, green marks the isocenter laser and yellow marks the patient positioning devices (PPDs).](image)

A crucial step in the workflow of radiotherapy is the treatment planning. Before the plan is made, the patient goes through a CT-examination and patient positioning devices (PPDs circled in yellow in Figure 1) are selected. To be able to find the same position in the treatment room the patient receives one tattoo on each side of the body and one in the frontal plane. If a laser was pointed through each tattoo, they would meet in isocenter, which should be the same as the target location. The data received from the CT are put into a software system for further analysis and calculations. Elekta’s products can be used with several software systems for radiotherapy treatment planning. However, Elekta has developed a specific program called Monaco, which is designed for being compliant with the Elekta Linac products [6]. Monaco has tools for dose calculation with the Monte Carlo algorithm. With the use of Monaco, Elekta claims that it is possible to accelerate the treatment workflow. This is said to be done by improved tool access and faster Monte Carlo dose calculations.

In the VersaHD and Infinity, a non-invasive 4D image guidance system is used in the patient positioning phase of the workflow in Figure 2, to make the treatment more accurate [7]. Initially, the patient is positioned according to data from the examination computer tomography. The patient’s position is then
corrected so that the lasers, coming from the laser source circled in green in Figure 1, matches the tattoos on the patient. When in place, the image guidance system is activated, meaning a cone-beamed computer tomography (CBCT) is done. Possible position changes are detected and can be corrected. The CBCT uses low dose x-rays and allows for simultaneous acquisition and reconstruction. In Figure 1 the CBCT-arm is circled in blue.

There are several ways and levels of patient monitoring during the fraction (treatment session). One way to keep track of the patient’s movements is to control the breathing with a technique called gating [8]. Elekta Linacs can be used with a gating system referred to as Active Breathing Coordinator (ABC) [9]. This system is mainly used for preventing target movement and for sparing essential surrounding tissue. Thus, ABC is most relevant in the treatment of left breast cancer, in which case the heart is close to target. By the use of a nose clam and a tube in the mouth, the patient is forced to breath with a certain frequency. After maximum inhalation the patient holds one’s breath, while radiation is delivered. During the deep breath the distance between breast tissue and heart is increased, decreasing the risk of dose to the heart.

As already mentioned an important aspect of the efficiency of radio treatment is a well functioning workflow. In the Instructions for Use [10] Elekta describes their proposed clinical workflow. The first of seven steps in this process is the patient preparation. In this phase the patient is prepared for imaging. The next step is the image acquisition with CT. These images are then processed in a computer and an individual treatment plan is created in a planning system. When treatment planning is done, the patient returns to the hospital and is setup in the treatment room. Before radiation can start, a pre-treatment image acquisition (CBCT) is executed and the position of the patient can be modified to match positions in the plan. After securing that the patient is in the right position, radiation delivery can start. If the patient changes position between fractions, new images can be acquired and the position can once again be corrected.

The workflow can be roughly summarized in the following steps (see Figure 2):

1. Patient preparation
2. Image acquisition
3. Treatment planning
4. Patient positioning
5. Pre-treatment image acquisition (CBCT)
6. Localization
7. Radiation delivery

![Figure 2: Proposed clinical workflow [10], courtesy of Elekta Instrument AB.](image)

2.2 C-RAD Catalyst

An accurate and precise patient positioning is crucial for radio therapeutic treatment to succeed. Correct patient positioning before and during the treatment ensures that as much radiation as possible reaches the target. Doing so also spares healthy tissue surrounding the target. Image guided radio therapy (IGRT) is a technique for controlling and overseeing the patient positioning.
There are several methods for IGRT, where x-ray and CBCT are among the most used. These methods have two disadvantages; they use ionizing radiation and since they do not image in real time they can not monitor the patient’s movements during the treatment [11]. These movements can be breathing or just movement of normal tissue, which can cause the target to move.

An additional method for IGRT is SIGRT (surface image guided radiation treatment). SIGRT does not use ionizing radiation and can be used to image in real time. C-RAD claims that their product The Catalyst System is a solution for SIGRT. The Catalyst System consists of a camera paired with a certain software. It offers patient tracking, both before and during treatment, integrated in the typical clinical workflow. The system has three main assisting functions [3]:

- Patient setup and positioning
- Intra-fraction motion detection
- Respiratory gating

The Catalyst System assists the patient setup and positioning by discovering and correcting any errors in the setup or positioning that may occur. Through colored light projection, the errors in the patients posture will be visualized directly on his or her skin. The error is based on a tolerance that the equipment determines, and if the patient is out of tolerance the treatment can not start. Depending on what kind of error it is, either the patient or the bed will need to move for it to be corrected. The Catalyst system enables the bed to be moved automatically without the need of manually entering the coordinates. This is instead done by the software sending the correct coordinates directly to the bed, which then adjusts. A visual representation of all this can be observed by the nurse, in real time on a computer screen with the associated software system. C-RAD claims this concept to be dose free, more time efficient and have high accuracy and precision.

During the treatment, the Catalyst System will continue to monitor the patient’s position. If the patient were to move out of tolerance, the system will stop the treatment immediately and resume when the patient is within tolerance. The system will also monitor the target area in the same way, but with a different tolerance.

The system also uses something called a ”gating solution” for both free breathing and deep inspiration breath hold (DIBH) [12]. The gating solution, or respiratory gating, is a technique for taking respiratory movement into account during radiotherapy [13]. The reason why respiratory gating is important is that the movement caused by the inhalation can cause the target to move as well. This is something that the previously mentioned IGRT techniques do not have [11]. The Catalyst system does this by using Audio Visual Coaching together with the paired software [3].

According to the Catalyst User Guide, the workflow consists of the following steps [14]:

1. Pre-setup (during patient positioning)
   Patient information is presented, different settings (scan volume, camera settings, surface averaging, display settings) can be adjusted, tolerances (target and surface) is determined and the suggested couch correction is displayed directly onto the patient.

2. Setup (during patient positioning)
   A reference image is taken (if it is the first fraction) and the possible need of surface and target positioning correction is displayed and then corrected.

3. Radiation delivery
   A respiration reference is taken, if respiratory gating is going to be done, with both audio and visual coaching available. Patient monitoring can also be done.

4. Summary of results.

In Figure 1 the Catalyst system is circled in pink.
2.3 AnyLogic and workflow analysis

Workflow analysis can be executed in numerous ways and with the help of many different tools. In this report the simulation software AnyLogic was used. By using a simulation tool, such as AnyLogic, it is possible to analyze and solve advanced real world problems [15]. This program gives the possibility to visualize alternative workflows, before implementing changes in the real case. AnyLogic is built on Java programming and supports three different simulation methods: System dynamics, Discrete event and Agent-Based modeling. They all represent different levels of abstraction, where System dynamic has a high level of abstraction and Discrete event a medium to medium-low level. The abstraction of Agent-Based modeling can vary depending on how many details are implemented. The Agent-Based approach focuses on specific agents (nurses, patients, etc.) and their interactions. To visualize a workflow a process flowchart is created, in which the agents interactions are mapped. The parameters of each object in the process flowchart can be defined to fit the real case as good as possible. These parameters can be for example time delays, agent speed and agent location specifications. The fact that AnyLogic is built on Java makes it possible to use Java-code when defining parameters. This can be used when specifying a varying time delay, where the variations can be seen as a distribution. With the use of built-in probability distribution functions, AnyLogic can generate unique values for each simulation, based on real data.

The simulation can be run for a chosen number of times, while using the Analysis tools to collect data. By combining the Analysis tools with Java-code, it is possible to collect output data from different parts of the flowchart. These data can then be exported to and analyzed.

2.4 Previous research

In 2016, a study published in Radiation Oncology titled "Evaluation of daily patient positioning for radiotherapy with a commercial 3D surface-imaging system (Catalyst)" was performed [11]. They compared the patient positioning for radiotherapy treatment using traditional methods and the Catalyst System in connection with an Elekta Synergy linear accelerator. This was done through calculating the mean set-up error for both methods on 25 different patients in their thoracic, abdominal and pelvic body regions. Their conclusion was that the Catalyst System did not provide a significant improvement to the set-up. It could, however, be useful as a complement for traditional methods.

Another study [16], published in 2012, examined the possibility to use laser scanning as a compliment to CBCT, with the purpose to reduce imaging dose. The CBCT was used with an Elekta Synergy accelerator and the optical system used was Sentinel Optical scanner from C-RAD. 21 patients were scanned with CBCT, their position was corrected to isocenter and an optical scan was performed. From the optical scan a desirable shift vector was calculated to perfect the positioning of the patient. The conclusion of the study was that there was good agreement between the two methods. However, differences could occur due to body changes or breathing movement. Despite this, the use of an optical scanner could decrease the use of CBCT.

In the study "Comparison of radiation dose, workflow, patient comfort and financial break-even of standard digital radiography and a novel biplanar low-dose x-ray system for upright full-length lower limb and whole spine radiography" published in 2016 in Skeletal Radiology a questionnaire was used to evaluate patients’ comfort in x-ray units [17]. In that questionnaire, different aspects were judged based on a 4 point rating, where 1 was the best and 4 was the worst. This report’s assessment protocol, seen in Appendix A, was inspired by that questionnaire.
3 Method

The method for this project was to collect relevant information during visits to Södersjukhuset and Sundsvalls Sjukhus. Before these visits, preparations were done to help with our measurements and observations at the hospitals. The information gathered was then compiled and analyzed using the software AnyLogic.

3.1 Preparations

In preparation for the hospital visits an assessment protocol was created and questions to the hospital staff and patients were written down. These documents were sent to the hospital in advance. The protocol was inspired by previous research in similar areas and can be found in Appendix A.

3.2 Measurements and observations

To gather information about the two workflows, two different hospitals were visited: Södersjukhuset and Sundsvalls sjukhus. Södersjukhuset is a hospital which does not use the Catalyst System, while Sundsvalls sjukhus does.

Arriving at SÖS, the head of the department was interviewed, see Appendix B. The rest of the day was spent in bunker 3, where a total of 14 treatments were observed (eight breast cancer and six prostate cancer). The time of two different segments were measured: the positioning time and the CBCT time. The positioning time was measured from the moment the patient entered the treatment room until the staff exited. The CBCT time was measured from the moment the CBCT scan was started to the moment the comparison to the reference image and the possible re-positioning was completed. Meanwhile radiation was delivered, the nurses explained the workflow and answered questions, see Appendix C. All patients were asked to rate the comfort, noise and side effects. After observing 15 treatments the radiotherapy specialist nurse CL was interviewed, see Appendix D.

In Sundsvall, the morning was spent in bunker 2, where a total of 12 treatments were observed (four breast cancer and eight prostate cancer). As at SÖS, the positioning time and the CBCT time were measured. Meanwhile radiation was delivered, the nurses explained the workflow and answered questions, see Appendix E. The patients were asked to do the same ratings as at SÖS. In the afternoon an hour was spent in the CT-room, observing image acquisition, with and without gating.

The material gathered from the hospitals was then summarized into tables and appendices. Mean values of time measurements were calculated through dividing the sum of all values with the number of values. The standard deviation, \( \sigma \), was calculated through the standard deviation formula seen in Equation 1. To determine if the calculated mean values were significantly different from each other, an unequal variances t-test was performed. The null hypothesis for the test was that there was no significant difference between the values. We used a 5% level of significance and the equation used can be seen in Equation 2.

\[
\sigma = \sqrt{\frac{\sum_{i=1}^{n} (x_i - m)^2}{n - 1}} \tag{1}
\]

\( x \) value  \
\( m \) mean value  \
\( n \) number of values

\[
t = \frac{m_1 - m_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \tag{2}
\]

\( m_1, m_2 \) mean values  \
\( s_1, s_2 \) variances  \
\( n_1, n_2 \) number of values
3.3 Mapping and analyzing

After visiting the hospitals the two workflows (with and without Catalyst) were mapped and differences were identified. Microsoft PowerPoint, version 15.32, and AnyLogic Simulation Software, Personal Learning Edition 8.4.0, were used for the mapping and the analyzing process. In AnyLogic, both hospitals were sketched up and flowcharts were created, including every step of the workflow for each hospital. The time segments used in AnyLogic were calculated mean values and standard deviations from the hospital data for both breast and prostate treatments. Using these values in normal distribution, AnyLogic assigned a unique time for positioning and CBCT for each patient in every simulation. The model was created using the Process Modeling Library and the Analysis tools. The AnyLogic model was limited not to cover first time treatments, gating patients or treatments without CBCT. The following simulations were run and the number of patients treated during a day (eight hours) was noted:

- **SÖS - real workflow**: simulation of the real workflow, disregarding first visits and treatments without CBCT. The interarrival time was set to 15 minutes, with 4 patients arriving every time.

- **Sundsvall - real workflow**: simulation of the real workflow, disregarding first visits, treatments without CBCT and gating patients. The interarrival time was set to 15 minutes, with 2 patients arriving every time.

- **SÖS - minimizing gaps in treatment schedule**: simulation with a constant queue in the waiting room. Increasing arrivals per hour, from 16 to 32, and thus making sure the waiting room is never empty. The interarrival time was set to 15 minutes, with 8 patients arriving every time.

- **Sundsvall - minimizing gaps in treatment schedule**: simulation with a constant queue in the waiting room. Increasing arrivals per hour, from 8 to 20, and thus making sure the waiting room is never empty. The interarrival time was set to 15 minutes, with 5 patients arriving every time.

- **Sundsvall - removing the use of the CBCT**: simulation with treatments without CBCT. The CBCT-sequence of the flowchart was removed and interarrival time was set to 15 minutes with 5 patients arriving every time.

Each simulation was repeated 100 times and mean values and standard deviations were calculated from the output values from each repetition.
4 Results

The results were primarily based on the information gathered while visiting the two hospitals, SÖS and Sundsvalls sjukhus, and their answers to the questions asked. These interviews can be seen in Appendices B-E.

4.1 Södersjukhuset

The measured time segments and the patients’ answers regarding the Comfort and Noise are presented in Table 1. The mean values of these results are presented in Table 2, which is the values used for the grading of the Time efficiency, Comfort and Noise.

Table 1: Time segments and grading of comfort and noise at SÖS

<table>
<thead>
<tr>
<th>Cancer type</th>
<th>Positioning time</th>
<th>CBCT time</th>
<th>Comfort</th>
<th>Noise level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breast</td>
<td>2 min 30 s</td>
<td>-</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>3 min 55 s</td>
<td>-</td>
<td>4</td>
<td>3</td>
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<tr>
<td></td>
<td>3 min</td>
<td>1 min 30 s</td>
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<td>8 min 50 s</td>
<td>6 min 15 s</td>
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<td>4</td>
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<td>-</td>
<td>-</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>3 min 30 s</td>
<td>3 min</td>
<td>1</td>
<td>4</td>
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<td></td>
<td>4 min</td>
<td>3 min</td>
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<td>4</td>
</tr>
<tr>
<td></td>
<td>4 min 10 s</td>
<td>-</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Prostate</td>
<td>-</td>
<td>-</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>5 min 10 s</td>
<td>3 min</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>3 min 10 s</td>
<td>3 min 45 s</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>4 min 10 s</td>
<td>3 min 15 s</td>
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<td>2 min 40 s</td>
<td>3 min 20 s</td>
<td>3.5</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>4 min 35 s</td>
<td>3 min 45 s</td>
<td>3</td>
<td>3</td>
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Table 2: Mean values for time (with standard deviation), comfort and noise at SÖS

<table>
<thead>
<tr>
<th>Cancer type</th>
<th>Positioning time</th>
<th>CBCT time</th>
<th>Comfort</th>
<th>Noise level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breast</td>
<td>4 min 15 s ± 2 min 6 s</td>
<td>3 min 26 s ± 1 min 48 s</td>
<td>2.86 ± 3.0</td>
<td>3.86 ± 4.0</td>
</tr>
<tr>
<td>Prostate</td>
<td>3 min 57 s ± 1 min 1 s</td>
<td>3 min 25 s ± 20 s</td>
<td>3.58 ± 3.5</td>
<td>3.67 ± 3.5</td>
</tr>
<tr>
<td>Both</td>
<td>4 min 20 s ± 1 min 51 s</td>
<td>3 min 25 s ± 1 min 15 s</td>
<td>3.18 ± 3.0</td>
<td>3.79 ± 4.0</td>
</tr>
</tbody>
</table>

The remaining aspects was graded using the interview answers from Appendices B-E. These notes were the ones that were mainly used:

Resources: Four nurses per bunker were scheduled to execute radiotherapy from 07.30 am to 03.30 pm or 03.45 pm. Each treatment required two nurses to work actively, while the others did either paperwork or took a break.

Reliability: When installing the VersaHD at SÖS, the Catalyst system was also installed. During the summer of 2018, SÖS had a test-run with the Catalyst system. However, they also recently changed software systems and therefore the use of Catalyst was put on hold. The nurses present during the test-run mentioned that it felt very good to use it. Another nurse mentioned that they do not feel the need for motion tracking during the treatment. They are currently not doing any gating as SÖS.

Cost: Through mail conversation with Jenny Granström (Sales Manager at Elekta Instruments AB), list price for a Linac was found to be approximately 17M SEK.
Dosage: The dosage varies depending on which treatment the patient is going through. The total treatment dosage lies between 40 and 80 Gy. Per Carlsson (Vice President Concept Exploration Elekta Instruments AB) gave an estimation of the dosage from the CBCT to approximately 10 mGy. At SÖS, a CBCT is done before every fraction for prostate cancer patients, and before the first three fractions for breast cancer patients.

Side effects: The most commonly mentioned side effects can be seen in Table 3.

Table 3: Most commonly mentioned side effects at SÖS

<table>
<thead>
<tr>
<th>Breast cancer</th>
<th>Prostate cancer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blisters</td>
<td>Urinates more often</td>
</tr>
<tr>
<td>Burns</td>
<td>Hurts while urinating</td>
</tr>
<tr>
<td>Fatigue</td>
<td>Diarrhea</td>
</tr>
</tbody>
</table>

An overview of the entire workflow, based on observations at the hospital, can be seen in Figure 3 and 4.

Figure 3: Flowchart representing the workflow sequences prior to the treatment day at Södersjukhuset

Figure 4: Flowchart representing the workflow sequences during a treatment day at Södersjukhuset
### 4.2 Sundsvalls sjukhus

The measured time segments and the patients’ answers regarding the Comfort and Noise are presented in Table 4. The mean values of these results are presented in Table 5, which is the values used for the grading of the Time efficiency, Comfort and Noise.

<table>
<thead>
<tr>
<th>Cancer type</th>
<th>Positioning time</th>
<th>CBCT time</th>
<th>Comfort</th>
<th>Noise level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breast</td>
<td>3 min 55 s</td>
<td>-</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>5 min</td>
<td>4 min 15 s</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>8 min 30 s</td>
<td>3 min 30 s</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>4 min 10 s</td>
<td>2 min 50 s</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Prostate</td>
<td>3 min 20 s</td>
<td>-</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>2 min 40 s</td>
<td>-</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>3 min 30 s</td>
<td>3 min</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>3 min 20 s</td>
<td>4 min</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>4 min 20 s</td>
<td>-</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3 min 40 s</td>
<td>4 min 55 s</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>3 min 15 s</td>
<td>5 min</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>3 min 58 s</td>
<td>2 min 10 s</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cancer type</th>
<th>Positioning time</th>
<th>CBCT time</th>
<th>Comfort</th>
<th>Noise level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breast</td>
<td>5 min 24 s ± 2 min 7 s</td>
<td>3 min 32 s ± 43 s</td>
<td>3.67 ± 3.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Prostate</td>
<td>3 min 30 s ± 30 s</td>
<td>3 min 49 s ± 1 min 14 s</td>
<td>3.75 ± 4.0</td>
<td>3.75 ± 4.0</td>
</tr>
<tr>
<td>Both</td>
<td>4 min 25 s ± 1 min 44 s</td>
<td>3 min 42 s ± 1 min 1 s</td>
<td>3.73 ± 4.0</td>
<td>3.82 ± 4.0</td>
</tr>
</tbody>
</table>

The remaining aspects was graded using the interview answers from Appendices B-E. These notes were the ones that were mainly used:

**Resources:** Four to five nurses per bunker were scheduled to execute radiotherapy from 07.30 am to 03.30 pm or 03.45 pm. Each treatment required two nurses to work actively, while the others did either paperwork or took a break.

**Reliability:** The nurses at Sundsvalls sjukhus said they do not feel that they could go back to the way they used to work, without the Catalyst System. The system allows them not to have to constantly watch the patient during the treatment. Even if they were to constantly watch the patient, they could never detect as small motions as the Catalyst system could. However, the nurses also said that the Catalyst system only interrupted the treatment due to movement a few times during the 4 years that they have been using it. Additionally, they are able to perform comfortable gating for patients in need.

**Cost:** Through mail conversation with Jenny Granström (Sales Manager at Elekta Instruments AB), list price for a Linac was found to be approximately 17M SEK and the additional cost for the Catalyst System approximately 2M SEK.

**Dosage:** The dosage varies depending on which treatment the patient is going through. The total treatment dosage lies between 40 and 80 Gy. Per Carlsson (Vice President Concept Exploration Elekta Instruments AB) gave an estimation of the dosage from the CBCT to approximately 10 mGy. At Sundsvalls sjukhus, a CBCT is done before every fraction for prostate cancer patients, and before the first two fractions and then before one fraction per week for breast cancer patients.
Side effects: The most commonly mentioned side effects can be seen in Table 6.

Table 6: Most commonly mentioned side effects at Sundsvalls sjukhus

<table>
<thead>
<tr>
<th></th>
<th>Breast cancer</th>
<th>Prostate cancer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin irritation</td>
<td></td>
<td>Hurts while urinating</td>
</tr>
<tr>
<td>Numbness</td>
<td></td>
<td>Leakage</td>
</tr>
<tr>
<td></td>
<td>Sore after treatment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gases</td>
<td></td>
</tr>
</tbody>
</table>

An overview of the entire workflow, based on observations at the hospital, can be seen in Figure 5 and 6.

Figure 5: Flowchart representing the workflow sequences prior to the treatment day at Sundsvalls sjukhus

Figure 6: Flowchart representing the workflow sequences during a treatment day at Sundsvalls sjukhus

4.3 Significance test

The significance test gave a t-value of 0.43, when comparing values of positioning time for breast cancer treatments at SÖS and Sundsvalls sjukhus. Doing the same comparison for prostate cancer treatments the t-value was 0.41.
4.4 Grading

The results presented in Subsection 4.1 and 4.2 combined with the Assessment protocol were used to grade the different aspects. Table 7 contains each workflows overall grading and the grading for every aspect.

Table 7: Grading for SÖS and Sundsvalls sjukhus using the Assessment protocol

<table>
<thead>
<tr>
<th></th>
<th>SÖS Breast</th>
<th>SÖS Prostate</th>
<th>Sundsvall Breast</th>
<th>Sundsvall Prostate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time efficiency</td>
<td>3.5</td>
<td>3.5</td>
<td>3.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Comfort</td>
<td>3.0</td>
<td>3.5</td>
<td>3.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Noise</td>
<td>4.0</td>
<td>3.5</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Resources</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Reliability</td>
<td>3.0</td>
<td>3.5</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Cost</td>
<td>2.0</td>
<td>2.0</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Dosage</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Side effects</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Average</td>
<td>≈ 3.19</td>
<td>= 3.25</td>
<td>≈ 3.25</td>
<td>≈ 3.38</td>
</tr>
</tbody>
</table>

4.5 Improvement areas

When interviewing the nurses at the hospital, they presented several improvement ideas. These were the most commonly mentioned:

- **Engine for the CBCT**: for improving the ergonomics of the nurses. Also being able to steer the CBCT arm from the control room, decreasing the risk of it being in the way of the Catalyst system.

- **Laser height adjustable**: improve the ergonomic for nurses during positioning, by not having fixed laser lights and thus being able to choose the height of the couch more freely during positioning.

- **Lower couch for HexaPOD**: being able to lower the couch with HexaPOD (a table top device, making it possible to move the couch in six angles) more, since the HexaPOD makes the couch about one decimeter higher. The height can make it difficult for patients with movement difficulties to climb the couch.

- **Retractable kV detector**: making it possible to retract the kV detector arm. When the CBCT is not used, the kV detector can sometimes be in the way for the nurses.

4.6 Simulation in AnyLogic

The simulations in AnyLogic gave us a number of treatments performed in one work day (8 hours). These values for each simulation are presented in Table 8. Screenshots from AnyLogic of the different simulations are presented in Figure 7-10.

Table 8: Simulation results with mean values and standard deviations from Table 2 and 5

<table>
<thead>
<tr>
<th>Simulation</th>
<th>No. of treated patients/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOS real workflow</td>
<td>121 ± 1.86</td>
</tr>
<tr>
<td>SOS minimizing gaps</td>
<td>121 ± 1.99</td>
</tr>
<tr>
<td>Sundsvall real workflow</td>
<td>64 ± 1.13</td>
</tr>
<tr>
<td>Sundsvall minimizing gaps</td>
<td>64 ± 1.33</td>
</tr>
<tr>
<td>Sundsvall without CBCT</td>
<td>85 ± 1.57</td>
</tr>
</tbody>
</table>
Figure 7: *The real workflow at SÖS*: The blue flowchart in the upper part of the figure shows the sequences of the workflow, from arrival to exit. The figure shows the four bunkers at SÖS, where two patients are getting their treatment and two bunkers are empty. There are no patients waiting in the waiting room.

Figure 8: *The workflow at SÖS, with minimized gaps*: The figure shows the four bunkers at SÖS, where four patients are simultaneously getting their treatment. There are always patients in the waiting room.

Figure 9: *The real workflow at Sundsvalls sjukhus*: The figure shows the two bunkers at Sundsvalls sjukhus, where one patient is treated and one is positioned. There are no patients in the waiting room.

Figure 10: *The workflow at Sundsvalls sjukhus, without CBCT*: The figure shows the two bunkers at Sundsvalls sjukhus, where two patients are positioned. The CBCT-sequence of the flowchart is removed. The yellow square shows number of patients treated in a day. The numbers are updated for each simulation, every 8 hours (480 minutes).
5 Discussion

The discussion contains motivations for the grading and other parts of the results, analysis of the improvement ideas gathered from the hospital and improvement ideas for the method of this project. The results from the simulations in AnyLogic are also discussed. Some measurements either became invalid or were forgotten, this was because questions were asked, the workflow was observed and time segments were measured at the same time. This is what caused the empty spaces in Table 1 and 4. This could be avoided, as mentioned in Subsection 5.4, by doing more visits at each hospital. Another issue worth mentioning is that these are only two examples of workflows, with and without the Catalyst system. All hospitals have different routines and how Sundsvalls sjukhus is working with the Catalyst system, might not be how other hospitals are working with it.

5.1 Grading aspects

The grading of the different aspects of the workflows, using the assessment protocol, was done putting the workflows in respect to each other. If the workflows were to be graded without the influence of each other, the grading might have looked different. For example, the workflows might have received the same grade for time efficiency and cost. It was decided to grade them with respect to one another, to make sure that even small differences were highlighted.

Time efficiency

From the results in Table 2 and 5 the grading for time efficiency was done. The final grading can be seen in Table 7. According to this grading, the time efficiency is equal for both cancer types at SÖS and for prostate cancer treatment at Sundsvalls sjukhus. The breast cancer treatment at Sundsvalls sjukhus however, turned out to be slightly less time efficient. The significance test in Subsection 4.3 shows that the null hypothesis cannot be rejected, since the t-value is larger than 0.05. This means there is no significance between the positioning times for the two hospitals. However, when developing products at Elekta, a time efficiency gain of only half a minute per patient can make a modification worth implementing. Also, these results are partly due to the fact that only four breast treatments were observed during the visit to Sundsvall. The positioning for one of these treatments took double the time of the other three, which made the mean value much higher. If more than four treatment had been observed, the result might have had a different outcome. Therefore, we have chosen to grade SÖS breast treatment lower despite the results of the t-test.

The time efficiency could be improved in multiple areas. For example, the patient could get undressed in a locker room, instead of in the treatment room. This would save time, both when the patient enters the room and after treatment. The problem would be that the patient would have to be naked for a longer time, which might be uncomfortable. By having a minute to get undressed and talk to the nurse in the treatment room, it can be argued that the patient will be more relaxed and less worried about the treatment, decreasing the risk of movement during radiation delivery.

If the surface scanning technique could replace the CBCT all together the workflow would be more time efficient. Doing this would mean removing step 4.4 (CBCT pull out), 6 (Image acquisition) and 7 (Localization) in Figure 4 and step 4.5 (CBCT pull out), 7 (Image acquisition) and 8 (Localization) in Figure 6. Currently with the Catalyst system in Sundsvall, CBCT is executed for the first two breast treatments and then once a week for validation. For prostate cancer however, a CBCT is executed before every fraction. This is because the target is not located at the surface, which it usually is in a breast cancer patient. Before radiotherapy, golden seeds are implanted close to target in the prostate cancer patient. After the CBCT scan, the nurses control that these seeds are within a certain tolerance. If the patient has gases or a filled bladder the golden seeds, and thus also the target, can be moved out of position, which is why the CBCT is done daily. These internal movements can not be detected with the Catalyst. The fact that CBCT is still used, makes the workflow with and without Catalyst equally time efficient. If the golden seeds could be replaced with something that could be spotted without the CBCT, the time efficiency could be improved.
Comparing the two flowcharts for the workflow sequences prior to treatment day in Figure 3 and 5, it is clear that the workflow for Sundsvalls sjukhus is less time efficient, since this flow includes the additional step Image acquisition with DIBH. However, this step is crucial for treating a patient with DIBH and no improvements could therefore be done to make the pre-treatment workflow more time efficient.

One aspect that could affect the time efficiency is if the Catalyst system has to interrupt the treatment repeatedly. As mentioned in Subsection 4.2, this is very rare, according to the nurses at Sundsvalls sjukhus. How much the Catalyst system interrupts depends on the tolerance of the system. A smaller tolerance causes the system to interrupt more, since it is more sensitive to movement, and the opposite for a larger tolerance. However, a smaller tolerance can increase the reliability, while a larger can decrease it.

**Comfort**

The comfort aspect in the Assessment protocol is entirely based on patients’ ratings, which were surprisingly high. Most patients did not have any comments about the comfort at all and rated it as a 4. This is probably due to a combination of the fact that the treatment is executed fast and that they do not have anything to compare it to. The most common comment about comfort was that the couch and the neck support was too hard. To improve the patient comfort, it might be possible to create a thin cover of a softer material. The reason why the neck support is hard is that the patient’s head must be still. By using a hard neck support the head is mobilized to intended position. None of the patients seemed to think that the couch was hard to climb or that any of the equipment caused claustrophobia.

Some observations that could affect the grading were done and the nurses also mentioned some things that the patient did not mention when grading the comfort. Firstly, at SÖS, the nurses had to push and drag the patient around physically to get them in the correct position. When using the Catalyst system, the nurses barely had to touch the patient. Leading to the conclusion that the comfort for a treatment with the Catalyst system is higher than without it. However, the fact that you have to be completely naked around the treatment area might be uncomfortable for some patients. Patients with prostate cancer, for example, can not have underwear on at all while being positioned and treated. This is something that might decrease the comfort aspect of the workflow with Catalyst.

**Resources**

To execute a treatment with the Elekta VersaHD or Elekta Infinity, two nurses are needed. This is the case both with and without the Catalyst system. However, there are more nurses scheduled than needed at both hospitals, making it possible for the nurses to take breaks without scheduled treatment gaps. It would be hard to decrease the resources, since two nurses are needed to do the positioning and therefore both hospitals are rated 4.0 for resources. If the positioning could be done by one single nurse, less resources could be used. This would be if the use of tattoos could be discontinued and the whole positioning could be done with Catalyst. This is because the tattoos requires one nurse at each side to adjust the positioning, since an adjustment on one side can cause changes in the positioning on the other side. However, patient set-up would probably take more time with only one nurse, since the two are simultaneously doing tasks, such as placing PPDs, double checking the patient’s social security number and treatment settings.

**Reliability**

According to the nurses at SÖS, their way of positioning and treating felt reliable. They did not feel any need to monitor the patient’s movement during treatment. Still, we have chosen to grade the reliability of Sundsvalls sjukhus higher. One reason for this is that a few nurses at Sundsvalls sjukhus used to work at the hospital before they started using the Catalyst system, and they mentioned that they could not imagine going back to that work procedure. Another reason is the motion detection function that the Catalyst system has, which makes it possible to detect millimeter sized movements. Something that is impossible to do with the naked eye. Lastly, the possibility to perform respiratory gating is something that we feel increases the reliability of the treatment with the Catalyst system. As mentioned above, something that could affect the reliability is the set tolerance, since a low tolerance makes the system more sensitive to movement.
Dosage
The dose aspect can be viewed and graded differently depending on the approach. The CBCT delivers a high dose compared to not receiving any dose, but compared to the dose you receive going through a cancer treatment, the additional dose is almost non-existent. We decided to grade all the workflows with the same grade, 3, since the CBCT was used about equally frequently. Thus, it could not be argued that the use of Catalyst decreases the dose. The reason why it was given a 3 and not a 4 is that it is still technically possible to lower the need of the CBCT. However, it might not be as safe and can therefore lower the Reliability.

Noise
Since we were not present in the treatment room during the treatments, we have no observations to discuss regarding the noise aspect. Therefore, the noise aspect is entirely based on patients’ opinions, and they all seemed to agree that the noise was not a problem. The nurses mentioned there is some noise, but believed that the reason that the patients did not mind it was because it lasts only during the delivery of radiation, which is just a couple of minutes. The nurses also had music playing in the treatment room at both hospitals for the patients to listen to while undergoing treatment. This was partly to draw attention from the noise, but also to lighten the mood. Some patients asked the nurses to turn up the volume of the music. This might be a sign of the noise level being annoying for the patients, or they simply liked listening to music. It was also noted that the patients tended to compare the treatment to examinations, such as MRI (Magnetic Resonance Imaging), which is known for being loud and time consuming.

Side effects
The frequency of and the type of side effects were about the same at both hospitals. By interviewing the nurses, it was learned that side effects often occur after 2-3 weeks of treatment or not at all, depending on how sensitive the patient is to radiation. When asking the patients about their side effects, a correlation between fraction number and whether or not they had experienced any side effects was noted. The higher number of fractions, the more likely it was that they had experienced side effects. The most common side effects were listed in Table 3 and Table 6. These side effects were found to be fairly equal for both hospitals. Also, it was investigated if there was a connection between the use of the Catalyst system and less or milder side effects. No such connection could be seen. One reason for this might be that the CBCT is used to the same extent in both cases, since we had a theory that additional dose to healthy tissue could cause additional/more severe side effects.

5.2 Design improvements
One improvement suggested by the nurses was the ability to automatically take the CBCT arm out of the Linac. Today, this is done by hand. Doing this about 30 times/day is not good for the nurses ergonomically, since the CBCT arm is so heavy. Also, making it possible to steer the CBCT arm from the control room would ease the use of Catalyst, since the arm can block the system in some cases.

Another improvement was to make the laser height adjustable. At the moment, the lasers are attached to the wall (see green circle in Figure 1) and are therefore at a fixed height at all times. When the nurses are positioning the patient according to the tattoos in the transverse and coronal plane, the couch needs to be at the same height as the lasers. This causes the couch to have to be at a certain height, which can be problematic for nurses who are not the appropriate length for the couch. Working with something that is either too high or low for you can be a problem from an ergonomic perspective. We believe this can be solved by making the laser adjustable to a certain number of heights, 3 different index for example. By doing so, you can make sure that the lasers on both sides are on the same heights (index) and the nurse can adjust the height depending on his or her length. A different approach to solve this problem is to position the patient in the sagittal plane first. This can be done at any height, avoiding the problems mentioned in the previous paragraph. When the patient is correctly positioned in the sagittal plane, the nurses can continue position the patient in the coronal plane by only, in theory, raising the table.
Lastly, the nurses suggested that the couch should be lower since the HexaPOD makes it about one decimeter higher. Some patients have difficulties to move and some are bedridden, which can make the couch height a problem. For example, patients can have trouble climbing the couch themselves and the nurses can have trouble moving the patients from their bed to the couch. This can cause discomfort for both patients and personnel.

5.3 Simulation in AnyLogic

The real workflows (see Figure 7 and 9) and two additional scenarios (see Figure 8 and 10) were simulated in AnyLogic. The two additional scenarios were scenarios which might make the workflows more time efficient and thus enable more patients to be treated per day. Since we did not have any data of how many gating patient treatments, first visit treatments and treatments without CBCT were executed everyday, the simulations were limited not to cover these cases. The same limitations were applied to all simulations to make them comparable.

The first scenario was always to have patients in the waiting room, ready for their treatment if the previous treatment would finish earlier, and thus using that gap time. In theory, this should increase the number of patients treated per day. We believe that the small amount of data with large deviations made the treatments more time consuming than expected. However, this scenario is not applicable in reality. Many patients undergoing radiotherapy are healthy enough to work and have a relatively normal life. If these patients would have to sit in the waiting room all day instead of having an appointment, it would affect their everyday life more than necessary.

The second scenario was not to perform any CBCTs. This scenario was only simulated at Sundsvalls sjukhus, because it is only at this hospital that the removal of the CBCT is fairly possible, since the Catalyst system also verifies the positioning. Also, the positioning time measurements at Sundsvalls sjukhus included a check with Catalyst. If the same scenario was to be simulated with the values from SÖS, the results would be misleading since removing the CBCT would mean removing the positioning verification all together. The result from this was that the number of patients treated per day went from 64 to 85, an increase of 21 patients (33%). Assuming that treatments are executed every weekday 52 weeks a year, this would equal an increase of 5460 patients per year (not including patients being treated for the first time).

The scenario without CBCTs can be viewed as both realistic and non-realistic. When visiting Sundsvall, we never experienced that the CBCT discovered a positioning error that the Catalyst system had not. This implies the CBCT is not necessary, however, the Catalyst system can only control that the surface of the body is correctly positioned. If something would have changed inside the body, the Catalyst system would not notice it and therefore healthy tissue could be damaged. The CBCT can control the position of internal parts, which is the reason it can be considered very necessary in some cases. This especially applies to patients with prostate cancer, since the prostate (and therefore the target) is not located at the surface of the body.

5.4 Improvement report

One way to improve the method is to gather more data, which could be done by visiting the hospitals more than once. By doing so, we would be able to get more data to calculate a mean value from. When visiting Sundsvalls sjukhus, we were not able to see many patients being treated for breast cancer. This caused one of our measurements to affect the mean value very much. The measurement is not incorrect, but with few values, the mean value can be slightly misleading. That one measurement can be seen in Table 4 under Positioning time for breast cancer. Our perception was that this was a special case that required extra time, but since we were not able to gather a lot of other values we can not be sure about this.

By spending more days at the hospital, the focus areas could be divided for better result. For instance, the first day could be spent only performing interviews and observing the workflow. The information could
then be summarized and follow-up questions could be answered during the second visit. The remaining of the second and up-coming visits could then be used for measuring time efficiency, comfort and noise level.

Another way to improve the report would be to visit more hospitals than SÖS and Sundsvalls sjukhus, maybe even hospitals in other countries. More data could then be collected to give a more general grading for workflows with and without the Catalyst system, since all hospitals have different routines. As mentioned earlier, this report only examines how two specific workflows perform in comparison to one another. Workflows from other hospitals might generate different results.

5.5 Future studies

For future studies, the accuracy aspect could be taken into consideration and be added to the Assessment protocol, to determine if SIGRT is worth implementing or not. During the visit to Sundsvalls sjukhus, not a single treatment was interrupted by the Catalyst system, meaning the patient never moved out of tolerance. If this is always the case, it might seem unnecessary to implement this technique in the next generation of Elekta Linacs. However, if the accuracy of the treatment is improved, if so only for a few millimeters, surrounding tissue can be spared and thus risks can be minimized.

Another possibility is to study SIGRT products from other companies. These might contain functions and applications that C-RAD and the Catalyst system do not have, that can be worth implementing when developing future Linacs. It is also possible to compare the features of another company’s product and Catalyst, to find out which is best at what they are supposed to do.
6 Conclusion

Comparing a Linac treatment workflow without a surface scanning system with a Linac treatment workflow with a surface scanning system, it can be established that there are no great differences in the time efficiency perspective. However, considering the higher reliability and the higher comfort for the patient, optical surface scanning can improve the workflow of Elekta Linacs and is therefore worth implementing.

From the AnyLogic simulations two conclusions can be drawn:
- Minimizing treatment gaps would not improve the workflow, if positioning can not be done faster.
- Removing the use of CBCT would increase the number of treated patients from 64 to 85 per day (disregarding first visits and patients who receives a treatment with respiratory gating).
7 References


## Appendices

### A Assessment protocol

<table>
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B Interview with Maria Winemar, Section Director of the Radiotherapy Department at SÖS

*How many patients do you treat in a day?*
According to Maria they treat about 120 patients/day in 4 different treatment rooms (bunkers).

*When was the system installed?*
Maria tells us the Catalyst system was installed a year ago and they did a test run the passed summer. The evaluation of the test run is still in working progress. However, SÖS recently implemented Elekta’s softwere to their equipment, putting the use of Catalyst a bit on hold.
Interview with Specialist Nurses at the Radiotherapy Department at SÖS

Do you feel a need of faster/more effective positioning of the patient?
The specialist nurse Helena who worked with Catalyst at their test run of Catalyst during the summer answers this for us. According to her the positioning were actually less time efficient using the Catalyst system. She estimated that the treatment time per patient increased by about 5 minutes. The reason for this, she believes, is that technical solutions takes time.

Do you feel a need of motion monitoring of the patient during the treatment?
Helena continues answering this question as well. At the moment, they do not have the possibility to track the patients movement during the treatment. This can be a problem due to the fact that several patients suffers from cough and allergies, which can cause them to move. Therefore she believes that it could be a good idea to track the patient's movements during treatment.

Did you (Helena) notice any other advantages and/or disadvantages with using the Catalyst system?
Helena says that she thought it felt very good working with Catalyst. Especially when the treatment concerned superficial tissue, breasts for example. According to her, it felt very logic to use a surface based positioning system in those cases.

Another factor she liked with the Catalyst was that you were able to take a reference image in the treatment room just before the treatment. A lot can happen from the point that the initial CT is taken to the point where the treatment is going to start, making the reference image more difficult to use.

Lastly, she says that with the Catalyst you didn’t have to move the patient around as much.

At what time does the department open and when do you have your first patient?
The nurses tells us the department opens at 07:00 am every day. Then, a daily control of the equipment is performed. This is done by running an automatic program. If there is any problems, an engineer or a physicist is called depending on the problem. Normally, the first treatment of the days starts at 07:30 am.

How much time per patient do you account for?
15 minutes/patient normally. If it is a patient being treated for the first time, or if they have more than one target, 30 minutes are set aside for each patient.

How many people work in each bunker?
Two specialist nurses work together at each treatment. One prepares the treatment room and one prepares the program. When the patient enters the room they both assist with the positioning. Then, they both leave the treatment room to begin the treatment. They take turns controlling the positioning and running the treatment. If all staff is present, there are four nurses in each bunker. By being four, they have the opportunity to take breaks and continue the treatment during lunch hours. Additionally, the bunker can still work as usual if someone would be sick.

How many fractions do you normally do? How does the dose differ between the different fraction divisions?
The most common division for treatment of breast cancer at the moment is 16 or 25 fractions. At 16 fractions a dose of 2.65 Gy/fraction is delivered, and at 25 fractions a dose of 2 Gy/fraction is delivered. In the future, it is planned to change this to 15 fractions and 2.67 Gy/fraction. The total amount of dose delivered from the whole treatment should be approximately 40.2 Gy. For treatment of prostate cancer you usually do 21-22 fractions and the dose per fraction should be between 3 and 3.5 Gy.

What is done before the patient enters the therapy room?
Before the patient enters the room the couch is wiped off with disinfectant. Then, the patient’s medical record is opened. The medical record tells the nurses which PPDs (patient positioning devices) to place out
and at which index the couch is going to be placed. Example of PPD’s that are being used are neck support, foot support and support for the fold of the knee.

*Are they using DIBH at SÖS? Are they using ABC instead?*
Currently no kind of gating is used at SÖS. However, it is planned to be implemented it in the future. The advantage of gating is that you can be sure to avoid giving dose to the heart (when treating breast cancer). Helena also mentions that gating can not be applied to every patient, since some patients are not able to hold their breath long enough. Also, the gain is not the same in all cases. For example it is more important to avoid dose to surrounding tissues on the left side, since the heart is placed on this side. Working with gating you can decrease the margins.

*How often do you use the CBCT?*
The specialist nurses informs us that when treating breast cancer, they only do a CBCT the first three fractions. During the remaining fractions, position is verified using tape placed on the patients chest at a certain angle. For treatment of prostate cancer, the CBCT is done before every fraction. This was also the routine when using the Catalyst system.

*What parts of the treatment can be experienced as unpleasant? What are the side effects of the treatment?*
According to the specialist nurses the most common unpleasant aspects of the treatment is the noise level of the machine and that the skin turns hot, red and irritated. The reaction to the treatment depends on how sensitive the patient is to radiation. If there are any side effects, they usually do not occur before 2-3 weeks of treatment. In some cases the patient do not experience any side effects until after the treatment is finished.

*Is there any change in the design that would simplify the usage?*
The specialist nurses mentioned several improvement ideas that they had, these were:

- Engine for the CBCT: At the moment, the specialist nurses have to manually pull out the CBCT from the Linac. This is something that is not hard to do one single time, but to do it several times per hour and several hours a day makes it very non-ergonomic. They suggest that an engine should be able to do this by the press of a button.

- Control mechanism at the table: There is a control mechanism to steer the couch that is currently attached to the table and which can’t be moved. The nurses would like to be able to detach this control since its easier to use and understand than the remote control.

- The height of the table: Since the laser is attached to the wall, the height of the table can not be adjusted for the nurses while positioning the patient. This means that the nurses often have to work with their arms in an unnaturally high position, which can cause work related injuries.

*What are the biggest problems with the treatment/are there any problems?*
Gas/feces in the prostate patient can cause the target to move. If the offset is too big and the target is moved outside the tolerance area, the patient has to go to the toilet or a catheter has to be used to ease the gases. This happens frequently.
Interview with Christina Ledenkvist, Radiotherapy Specialist Nurse at SÖS

Are there any changes in design that would simplify the use?
According to Christina the focus should be to improve the ergonomics for the staff and to make the machine more patient friendly. Some problems in the design that she mentioned:

• HexaPOD: this application makes the table one decimeter higher, which can make it hard for some patients to climb the table by themselves. Also, the height difference makes it hard for the staff to move bedridden patients from the bed to the table.

• Steering station at the table: sometimes it can be hard to steer the bed from the steering station since it is screwed to the table. The nurses are aware of the possibility to steer the table with the handheld controller, but since that is more complicated (with more clicks to accomplish the wanted movement) they prefer to use the steering station.

• Display placement: the displays are not optimally placed. In some cases it is hard to make adjustments while looking at the screens. It can also be hard to see the screens, since they are placed relatively far away from the table.

• Software bugs: it is not unusual that the program used in treatment crashes due to bugs, in which cases an engineer needs to be called in.

• Mosaiq: the program is generally cluttered, the font is too small and the layout is too gray and dull. Preferable would be better graphics and a more colorful layout.

What happens during the patient’s first visit at the department?
The first thing that happens is that the patient receives information about the treatment. Also, she gets the opportunity to ask any questions in mind. When everything is clear, a computer tomography is executed, PPD’s are selected and the patient is tattooed in the right position. Christina has never heard of any case of side effects (infections etc.) of the tattoos.

Is there any plug in the workflow, that causes delays?

• Booking: every patient is to be treated with a certain number of fractions. This can cause plugs in the workflow if there are many patients in need of treatment.

• The doctor’s tumour modelling: before treatment the doctor need to model the target. This must be done before the first fraction and can thereby cause delays.

• Incomplete radiation notification (referral): sometimes the doctor sends the referral before everything is done, because they want the patient to start treatment as soon as possible.

Do you feel a need to monitor the patient’s movement during treatment?
According to Christina there is no strong need to monitor the patient’s movement during treatment. The nurses feel comfortable enough with the equipment used today.
Interview with Nurses at the Radiotherapy Department at Sundsvalls sjukhus

For how long have you used the Catalyst system?
For four years. The "three-camera-system" (Catalyst HD) has been in use since October 2018.

How many patients do you treat in a day?
About 25-30 patients/day in two different treatment rooms (bunkers), depending on number of start treatments (first fraction) and number of gating patients.

How many people work in each bunker?
Two at least, but usually 4-5 nurses.

How much time per patient do you account for?
15 minutes/patient normally. If it is a patient being treated for the first time or a treatment with gating 30 minutes/patient, and if it is a first time treatment with gating 45 minutes/patient.

At what time does the department open and when do you have your first patient?
The first patient is scheduled to 07:30 am, and the department opens at 07:00 am. Before the first patient arrives, a morning control is performed by the nurses. If there are any problems, an engineer or a physicist is called depending on the problem. They have their last patient at 15:30 or 15:45.

Do you still use tattoos?
The nurses informs us that they do still use the tattoos, but they are investigating the possibility to get rid of them. The reason that they are still using the tattoos is to get the patient in the correct angle. At the moment, they do not have any possibility to change the angle of the patient through the couch. Therefore, the tattoos are necessary to get the patient correctly positioned.

The reason that they want to get rid of the tattoos is that it is a minor infection risk, and that some patients do not like getting tattooed.

If the Catalyst system in one bunker would go out of function - would you perform treatment without it or only use the other bunker?
Preferable would be to use the other bunker, since most of the nurses have not performed treatments without the Catalyst system and would not be comfortable without it. If they were to use the Linac without the Catalyst system, the nurses would have to read the manuals and directions for treatment without it. For now, the nurses cannot imagine going back to how they used to work before (without Catalyst).

How often do you use the CBCT?
A CBCT is done for every fraction for patients being treated for prostate cancer, that still have their prostate. Patients who have had their prostate removed or patients being treated for breast cancer goes through a CBCT the first two fractions, and then once a week for control. Additionally, if there are any insecurities regarding the positioning, a CBCT is always done just to be sure.

What are the advantages and/or disadvantages with the Catalyst system?
The nurses explained that they really much appreciated the motion detection during the treatment. That means that they do not have to constantly watch the patient to detect possible movement. They also add that they would never be able to detect such small movements as the Catalyst system can.

Another advantage mentioned was the ability to move the couch from the control room. If the patient moved after the positioning was made, the nurses can adjust the couch accordingly with the Catalyst system. They are also able to do respiratory gating with the Catalyst system, something they consider to be essential.

One disadvantage from the patient’s perspective is that they have to be naked around the treatment area.
during the treatment, since the Catalyst system detects skin. This means that prostate patients cannot have underwear on, which can be a bit uncomfortable for some patients. The nurses continue to tell us about how they even had to ask one patient to shave the treatment area because the Catalyst System was not able to detect the skin properly. They have also discovered that changes in skin tone can cause the same problem. This is usually resolved by taking a new reference image or changing the settings of the system.

*What tolerance do you use for the Catalyst system?*
A tolerance of 5 mm in each direction and a tolerance of 5 degree gradient.

*How many fractions do you normally do? How does the dose differ between the different fraction divisions?*
Number of fractions can vary between 15 and 35, depending on the tumour. Most common dose per fraction is between two and three Gy.

*How often does the Catalyst system interrupt the treatment?*
It does not happen often, only a few times since Sundsvall's sjukhus started using the equipment (in 2015).

*How does DIBH work? When do you use it and when do you not use it - why?*
When using DIBH, the treatment becomes more advanced and therefore more time consuming. The first thing done is that the patient goes through a CT before the dose planning is done. The patient is scanned using a Sentinel (a surface scanning system for CT) while asked to breath normally. A base line representing the natural position of the patient’s chest is then registered. Then, the patient is asked to take a deep breath and hold it steady for around 20-30 seconds. The Sentinel system then registers the raise of the patient’s chest and an area with a 3 mm tolerance is chosen for how deep the inhalation is going to be. During this process, a screen in front of the patient’s eyes shows them their breathing. This helps them to keep their inhalation at the right depth. Both the base line and the area of deep inhalation are then sent to the radiotherapy treatment department.

Later, during the treatment, the patient is going to repeat what they did during the CT-scan. When they feel ready, they take a deep breath and hold it within the area that they are supposed to. When the inhalation is within the tolerance, the treatment is initiated. The patient holds one’s breath for as long as possible and then continues to breath normally, and the treatment stops. This is then repeated until the treatment is complete.

The treatment itself is done through a pre-set amount of angles and therefore take a different time depending on the number of angles. However, radiotherapy treatment with gating is always more time consuming (30 min/patient instead of 15 and 45 min/patient instead of 30 at first fractions). Which is why it is only used when treating left breasts (because of the heart) and parasternal lymph nodes. Gating is usually not done on patients older than 75 years.

*Does the application affect the mobility for the staff or the patient?*
Since the cameras are placed up in the ceiling, they do not affect the mobility for neither the staff nor the patients. However, nothing can be placed in front of these cameras since the projection would be disturbed, which causes some limitation.

*Do you use Couch Control?*
Yes. This technique makes it possible to make small adjustments with one single button. It also allows for finer adjustments than those that could be made manually.

*Do you have to override the system often?*
Yes, it happens at least once a week that the system must be overridden. A typical case when this has to be done is when the tissue might have swollen from radiation. In case of tissue structure changes, the surface
do not match the Catalyst reference image, even though the CBCT shows that the inner structures are in the right position.

What are the biggest problems with the treatment/are there any problems?
The biggest and most common problems are problems with software and connection problems between the systems.

Is there any change in the design that would simplify the usage?
The following were suggestions to changes that came up:

- Engine for the CBCT: the nurses at Sundsvalls Sjukhus think that the possibility to control the CBCT from the control room would be an improvement. Both because they would not have to pull it out manually and because it would decrease the risk of the CBCT blocking the Catalyst system.

- Retractable kV detector arm: in treatments where the CBCT is not used the kV detector arm can sometimes be in the way for the nurses. An improvement would be to make this arm retractable.

What is done before the patient enters the therapy room?
The couch is wiped off with disinfectant, PPDs according to the notes in the chart and a thin piece of paper is placed onto the couch. This is something that takes around 2-3 minutes, but can take different amount of time depending on if the patients is ready or not. The Catalyst system does not require any additional preparation.