Vysoká škola ekonomická v Praze

Fakulta informatiky a statistiky

# Multi-criteria model of information technologies and their impact on patient outcomes in oncology

DIPLOMOVÁ PRÁCE

Studijní program: Aplikovaná informatika

Studijní obor: Informační systémy a technologie

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Praha, duben 2019

## Prohlášení

Prohlašuji, že jsem diplomovou práci „Multi-criteria model of information technologies and their impact on patient outcomes in oncology" vypracoval samostatně za použití v práci uvedených pramenů a literatury.

V Praze dne 29.04.2019 ........................................................

Bc. Marián Bača

## Poděkování

Chtěl bych poděkovat Ing. Martinovi Potančokovi, Ph.D. za odborné vedení práce a také za všechny rady a připomínky, které mi pomohli při její tvorbě. Dále bych velmi rád poděkoval všem onkologům, fyzikům a dalším pracovníkům v oblasti zdravotnictví a eHealth, kteří se zúčastnili rozhovorů.

## Abstrakt

Tato práce se zabývá tématem zlepšení pacientových výsledků v onkologické péči v České republice, a to použitím informačních technologií. Cílem práce je vytvořit multikriteriální model informačních technologií pro zdravotnický systém v České republice berouc do úvahy typ technologie, její schopnosti a související dopad na pacienta a fázi rakoviny. Aby bylo možné dosáhnout tohoto cíle, je potřebné zjistit úroveň dopadu navrhovaných opatření a proveditelnost implementace v prostředí České republiky. Toho je zamýšleno dosáhnout dvojím způsobem. Výstupem první metody je analýza současného stavu v České republice a hodnocení navržených technologií, jejich schopností a jejich dopadů na pacienta. Výstupem druhé metody je zhodnocení proveditelnosti implementace navržených technologií v České republice.

## Klíčová slova

eHealth, informační technologie, model, onkologická péče, rakovina, zdravotnictví

## JEL klasifikace

L86 - Information and Internet Services • Computer Software, H75 State and Local Government: Health • Education • Welfare • Public Pensions

## Abstract

This Master's Thesis deals with the topic of improving patient outcomes in oncology care in the Czech Republic leveraging information technologies. The aim of this thesis is to create a multi-criteria model of information technologies which would fit into health care system in the Czech Republic considering the type of technology, its capabilities and its impact on patient and cancer stage. In order to achieve this goal, it is required to determine the level of impact of the proposed measures and the implementation feasibility in the Czech republic. This is intended to be done by two different methods. The output of the first method is the analysis and evaluation of the proposed technologies, their capabilities and their impact on a patient. The aim of the second method is to assess the implementation feasibility of the proposed technologies in the Czech Republic.

## Keywords

eHealth, cancer, health care, information technologies, model, oncology care

## JEL Classification

L86 - Information and Internet Services • Computer Software, H75 State and Local Government: Health • Education • Welfare • Public Pensions

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## List of abbreviations

| | |
|---|---|
| AI | Artificial intelligence |
| API | Application programming interface |
| CCC | Comprehensive cancer center (Czech Republic) |
| CDS | Clinical decision support |
| EHR | Electronic health record |
| DVH | Dosage-volume histogram |
| DSR | Design science research |
| HIS | Health information systems |
| HIT | Health information platform |
| IASW | Individual application software |
| IMRT | Intensity modulated radiotherapy |
| ML | Machine learning |
| OAR | Organs at risk which could get damaged during a therapy, usually a radiotherapy |
| PACS | Picture archiving and communication system |
| PROs | Patient reported outcomes |
| RCG | Regional cancer group (Czech Republic) |
| TASW | Typed application software |

# Introduction

## Topic description

There are many information technologies such as smartphones, wearables, artificial intelligence and its subsets such as machine learning which have emerged in the twenty-first century. They have slowly found their way into business sphere and everyday life of people. However, their adoption in health care, particularly oncology, is much slower. There are several publications, such as Improving Cancer-related outcomes with connected health (President's Cancer Panel, 2016) or Oncology Informatics: Using Health Information Technology to Improve Processes and Outcomes in Cancer (Hesse, et al., 2016) which depict how selected information technologies could improve patient outcomes and their treatment. However, the overall research and adoption is still in early stages and conclusions of the publications sometimes differ from each other. When it comes to the Czech Republic there is an initiative called "The National eHealth Strategy of the Czech Republic" (Ministry of Health of Czech Republic, 2019) which aim is to deliver modern health care system based on information technologies. There is also an Initiative's strategic document called "Strategy of Computerization of Health Care in the years of 2016-2020" (Ministry of Health of Czech Republic, 2016) which describes set of measures which are needed in order to achieve its goal in the years 2016-2020. These measures describe information technologies and how they should be used and implemented. On the other hand, the mentioned document is very general and contains no specific recommendation for the oncology field.

That is why this master's thesis deals with the topic of improving patient outcomes and oncology care in the Czech Republic leveraging information technologies. Information needed to accomplish the goals set in this work were acquired from extensive literature research as well as from various experts and doctors in this field.

## Aim of the thesis

The aim of this thesis is to create a multi-criteria model of information technologies and assess their impact on patient outcomes in oncology in the setting of health care system of the Czech Republic. Each technology is assessed by the following criteria:

- Technology capabilities by cancer stage
- Use-cases of technology capabilities
- Degree of impact of a technology capability

The intended purpose of this model is to show how technologies can improve oncology care and promote use of these technologies in clinical practice to:

- Reduce disparities between recent technological advances and clinical practice
- Improve patients' care by leveraging patient and other clinical data
- Engage patients in their oncology care

This aim consists of four objectives:

1. Creation of multi-criteria model based on literature research
2. Evaluation of this model by assessing the current situation in the Czech Republic and confronting this model with professionals related to this field
3. Enhancement of the multi-criteria model of technologies with acquired information from these interviews
4. Evaluation of feasibility of the model by creating a project proposal for a comprehensive cancer center

## Thesis specification and limitations

As it was mentioned before, the scope of this thesis is to create a multi-criteria model of technologies in oncology care. Because oncology care is really a broad field, some specifications and limitations must be specified. The final technology model is based on extensive literature reviews and expert interviews. The mentioned technologies are limited to the cancer continuum including prevention. Technologies facilitating research and research itself such as drug trial tests are out of scope of this thesis. It should be also noted that this thesis is not written by a medical professional, therefore it does not suggest any changes in the medical care procedures except of recommendations of technologies which could aid the mentioned processes.

## Methodology

Design Science Research methodology (Peffers, et al., 2007) is used to achieve the goal defined in this thesis. This model can be divided into six parts:

- Problem definition: slow adoption of modern information technologies in oncology care as it is defined in the topic description.
- Define the objectives of solution: it is needed to specify these technologies which can serve to solve the defined problem. The second chapter aims to define these technologies and it is based on extensive literature research.
- Design and development of an artifact: an artifact in the thesis is a multi-criteria model of information technologies which is created in the third chapter.
- Demonstration: the third chapter also demonstrates the impact presented by created artifact.
- Evaluation: the current stage of oncology care in the Czech Republic, an evaluation of an artifact by medical professionals and evaluation of its feasibility are all used to an overall assessment of the created artifact. Also, the iteration back to the design stage is needed as there are valuable inputs from medical professionals available and the model is complemented by the impact assessment.
- Communication: the importance of the created and evaluated artifact is explained together with its contributions and pitfalls.

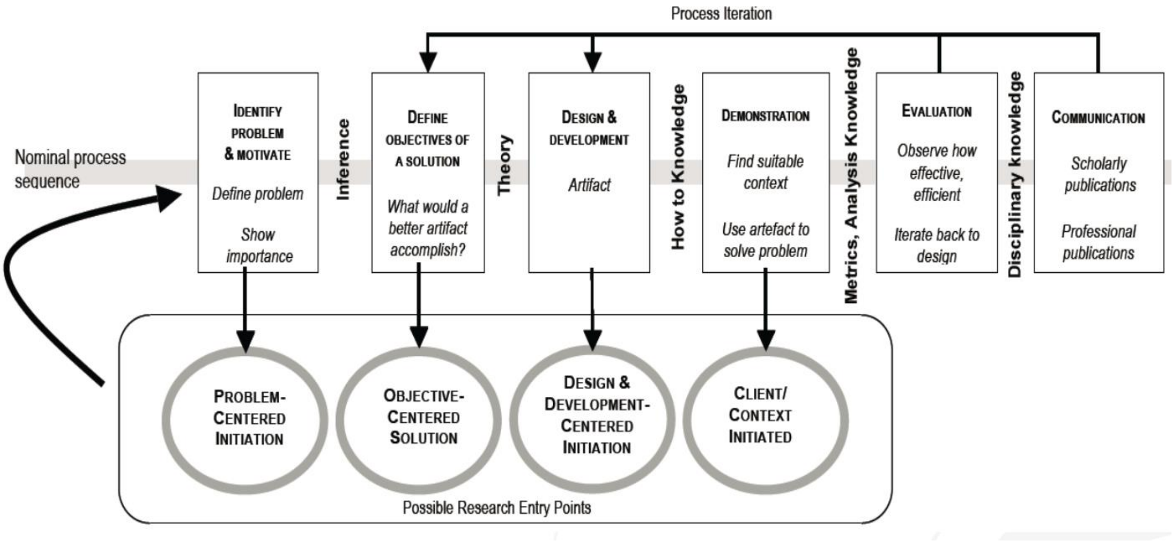


Figure 1: Design Science Research Methodology (Peffers, et al., 2007)

The analysis of current state of oncology care and verification of the artifact are intended to be done by conducting series of qualitative interviews in selected hospitals and cancer related organizations in the following two countries. It is planned to do the interviews personally in the Czech Republic and by audio calls or e-mails in the United States.

These interviews are intended to be semi-structured, where the most important questions regarding the theoretical findings are asked, however the rest of the interview is dependent on interviewee's specialization and organization.

The structure of interviews follows a dramaturgical model. The model uses a metaphor of a theater to explore social life. Social interactions are there seen as a drama where there are actors who perform on a stage using a script. Therefore, appearance and manners are very important. In this model qualitative interviews are social interactions. (Myers & Newman, 2007)

This model can be divided into these steps (Myers & Newman, 2007):

- Preparation (stage): define and find interviewees. Prepare a suitable setting for an interview.
- Understanding the roles (actors): both the interviewer and the interviewee can be seen as actors. The researcher has to play the part of an interested interviewer; the interviewee plays the part of a knowledgeable person in the organization. It is important for an interviewer to engage empathetic listening, behave in a professional yet relaxed manner and respond accordingly.
- Understanding audience: academic community and the readers of this thesis produced may be seen as the audience. Also, confidentiality and anonymity can be assured in case the interviewee works in a very competitive industry.
- Interview structure (script): in a semi structured interview, the interview is scripted beforehand. The script should not be over-prepared so there is a space for openness, flexibility and improvisation. The script should contain:
    - The opening: introduction of the interviewer

    - Introduction: explaining the topic and purpose of this interview
    - Key questions
    - Closure: asking permission for follow-up questions and asking who else could be interviewed. This technique is also called snowballing.
- The entry: In this case impression is very important and particularly first impression. It is important to make interviewee feel comfortable and to minimize social dissonance.
- The exit: The purpose of this stage is to prepare the way for the next interview, create a possibility to ask follow-up questions and find others to be interviewed.

The chapter concerning the Czech Republic also contains final multi-criteria model which is enriched with findings in the mentioned chapter.

Finally, there is a feasibility evaluation of the model created in the chapter concerning the Czech Republic which is done in a form of a project proposal. This project proposal consists of:

1. Initial study: this chapter contains the evaluation of technologies contained in the mobile as well as their alignment with the initiative The National E-Health Strategy of the Czech Republic and other project aspects such as project goals, funding, stakeholders and a project plan
2. Design and analysis: this chapter contains the description of how the technologies selected in the initial study should be implemented

# Literature Review

This chapter contains information about selected publications dealing with a topic of improving patient outcomes in oncology through information technologies or use of them in this field in general way. Each publication is briefly introduced, and it is explained why it is mentioned in this thesis.

In order to gather all relevant information to this topic the following keywords and combinations of them were used: cancer, cancer care, oncology, telemedicine, telehealth, eHealth, electronic health, HIS, health information systems, EHR, mHealth, mobile health, machine learning, AI, artificial intelligence, big data, clinical decision support, CDS and wearables.

The following sources were used to obtain this information:

- ProQuest
- Google Scholar
- US National Library of Medicine
- Web of Science
- Research Gate

**Oncology Informatics: Using Health Information Technology to Improve Processes and Outcomes in Cancer** (Hesse, et al., 2016)

The purpose of this book is to provide guidance in leveraging progress in informatics in different stages of cancer. It collects American National Cancer Care Institute evidence and presents it into format which is suitable for a broad spectrum of readers.

In the very beginning of this book, the authors argue that information technologies allow to adopt predictive, proactive, precise and participative care in regard with aging population, increasing costs of oncology care and its growing complexity. However, according to authors, this will require to create the necessary technologies for collecting and processing huge amount of data to support decision making, create distributed platform for information sharing and improve quality of care, research and empower patients and families.

The book is divided into four major sections:

- Opportunities for HIT in oncology care: by creating learning systems, reducing community disparities, data liquidity between research participants and patients, and improving patient engagement
- Support across continuum: the book tackles the role of information technologies in primary prevention, early detection, treatment, survivorship and palliative, end of life care.
- Science of oncology informatics: explaining oncology informatics as a mix of information sciences, cognitive research, organizational theory and behavioral medicine. The book explains topics such as tools for data visualization of utilization of health services, behavioral and psychological sciences, connecting health systems, informatics of cancer surveillance and medical imaging.
- Analysis of acceleration of progress: by crowdsourcing advancements in health care research, improving clinical trials by patient-centered approaches and creating new clinical research methods and HIT infrastructure to support comparative effectiveness research

Despite the fact the book is strongly connected to the specific realities of the United States health care; it provides quite a comprehensive glimpse into use of information systems in oncology care together with theoretical and practical examples of their use.

**eHealth a telemedicína: učebnice pro vysoké školy** (Středa & Hána, 2016)

The purpose of this book is to introduce eHealth and telemedicine to students of medicine. This book provides introduction to technical complexity of eHealth and telemedicine, its history and political situation. The book also provides introduction to information and expert systems in health care. The main part of this book explains clinical telemedicine in various medicine fields. The biggest usefulness of this book is in providing well-arranged information about eHealth and related topics.

**The National E-Health Strategy of the Czech Republic** (Ministry of Health of Czech Republic, 2016)

The National E-Health Strategy of the Czech Republic is a strategic document of Ministry of Health of the Czech Republic which purpose is to implement specific means of eHealth in the health care of the Czech Republic. It is a part of this thesis to assess how the proposed technologies fit in this strategic document.

**Health Information Systems - Architectures and Strategies 2nd Edition** (Winter, et al., 2011)

This book provides comprehensive look into health information systems and their importance. Authors of this book emphasize the importance of health information systems and their management in delivering health care at higher quality while lowering costs in single institutions and distributed environments alike. The book covers complex topics such as:

- Information processing in health care institution
- Introduction to HIS
- Modeling of HIS
- Quality of HIS
- Strategic Information Management

This book is instrumental in understanding the role of health information systems in oncology and finding capabilities which can improve patient's outcomes and/or comfort.

**Improving Cancer-Related Outcomes with connected health** (President's Cancer Panel, 2016)

This report was created by the Cancer Panel of the president of the United States to show how advances in the use of technologies improve health care, more specifically the oncology care. On the other hand, it also shows there are many challenges and obstacles which need to be resolved in order to deliver high-quality and patient-centered oncology care. The report is divided into three parts and each of them contains set of objectives which need to be reached. Each objective is comprised of several specific actions which directly show what improvements should be made. This report provides an overview of challenges and opportunities in oncology care in the United States. The main contribution of this report is to explain the need of HIS interoperability, integration with health applications and secured data sharing to get new insights in oncology.

**Data Needs in Oncology: "Making Sense of The Big Data Soup"** (DeMartino & Larsen, 2013)

This journal article explains how appropriate use of data can help in reducing costs in health care and increase value for all stakeholders. It identifies sources of data, challenges of data generation, collection and application for clinical, regulatory and other decision making.

According to authors possible data sources can be:

- Cancer registries
- EHRs
- Patient reported data (patient reported outcomes - PROs)
- Claims data

This article argues that data should be moved from isolated data sources into an integrated system which gets data from several sources in order to turn them into the actionable knowledge which can improve patient care and increase its value.

**Workflow-driven clinical decision support for personalized oncology** (Bucur, et al., 2016)

This paper presents a clinical decision support (CDS) framework created by authors to support complex decisions. They argue that while the adoption of CDS in oncology may help medical professionals with high complexity, improve patient outcomes and reduce a knowledge gap between research and practice. These solutions are limited in providing support in complex decision making in personalized oncology care. The work further describes what features should CDS have and describes a new framework created by authors.

**The Emerging Role of Mobile Health in Oncology** (Tran, et al., 2017)

This journal article describes opportunities and challenges of mobile health in oncology in order to provide a remote high-quality care. This article covers topics such as evolution of mHealth, its adoption by health care providers and consumers, challenges such as privacy, security, data ownership and confidentiality, HIS integration and various opportunities presented by mHealth. This article argues that mHealth has its place in oncology care and can provide opportunities to improve it, but certain challenges have to be resolved.

# 1 Introduction to oncology

## 1.1. Cancer definition and types

First of all, it should be noted cancer is not a one, single disease rather than a common name for a collection of related yet distinctive diseases. In all cases, the disease begins with uncontrollable division of cells and their spreading into surrounding tissues. In normal state, human cells have certain life cycle which starts with cell division and ends with death of a given cell when it is old or damaged. In case of cancer, however, this lifecycle is disrupted. Cells become more and more abnormal and the cells which are on the end of their lifecycle survive and redundant cells are created. These redundant cells divide without stopping and usually create masses of tissues called neoplasm or tumor. (National Cancer Institute, 2015)

Neoplasm can be generally divided into two categories which are benign and malign. The difference between them is that benign tumors do not spread into neighboring tissues and can be removed more easily. They tend to grow, however, to larger sizes. (National Cancer Institute, 2019) Malign tumors are also called cancer. There is also a category of tumors called premalignant which do not appear to be cancerous but there is a certain risk of their further development. Malignant tumors invade nearby tissues. Additionally, they can travel to more distant parts of a body through a blood stream or lymph systems and form new tumors there. (National Cancer Institute, 2015)

According to Medical News Today (Nordqvist, 2017) and UK Cancer Research (Cancer Research UK, 2017) tumors can be divided into these three categories and additional subcategories.

Benign tumors can be divided into four categories:

1. Adenomas
2. Fibroids
3. Hemangiomas
4. Lipomas

Premalignant tumors can be divided into these categories:

1. Actinic keratosis
2. Cervical dysplasia
3. Metaplasia of the lung
4. Leukoplakia

There are several types of malignant tumors:

1. Carcinoma: this type of tumor starts in epithelial tissues. These tissues cover the skin, all internal organs and body cavities.
2. Sarcoma: sarcomas form in supporting tissues of the body which include bones, cartilage and other fibrous tissues.

3. Germ cell tumor: these are tumors made from cells which served to reproduction purposes, so they mostly occur in testicles or ovaries.
4. Blastoma: these tumors are formed from embryonic tissues or developing cells called blastomas and there are far more common in children than adults.

Some types of cancer do not form neoplasms such as leukemia. In this case, bone marrow creates too many white cells which are damaged.

There are also other types of cancer which are:

1. Lymphomas: this cancer forms in lymph nodes
2. Myeloma: blood cancer which forms in plasma cells. Can form tumors in the bones or soft tissues.
3. Melanoma: it belongs to the most dangerous form of skin cancer which develops from unrepaired and damage DNA in skin cells.
4. Brain and spinal cord cancer: this cancer forms and develops in central nervous system. They are further divided according to the part of CNS where they were formed.

## 1.2. Causes of cancer

According to American Cancer Society (American Cancer Society, 2019) there are several possible factors which can trigger cell mutation and form cancer. These possible causes are further described in the following subchapters.

### 1.2.1. Family factors and genes

Because of a high prevalence of a cancer it is quite common to have several occurrences of it in a family. There might be several reasons to explain this phenomenon. First reason is that the family members exhibit certain behaviors or traits which cause higher cancer risk such as smoking, alcoholism and unhealthy eating habits. The second reason is something what cannot be so easily altered or reversed because this higher risk is caused by abnormal gene which is passed from generation to generation. This change in a gene which is not usual is called a mutation. It should be noted, however, that inherited gene mutations are less common than mutations which are acquired during a life time. (American Cancer Society, 2019)

### 1.2.2. Tobacco products

It is indisputable that there is a high correlation between use of tobacco products and malignant proliferation. There are several types of a cancer that can be linked to smoking such as lung cancer, bronchial cancer and other types which are not only limited to the respiratory system. Each year around six thousand people are diagnosed with lung cancer in the Czech Republic and around five thousand and five hundred patients die each year. (Dusek, et al., 2014) It is assumed seventy to ninety percent of lung carcinomas is caused by smoking. It has been proved that cigarette smoke contains over one thousand chemical compounds which affect cell metabolism, have inflammatory effects, support degenerative processes and some of them are carcinogenic. (Žaloudík, 2019)

### 1.2.3. Lifestyle

It is estimated (American Cancer Society, 2017) that around twenty percent of newly diagnosed cancers are caused by a poor lifestyle. Poor lifestyle includes but is not limited to body fatness, physical inactivity, alcohol abuse and poor nutrition. Being overweight increases a risk of several cancer types such as breast cancer, colon cancer, rectum cancer and others. One of the main reasons why there is a higher risk is that body produces more estrogen and insulin, hormones that can stimulate cancer growth. Having an active lifestyle has many health benefits and there is a lower risk of cancer among them. This is caused by bolstering of an immune system, hormone levels and reducing body weight. Eating properly and reducing use of alcohol is also an important part of a cancer prevention.

### 1.2.4. Radiation and sun rays

Ionizing radiation which includes radon, x-rays and gamma rays is a known carcinogen, because of its ability to penetrate a human body and damage DNA. These types of radiation are usually released in nuclear plant accidents or tests related to nuclear weapons. Certain medical procedures such as x-rays, computed tomography or positron emission tomography can also lead to a cell damage but on the other hand the risk of cancer development is very small, and benefits outweigh possible risks. (National Cancer Institute, 2015) It must be also noted that direct exposure to UV rays can lead to development of a skin cancer. It applies both to natural source of UV rays which is sunlight and artificial sources. The most common types developed from a long-term exposure are basal cell and squamous cancers. Melanoma, the more dangerous type of cancer, is less common. (American Cancer Society, 2015)

### 1.2.5. Virus infections

A virus has to enter a living human cell in order to reproduce itself. Most viruses do this by inserting their own DNA or RNA thus altering a host's cell. This alteration can lead to a cancer development. The most common viruses which can cause cancer are Human papilloma viruses, Epstein-Barr virus, Human herpes virus, Merkel cell polyomavirus, Hepatitis B virus Hepatitis C virus. (American Cancer Society, 2016) It should be noted, however, that getting infected by the mentioned viruses does not necessarily mean definitive cancer development but only its increased risk. This risk varies from person to person and it also depends on a type of virus and other factors.

## 1.3. History of cancer and an oncology care

The word cancer has its etymology in Greek words *karkinos* and it was used by a Hippocrates to describe carcinomas. He was not the first, however, to discover this disease. The oldest report of cancer comes from ancient Egypt and it stated that there is no treatment for it, only a palliative care. Many theories have been developed through the history of mankind, such as humoral theory, lymph theory, trauma theory, parasite theory and many others. Only in the twentieth century rapid advances in science allowed researchers to fully understand cancer and its origin. It began with a discovery of DNA structure by Watson and Crick who were awarded for that with Nobel Prize in 1962. Many important discoveries followed after this event including identification of cancer causes and its development in a body. (Sudhakar, 2009) The following chapter describes the most common approaches in the cancer treatment and their development.

### 1.3.1. Surgery

Surgeons from ancient times already knew that cancer would eventually come back after it has been removed. Surgeries were improved after invention of anesthesia in 1846 when entire tumors together with lymph nodes were removed. It was later discovered that cancer cells can spread to other parts of a human body through the blood stream which resulted in the understanding of the limitations of surgery in oncology care. New ways of performing a surgery together with imaging technologies have been developed since the seventies and have prevented most exploratory operations and facilitated less invasive ways of tumor removals such as cryosurgery, usage of laser or radiofrequency ablation. (Sudhakar, 2009)

### 1.3.2. Chemotherapy

In the past decades a combination of surgery, chemotherapy and radiation has been used to combat cancer. From a discovery of nitrogen mustard which can kill lymphoma cancer cells until today chemotherapy has been administered to patients resulting in successful outcomes for many patients. Nowadays new approaches to chemotherapy are being researched, including reduction of its side effects. (Sudhakar, 2009)

### 1.3.3. Radiotherapy

It was discovered in early twentieth century that radiation could not only cause cancer but also cure it. The development of radiotherapy resulted in several different ways which are used nowadays: (Sudhakar, 2009)

1. Conformal proton beam therapy: protons are used for killing tumor cells instead of x-rays
2. Stereotactic surgery: gamma knife for treating common brain tumors
3. Intra-operative radiation therapy: radiation of surrounding tissue following a surgical removal of a tumor

### 1.3.4. Immunotherapy

Immunotherapy is another approach to the cancer, and it has been advancing in the past decades. It boosts body natural defenses to fight cancer and it uses natural or artificial substances for that purpose. There are several types of immunotherapy such as usage of antibodies, nonspecific immunotherapy which boosts immune system to fight cancer, virus therapy and T-cell therapy. (Cancer.Net, 2018) It is a known fact that the immune system plays a major role in a development of neoplasm. The most known proponent of this approach is an American surgeon called William Coley who observed a regression of a sarcoma after an erysipelas infection. Afterwards he started injecting his patients, who had inoperable cancers, with vaccinations in order to create an immunity response. (Oiseth & Aziz, 2017) Nowadays, progress in a cancer biology and its better understanding have resulted to a state where immunotherapy is used and is accepted as a part of a complex cancer treatment. (Bartůňková, et al., 2015)

### 1.3.5. Targeted therapy

Since the nineties, the targeted therapy has been developed to overcome the shortcomings of the conventional medicine which not only killed cancer cells but healthy cells as well. Targeted therapy can be divided into three categories: (Sudhakar, 2009)

1. Growth signal inhibitors: growth factors inform cells when to grow and divide. Unfortunately, any change in this signaling contributes to the growth of cancer cells.
2. Apoptosis: is a natural process where cell dies if a DNA gets damaged. Certain drugs can force cancer cells to die.
3. Endogenous angioinhibitors: is a form of targeted therapy which stops tumors from creating new blood vessels.

# 2 Technologies

This chapter contains list of promising technologies which could improve outcomes of patients in oncology. Technologies analyzed (see chapter Literature Review) in this chapter can be divided into three categories:

1. Health information systems
2. Data analytics and decision support (Artificial intelligence and data analysis; Clinical decision support systems)
3. Telemedicine

The research of each technology was conducted in the similar manner and contains:

1. Description of technology: This chapter contains introduction to a technology or the group of technologies.
2. Technologies: In case the chapter describes a group of technologies, they are further described in this chapter.
3. Possible use-cases or adoption reasons: Purpose of this chapter is to highlight use-cases or adoption reasons of a given technology
4. Examples of use or case studies: Some technology chapters also contain real-life examples or case studies of use of a given technology. This applies to technologies which are not perceived to be widely used in a clinical practice in the Czech Republic.
5. Challenges with a given technology: Some technology chapters also describe different challenges or prerequisites which need to be resolved before a technology can be used.
6. Conclusion: Summarization of findings.

Information gathering was conducted by using several sources and keywords which are described in the chapter dealing with literature research.

It has to be noted that new technologies that would support and enhance oncology care cannot exist in vacuum, but rather have to be part of or integrated with health information systems and have a place in an existing health care system.  The assumption of this thesis is that all described technologies should be integrated or be a part of health information systems in order to provide a holistic picture of a patient and patient-centered care. That is why the first chapter describes health information systems and electronic health records and their importance.

The following diagram depicts relationships among technologies which are described later in subsequent chapters. It shows that all of them are part of eHealth. The purpose of this diagram is to show relationships and dependencies of each technology independently on any health care system. It does not intend to go into greater detail as opposed to Schema of Information system in health care institutions. (Potančok, 2012) There are several definitions of eHealth but according to Leoš Středa et al. (Středa & Hána, 2016) eHealth is a medicine field containing health informatics, a health care organization and a strategy which is focused on delivering medical service and information using internet and related technologies. Its aim is to improve health care on both local and global level.

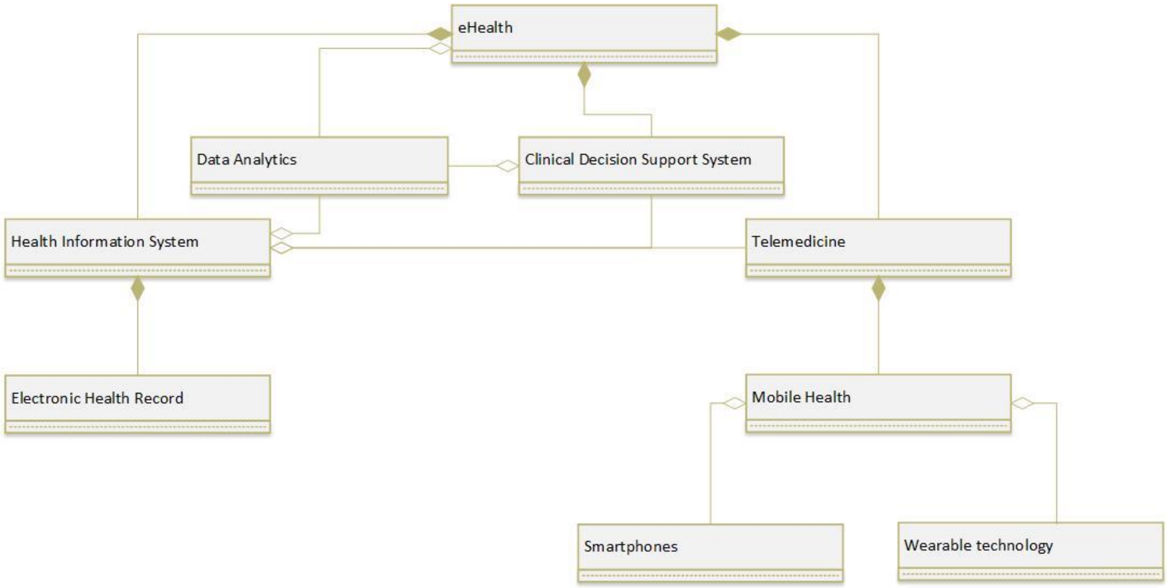


Figure 2: Relations of described technologies

## 2.1 Health information systems

### 2.1.1 Introduction

According to Alfred Winter et al. (Winter, et al., 2011) health information system (HIS) is a socio-technical subsystem of a health care organization which supports storing and processing information of a health care organization which might be a single institution ranging from a single doctor's office to hospital or group of health care institutions.

Health information systems can be divided into two categories which are institutional (deployed in one institution) or trans-institutional (used by a group of otherwise legally separated institutions). For all intents and purposes of this thesis health information system or its abbreviation means both types unless stated otherwise.

In order to successfully support patient care, HIS must successfully manage these tasks:

- Patient information are provided:
    - Up-to-date
    - At a right time
    - To the right people
    - In an appropriate form
    - In a right place
- Create knowledge base about diseases, side effects and medication interactions
- Track additional information about patient care such as: quality, performance and costs

According to Martin Potančok (Potančok, 2012) a HIS is composed of the following components:

- Central patient administration
- Electronic health record which can be divided in two parts:
    - Doctor's documentation
    - Nursing documentation
- Electronic request forms
- Management of operating rooms
- Ambulatory care

The main focus will be put on an EHR component due to the following reasons:

- This component is considered as a key feature of any health information system
- The quality of this component is perceived to be linked with the aim of the thesis which is to improve patient outcomes in oncology

#### 2.1.1.1 Electronic health records

Collecting and storing information about a patient is the most important function of any health information system. According to Alfred Winter et al. (Winter, et al., 2011) electronic health record is a collection of data related to a patient that is generated during the care of a patient and is stored electronically. There are two types of electronic health records. The first one is discreet which means that a given record is stored at a health care provider which might be one institution or a group of institutions which are linked together. The second type is provider agnostic, so the record is not dependent on any institution. There are several names and abbreviations for locally stored electronic health records, such as electronic patient record or electronic medical report which often overlap and create confusion. For the sake of clarity only one term, electronic health record, will be used in this thesis, unless it has to be explicitly defined. In that case it will be specified if it is a provider centric or a provider agnostic one.

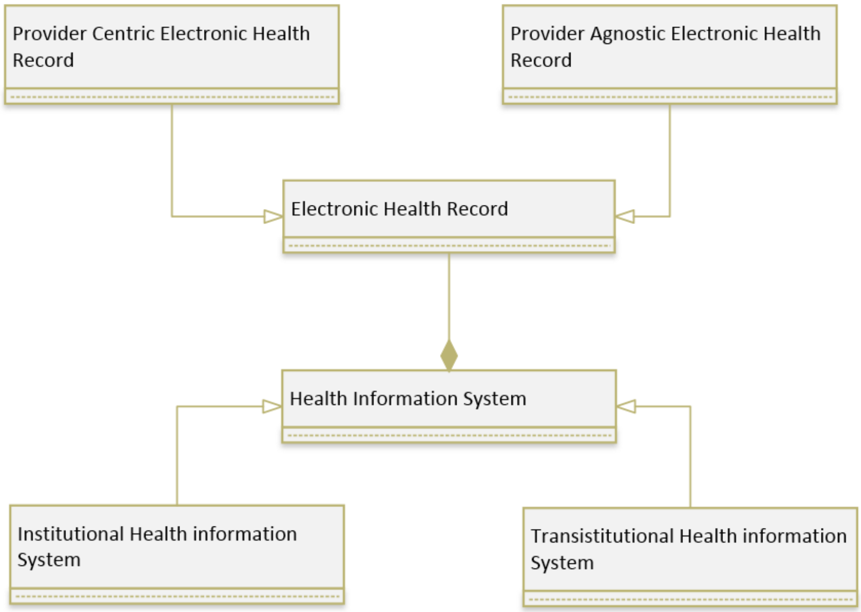


Figure 3: Relationship between HIS and EHR and their types

### 2.1.2 Adoption reasons

#### 2.1.2.1 Quality of care

Decisions of health care professionals are based on vast amount of information about a patient's current state. If the information is not complete, valid, up-to-date or accessible to the right people then a patient is exposed to a risk of medical errors in a form of undertaking redundant procedures or even worse, getting a wrong diagnosis or medication. A right health information system should manage all tasks related to patient information in the manner these risks are mitigated to the lowest possible level. (Winter, et al., 2011)

#### 2.1.2.2 Economic factors

According to the statistics (Český statistický úřad, 2017) European countries spent on average 8.7% of their total gross domestic product on health care in 2015. The Czech Republic spent 7.5% of its GDP which is around 353.7 billion CZK. It is not really clear how much of these costs can be accounted to information processing but according to Alfred Winter et al. (Winter, et al., 2011) the number is relevant. He argues that already in 1960s, around 25% of hospital costs were related to information processing. It can be only estimated how much non-computer information processing actually costs hence differs from computer-based processing. On the other hand, it can be estimated that the operating costs of maintaining paper-based archive can be much higher because of a bigger number of personnel and vast number of documents, not to mention costs due to mistakes made in those documents and a time needed to access them (Winter, et al., 2011). Therefore, it is evident that efficient computer-based information processing offers cost-reduction potential.

### 2.1.2.3 Productivity factors

Nowadays information systems and technologies play an important role in any organization's productivity. In other words, information belongs to important productivity factors of a hospital. Providing information which are independent on a place or time, accessible to the right people and in an appropriate form enhances productivity of health care, hospital management and competitiveness. (Winter, et al., 2011)

### 2.1.2.4 Holistic approach

High-quality information processing means that a complete picture of patient's care is available, and it is not dependent on hospital department or more desirably on health care institution. This holistic view mitigates potential negative consequences of having incomplete patient's information otherwise caused by information fragmentation when the patient is treated by various health care professionals. (Winter, et al., 2011)

By bringing together data from different sources thus creating this holistic view, an architecture for medical professional's decision support is created so a data-based decision can be made in a timely manner.

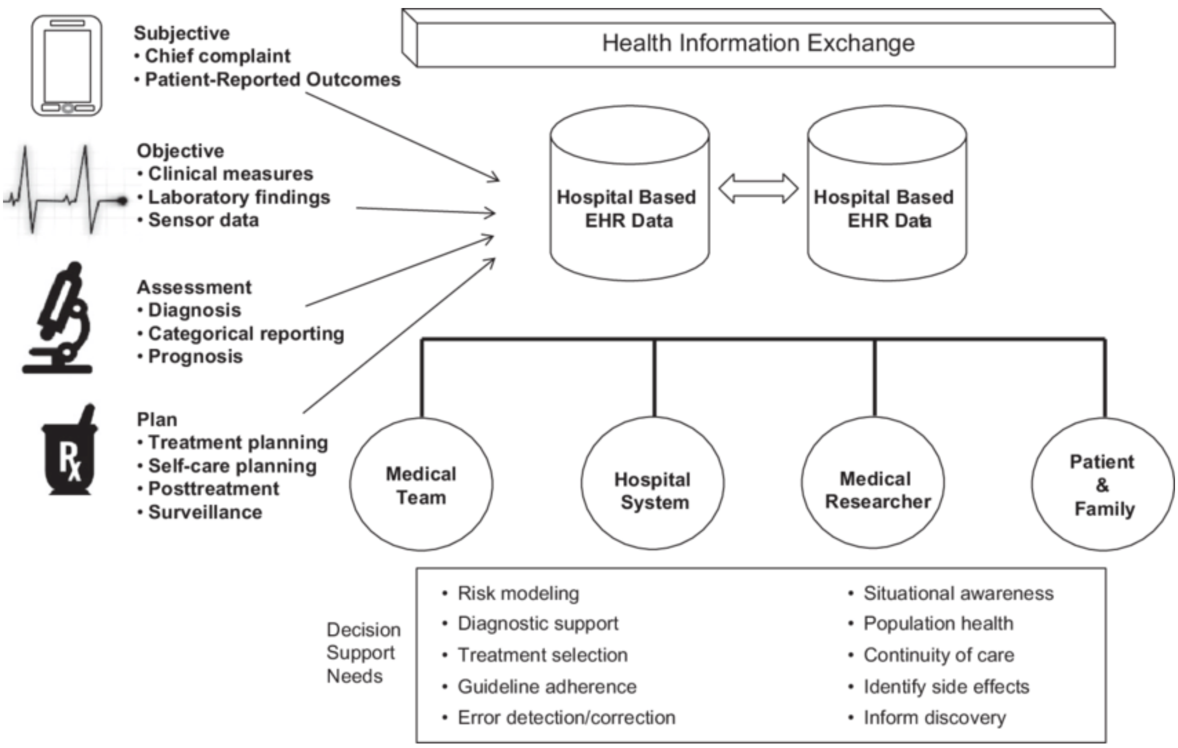


Figure 4: Example of decision support with fully connected data-driven environment of care (Hesse, et al., 2016)

#### 2.1.2.5 Patient engagement

It is possible to use data stored in HIS to create patient portals which can serve as a central point for engaging with patients. Patient portals can have functions such as secure messaging with patient's health care team or medical information sharing. Medical information sharing can range from simple functionality such as showing list of medications and diagnoses to sharing laboratory and radiology results, doctor's notes and clinical summaries. Patient portals can also provide educational materials related to a patient's condition. It is also possible to share patient-reported information such as PROs, important changes in health history, patient values and goals etc. More complex patient portals are more valuable for a patient, but on the other hand they are more difficult to maintain. Nevertheless, patient portals can improve patient engagement in their care as it was shown that secure messaging improves quality outcomes, care delivery and self-management. For example, creating a culture of patient engagement has been one of the key modernization efforts in United Kingdom health care as it was acknowledged as a way to cope with an aging population and increasing medical costs. (Hesse, et al., 2016)

### 2.1.3 Challenges

#### 2.1.3.1 User experience

Many users of health information systems report poor user experience while using them. This experience results from several reasons (President's Cancer Panel, 2016):

1. Complicated user interface
2. HIS is misaligned with clinical workflow or health care institution processes
3. Problems with stability

As a result, there is a higher risk of errors in patients' electronic health records. These errors might range from incomplete data to more severe mistakes. In order to mitigate this problem, it has to be ensured that HIS interface is intuitive and fully supports clinical workflows and processes. Only then health information systems can provide added value to users and patients. This has been a major problem in the United States because systems were not designed to be intuitive and usable enough to support outcomes that were expected. According to Presidents' Cancer Panel (President's Cancer Panel, 2016) EHR systems are often misaligned with clinical workflows and doctors spend more time on documentation and less time on direct patient care and even spend some time inserting patient data outside office hours.

#### 2.1.3.2 Security

There are some risks concerning storing patient's records in an electronic form. A patient record is probably the most sensitive information that can be stored about one person. Therefore, it has to be guaranteed that a health information system provides this information only to authorized persons. This comprises of availability, confidentiality and integrity. (Winter, et al., 2011)

#### 2.1.3.3 Legal issues

In order for electronic health records to be widely adopted, they must be supported by a legislative of a given country. A country should have laws in place which not only allow to store patient's record in an electronic way but also define requirements needed to accomplish it.

#### 2.1.3.4 Integration with 3rd party applications and devices

To fully facilitate benefits of mHealth applications and wearables, it has to be ensured that they can be easily and securely integrated with health information systems. This will ensure acquired data will not be duplicated which would be inefficient and could lead to poor data quality. This also applies to other applications and tools that can, for example, analyze large sets of data and provide results based on artificial intelligence or its subsets such as machine learning or data mining. Unfortunately, the majority of current health applications is disconnected from health care information systems. (President's Cancer Panel, 2016) This fact creates obstacles in increased patients' engagement in their health care and meaningful usage of data analysis tools.

#### 2.1.3.5 Electronic health record integration

Before electronic health records can be shared among several institutions, thus being institution agnostic, some questions regarding data structure and ownership have to be resolved. Another question is data availability and security and who should be responsible for it. According to Alfred Winter et al. (Winter, et al., 2011) there are several strategies available and they are sometimes combined in practice:

1. Provider-centric strategy: medical records are kept by the institution that created them and are available on demand to other organizations.
2. Patient-centric strategy: patient is primary owner of their data. They can create it on an internet portal and the record is filled by the patient and other medical professionals.
3. Regional or national-centric strategy: in this case, the health record is maintained centrally by a public institution either on regional or national level.
4. Independent health banks strategy: the health record is not maintained by any of the stakeholders in health care, rather by trusted neutral entity which would be responsible for managing it.

### 2.1.4 Conclusion

Only a health information system that can successfully accomplish all defined tasks can support introduction of subsequent technologies. It goes without saying that it does not make sense to introduce new technologies if the underlying information system is missing or does not function properly. There has been a substantial progress worldwide in this area, but there is still working to be done especially in areas of user experience, security and integration. Unfortunately, initial problems with implementations of EHR systems in the

United States (President's Cancer Panel, 2016) and failed implementation of electronic health documentation (IZIP) (Medical Tribune CZ, 2011) in the Czech Republic make the progress in this area even harder.

## 2.2 Artificial intelligence and data analysis

### 2.2.1 Introduction

Cancer treatment is unique for each case, since many variables such as type of cancer, cancer stage, patient characteristics, ability to undertake treatment and response to the treatment are considered. Additionally, radiographic assessment of a neoplasm commonly relies on visual interpretation or evaluation of it. (Bi, et al., 2019)

Clinical research, new approaches in treatment, technological advances, genome sequencing have caused positive changes in oncology care. On the other hand, they created mass amount of clinical, laboratory and imaging data. (Letzen, et al., 2019)

Artificial intelligence, its subsets and big data have a potential to help medical professionals to deal with a growing complexity of oncology care and put mass amount of generated data to use to improve for example decision making and evaluate patient prognosis.

### 2.2.2 Technologies

#### 2.2.2.1 Big data

Big data is a term for strategies and technologies needed to gather, organize, process, and gather insights from large datasets. (Ellingwood, 2016) Because of the size of processed data, quantitative issues of data are transformed into qualitative issues in the capture, processing, storage, analysis, and visualization of data. Big data are characterized by 4V:

1. Volume
2. Velocity
3. Variety
4. Veracity

Medical data are quite distinctive, because of their heterogeneity, and difficulty to access them. Most health care providers are reluctant to provide data or practice data science due to several reasons such as luck of incentives, additional cost, legal, security and privacy issues. Medical big data are relatively small to data from other areas, however lots of data come from cases which are difficult or impossible to reproduce. (Lee & Yoon, 2017) Possible sources of data can include interventional studies, e.g. clinical trials and non-interventional studies, e.g. registries, surveillance studies, EHRs etc. (DeMartino & Larsen, 2013)

Big data analytics techniques belong to the important prerequisites for advanced clinical decision support systems. These techniques can be divided into three groups:

1. Descriptive analytics: analysis of past events using historical datasets
2. Predictive analytics: analysis of possible future events using historical patterns
3. Prescriptive analytics: leveraging descriptive and predictive analytics to identify possible action with the best effort and benefit ratio (Bresnick, 2017)

#### 2.2.2.2 Artificial intelligence

Artificial intelligence is a term to describe an approach to identify complex relationships and recognize patterns within observational data which can change in the course of time or as new data are available.

In other words, artificial intelligence encapsulates several methods and approaches which include logic, machine learning, deep learning, computer vision etc. (Xu, et al., 2019)

Recent improvements in parallel computing and cloud-based computing have increased possibilities of utilization of an artificial intelligence. Also, significant increase of data sources in oncology presents opportunities for an artificial intelligence to improve oncology care. (Thompson, et al., 2018)

#### 2.2.2.3 Machine learning

Machine learning is a subset of artificial intelligence that uses algorithms to learn and develop computer programs from provided data to use them. The distinction to other data analysis techniques is that this approach to learn from data is not programmed explicitly.

There are several learning methods such as supervised, semi-supervised and unsupervised learning. The difference between them is that how much the provided data is labeled and classified.

There are also other machine learning techniques available (Letzen, et al., 2019):

- Artificial neural network (ANN): this is used to find complex nonlinear relationships and create predictions on a complex set of input and output data. Once it is trained, new data can be passed to artificial neural network and output can be predicted. According to Letzen et al. (Letzen, et al., 2019) this can be used for example to predict a tumor response to a certain treatment.
- Deep learning: it is a use of ANN which includes a large number of hidden layers between the input and output data. Convolutional neural network (CNN) is a type of deep ANN that can be used for example for decision support in radiologic diagnosis by classifying malignant and benign neoplasms based on patient's MRI.

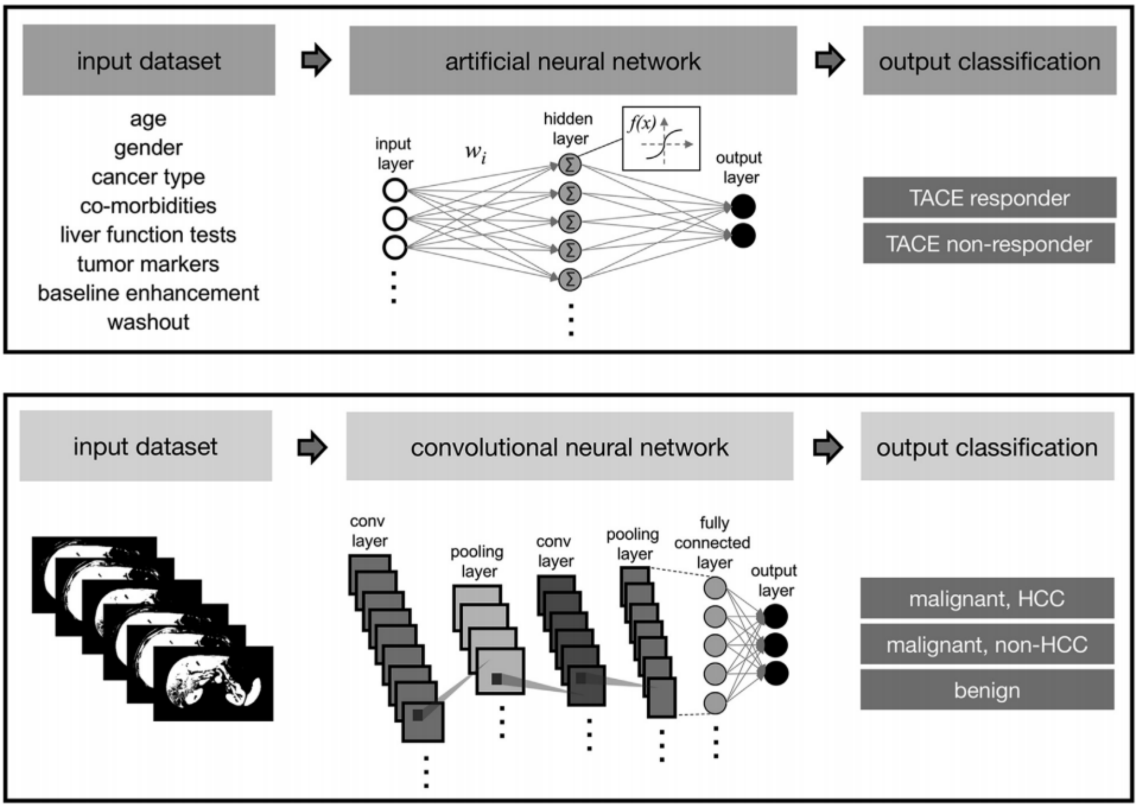


Figure 5: Basic schema of ANN (upper part) and CNN (lower part) use in oncology care. HCC: hepatocellular carcinoma; TACE: trans-arterial chemoembolization (Letzen, et al., 2019)

### 2.2.3 Use-cases

#### 2.2.3.1 Image analysis in radiology

According to Wenya Linda Bi et al. (Bi, et al., 2019) artificial intelligence, and deep learning in particular, can serve to quantify patterns in medical imaging data thus helping in detection, characterization and monitoring of tumors. In this case, AI can serve to reduce errors from omission by highlighting objects of interests in radiographs. This detection is also called computer-aided detection (CADe). CADe has been used as an aid to identify missed cancers in low-dose CT screening, detect brain metastases in MRIs and improved radiologist sensitivity for detecting abnormalities in general.

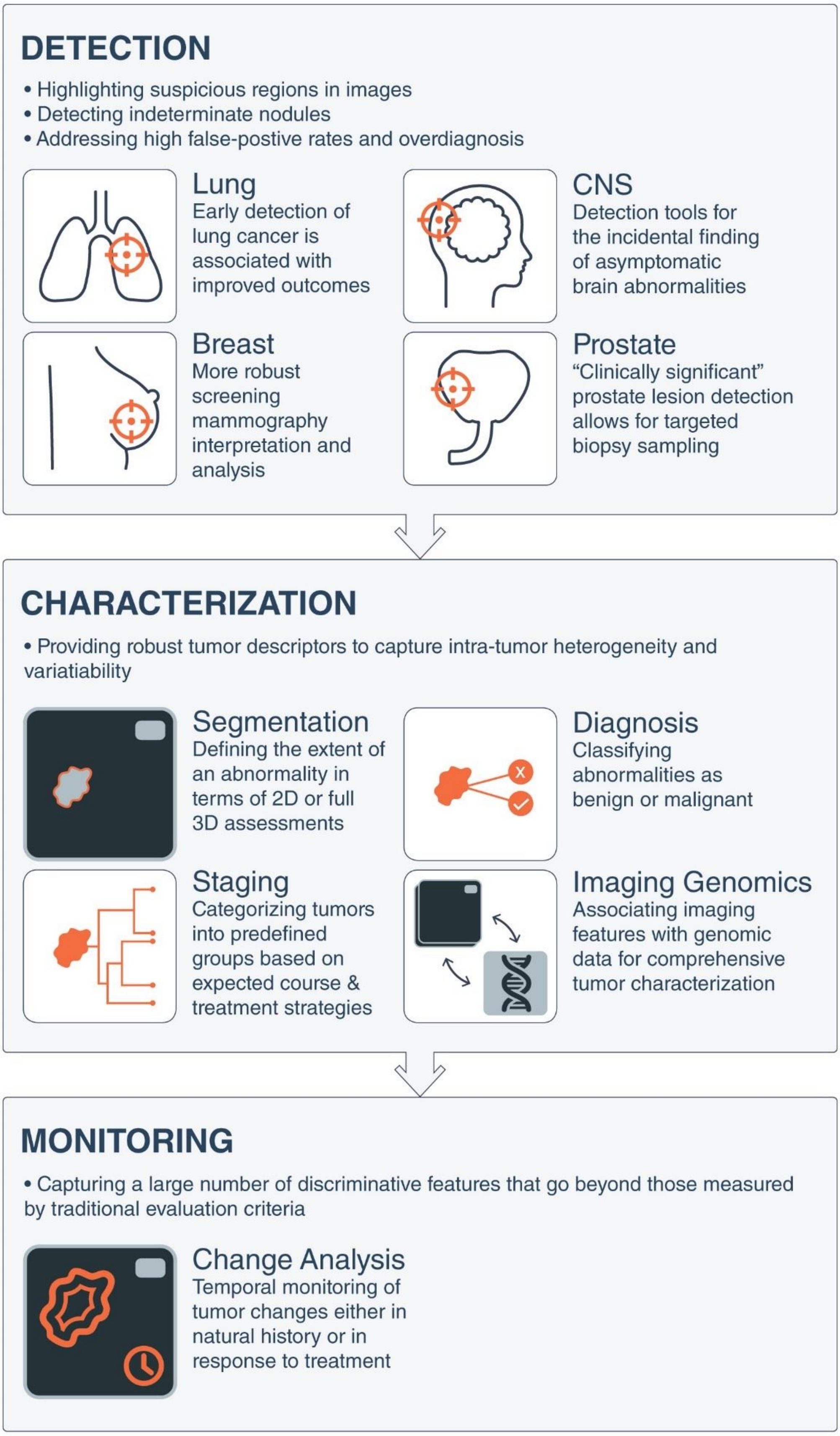


Figure 6: Application of AI in oncology imaging (Bi, et al., 2019)

### 2.2.3.2 Decision making

According to Sander et al. (Sanders & Showalter, 2018) massive amount data generated by HIS can be used to accelerate identification of new hypotheses to find new correlations among clinical factors, patients' outcomes and patient characteristics that cannot be studied in randomized and controlled trials. This can further help to divide patients into risk groups, treatment response groups and potentially design highly tailored therapy. According to Thompson et al. (Thompson, et al., 2018) the scope and accuracy of AI-based CDS remains principally limited to the limited availability of high quality clinical data and patients' outcomes and a lack of standardized processes and data structures among institutions. However, there are several initiatives such as for example CancerLinQ, EuroCAT, OncoSpace and FlatrionHealth which are starting to be used and are gaining acceptance.

### 2.2.3.3 Therapy planning in radiotherapy

Another use of big data and AI can be in radiotherapy. Radiotherapy, despite the fact that is already technically and physically personalized due to variations in anatomy and tumor characteristics, still can use AI to help optimize the dosage and predict toxicity.

Additionally, there are several studies regarding genes and tumor radio sensitivity and patient sensitivity. For example, tumor-specific genes affecting radio sensitivity in HPV related carcinoma of the oropharynx have been already found and used to guide treatment decisions. While the research regarding radio sensitivity and genomics in general is still in progress, it can be said that big data are the key to incorporate genomics into clinical decision making. (Sanders & Showalter, 2018) That is why Radiogenomics Consortium (RGC) was established in 2009 and consists of 194 investigators at 112 institutions in 26 countries. Its goal is to bring together collaborators to acquire data and samples to improve the study of radio genomics. (Benedict, et al., 2016)

There are also several projects described later which use AI to serve as automated segmentation and contouring tools. These tools serve to improve a selection of an area of an organ or a body intended for a therapy. They can be used to improve efficiency of a segmentation and contouring of target volumes and organs at risk. (Thompson, et al., 2018)

### 2.2.3.4 Patient prognosis

Big data and AI can be used to determine prognosis of oncologic patients. That will allow medical professionals to assess each cancer and decide how aggressively to treat it and what additional steps to take after a tumor is removed. Additionally, they can help in long-term outcomes predictions such as survival rate and adjustments in treatment. Example of this information can be used to determine whether to provide complementary treatment or it is useless. (Bishop, 2013)

### 2.2.4 Examples of use

#### 2.2.4.1 Centralized HIT platforms

There are several initiatives and projects in Europe and the United States which serve as centralized HIT solution to provide personalized medicine using big data and AI:

- CancerLinQ: one example of how big data and machine learning is used to provide actionable intelligence is CancerLinQ network (ASCO, 2019) created by ASCO which is later described in the CDS chapter. It uses direct feeds from HIS to aggregate data. Its future data sources may also include cancer registry data, claims data, genomics data etc.
- Flatrion Health: Flatrion Health (Flatrion Health, 2019) is similar to CancerLinQ and also extracts clinical data from patient records to enable research and optimize care. (Benedict, et al., 2016)
- Oncospace: Oncospace serves as a shared database for radiation oncology to provide decision support, help with treatment planning and research. According to them (Oncospace, 2019), their database aggregates clinical information about patients and their course of care to build knowledge upon them. The data is compiled in an analytical database to use it for a clinical quality control, evidence-based medicine, research and decision support. The goal is to use the knowledge to improve quality and safety of oncology care.
- Oncora Medical: Oncora Medical (Oncora Medical, 2019) is a Philadelphia startup which has been developing a precision radiation oncology platform. The platform uses various EHR data and registries data to learn from every patient in order to help medical professionals to help them with decisions regarding a patient's therapy.

#### 2.2.4.2 euroCAT

Similar but different project in terms of approach was launched in Europe called euroCAT. It uses both big data and machine learning technologies and is a collaborative project of radiotherapy institutes in Belgium, Germany and Netherlands. The local data are mined, pseudo-anonymized, remapped to common data model and made available to partners in the network. These trusted partners do not access these data directly, rather use machine learning algorithms to access different data stores to learn from them. This concept called distributed learning makes possible to share knowledge without data having to leave a particular institution. (Lustberg T, 2017), (Lambin, et al., 2013)

#### 2.2.4.3 Big data and AI as a part of a health information system

There are several vendors of radiation oncology health information systems or treatment planning systems worldwide which incorporate big data and/or some AI subsets in their solution. In other words, they provide ability to extract, transform and process information from underlying databases. It is expected that these systems will incorporate more data from patient's records in the future. (Benedict, et al., 2016)

#### 2.2.4.4 Contouring and segmentation systems

As it was mentioned before, there are several projects which use AI to help medical professionals to contour areas of interest intended for a therapy:

- Mirada DLC Expert: it uses deep learning technique to automatically contour areas of interest, hence the name of a product which stands for deep learning contouring. (Mirada, 2019)
- Microsoft InnerEye: project InnerEye (Microsoft Corporation, 2019) uses ML for automatic delineation of areas of interest in 3D radiological images. It also uses deep learning to help contour and segment neoplasm precisely from adjacent organs at risk.

### 2.2.5 Challenges

#### 2.2.5.1 Legal and regulatory

In order to be able to use big data it must be ensured that the legislative of a current state allows and supports usage of EHRs and some form of oncology registry either on regional or national level is established. Furthermore, it is needed to be ensured that the EHR processing is in accordance with GDPR. This can be ensured with the signed consent of a patient (The office for personal data protection, 2019)

#### 2.2.5.2 Security and privacy

Patients' privacy and security must be guaranteed prior using their data for any kind of analytics. One way to ensure it is to anonymize patient's data in that way that some patient's characteristics are not processed, and patient cannot be traced based on remaining characteristics. Another problem is data breaches. In United States alone, there were 477 breaches which affected 5.6 million patients in 2017. (Spitzer, 2018) According to a survey (DeMartino & Larsen, 2013) 85% of Americans have some kind of anxiety when it comes to EHR. They often worry about data breaches, corruption and damage or inaccessibility during an outage. Health care providers should therefore make sure that data security belongs to the top priorities in order to gain public trust and acceptance. It should be also noted that the data processing should be GDPR compliant so the prior approval from a patient is needed.

#### 2.2.5.3 Tools and algorithms

Even if the questions regarding security, privacy and legal issues are resolved, there must be created algorithms which are able to process massive and imperfect medical data. Additionally, human-computer interaction for visualizations should be created in order to fully make use of these data. (Hesse, et al., 2016)

#### 2.2.5.4 Data quality

It must be ensured that provided data are of certain quality and certain standard. There should be a mechanism in place which can validate and clean error-laden data. For example, there was a case in United States in which analysis of emergency room admissions showed that eight patients were 999 years old. There are plenty of errors which are missed by algorithms but can be spotted by an expert. (Hesse, et al., 2016) Furthermore, the variety of health information system causes that EHRs have often different data structure which complicates data analysis.

#### 2.2.5.5 Data equity

According to Thompson et al. (Thompson, et al., 2018) is crucial that clinical data come from diverse population to reduce biases, inequities and disparities. In other words, datasets with diverse data should reflect the population in which the they are going to be implemented.

### 2.2.6 Conclusion

With an increasing use of EHRs there is a growing size of generated data which can be put into further use. Also, other data sources such as national or regional oncology registries, health insurances' data, medical research and trials' data and other socioeconomic statistics can be used to enhance data from EHRs. It is evident AI and big data can be used in several variants in order to improve decision making based on real data and are an important prerequisite to a continuously learning CDS system. There are several examples from around the globe such as NIH Big Data to Knowledge Initiative (Hesse, et al., 2016), Integrated Cancer Information and Surveillance System at University of North Carolina Lineberger Comprehensive Cancer Center (President's Cancer Panel, 2016), CancerLinQ, euroCAT and others which prove that big data and AI are already helping in the field of oncology.

## 2.3 Clinical decision support systems

### 2.3.1 Introduction

Clinical decision support systems (CDS) can be defined as health information technologies applications that relate to individual patient health data to established knowledge bases and thereby assist in clinical decision making and health management. (Hesse, et al., 2016) First CDSs emerged in the second half of the twentieth century. They helped in various fields such as infectious diseases departments or laboratories. (Středa & Hána, 2016) Nowadays when there is an overwhelming amount of information available it is critical to ensure that medical professionals have tools to their disposal to determine what is relevant to their patients and their care in order to improve their outcomes. (Monica, 2017)

### 2.3.2 Use-cases

#### 2.3.2.1 Decision making and patient prognosis

The main reason for an adoption of a CDS system is the complexity of cancer, because as it is known it is not a single disease, rather than collection of distinctive diseases. Considering all factors such as cancer stage, patient characteristics and genome, cancer type and need of a multidisciplinary approach it can be quite difficult to determine the best treatment. The last reason is reducing the knowledge gap between clinical research and practice. (Bucur, et al., 2016)

With a growing complexity of oncology care medical professionals are challenged to recognize the molecular subsets of common cancers, interpret results of complex diagnostic tests, develop suitable treatment plans, so while standard CDS systems can help, in complex situations they are either lacking in functionality or information are outdated. (Hesse, et al., 2016). According to Walsh et al. (Walsh, et al., 2019) human cognitive capacity is typically constrained to five variables for decision making. So, in context of growing number of available biomarkers and therapeutic options, this is a limiting factor to reach an adequate decision as it is depicted in Figure 7. That is why they argue that the decision support systems must be multifactorial, what means they must include the following components in order to provide valid predictive models:

- Rapid learning health care systems: by using AI and big data to progressively deliver appropriate knowledge to appropriate users in the workflow process by reusing data from EHR and/or clinical trials to support decision making and evaluate patient prognosis. Possible examples are providing predictions for toxicity, tumor control, quality of life and cost effectiveness.
- Integrate all data: clinical, imaging, genetics and costs

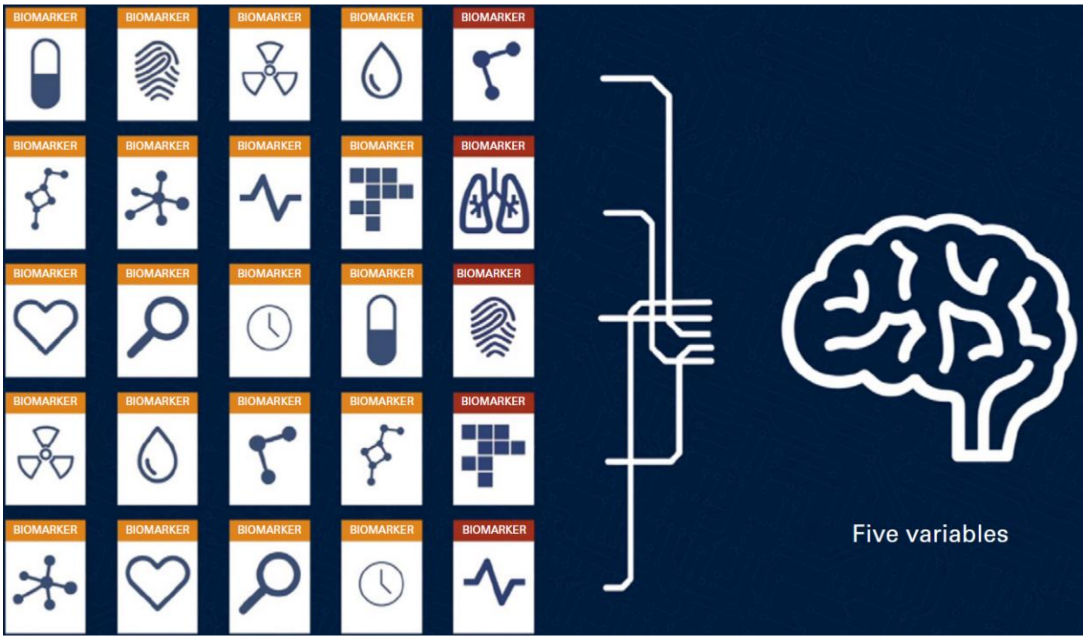


Figure 7: Typical human cognitive capacity (Walsh, et al., 2019)

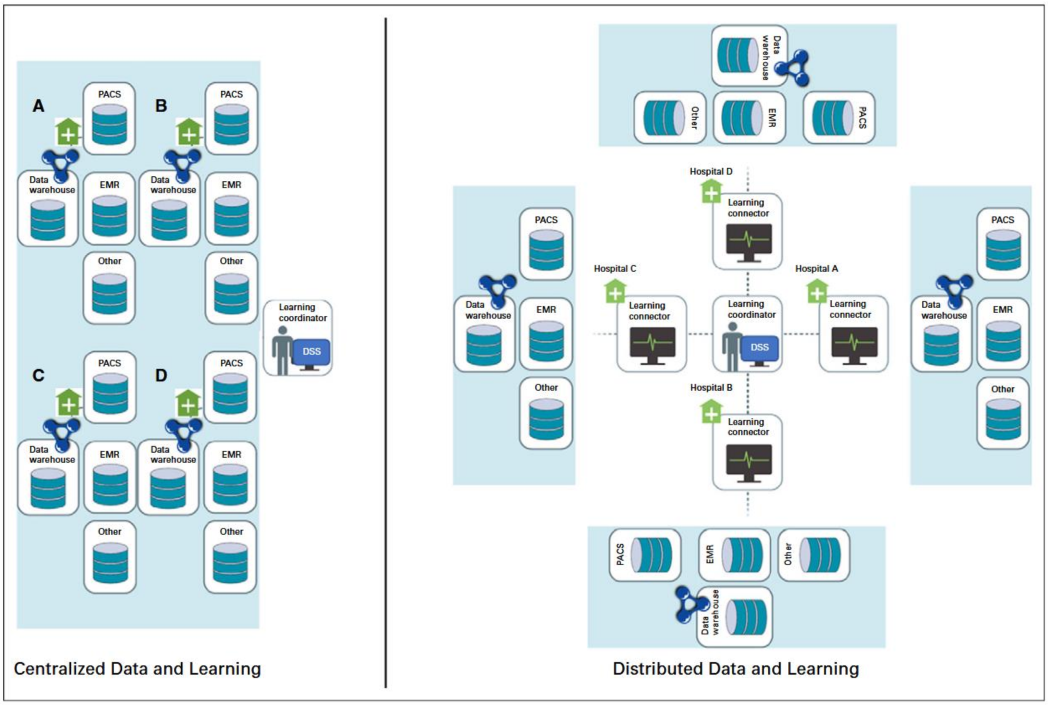


Figure 8: Centralized and distributed data learning approach (Walsh, et al., 2019)

### 2.3.3 Examples of use

#### 2.3.3.1 Hackensack Meridian Health

Hackensack Meridian Health is an integrated health care in Edison, United States which encompasses several hospitals, ambulatory care centers and other medical facilities. They created a gene expression profiling tool which helps oncologists and hematologists as a clinical decision support tool that uses large data sets (in terms of size) and improving decision making in oncology care. This tool helped them to improve clinical outcomes at patient level as well as to reduce total costs of care. The tool was later commercialized as a health information platform to provide new insights using EHR data and analytics such as machine learning. (Cota Inc., 2019) (Healthcare Informatics, 2017)

#### 2.3.3.2 CancerLinQ

According to (Hesse, et al., 2016) Cancer Learning Intelligence Network for Quality is a HIT platform designed as an oncology rapid learning healthcare system. It uses big data technology to use data from every patient. Its purpose is to meet a need for more effective, adaptable and comprehensive quality improvement tools at the point of care. CancerLinQ gathers data through direct feed from HIS of participating oncology care providers. Its main purposes are:

1. Provide real-time quality feedback to oncology practices
2. Provide CDS system to help medical professionals to choose the right therapy for each patient

3. Find new patterns to improve care by using analytics tools

CancerLinQ was launched in 2016 and more than 58 health care providers joined in the first year. (President's Cancer Panel, 2016)

#### 2.3.3.3 IBM Watson

The aim of IBM Watson for Oncology is to deliver patient care which is evidence-based and patient-centric, reduce unnecessary treatment variability and derive insights from large amounts of dynamically curated data. (IBM Corporation, 2017)

IBM started selling Watson to recommend treatments to doctors around the globe, but it was found out that Watson sometimes recommended treatment plans that were either incorrect or unsafe. The main problem of Watson was that it had been fed by incorrect data containing model cancer cases and hypothetical patients instead of real patient data. There are some cases, however, where Watson is already helping such as Mayo Clinic health care company, Manipal Hospital in India and Memorial Sloan Kettering Cancer Center. (Nelson, 2018) IBM Watson shows that power of any AI system relies on input data.

### 2.3.4 Challenges

In order to be able to fully leverage a learning CDS system, these prerequisites in the subsequent chapter should be resolved.

#### 2.3.4.1 Need of real data

To get the best from CDS system, it is required that it has access to all data needed to reach a correct and meaningful decision. Input data should have the following attributes:

- Realness: it is meaningless to provide recommendations based on a model and idealized cancer cases
- Comprehensiveness: it is needed that data acquired from HIS provide a complete picture of a patient and no important detail is omitted.
- Validity: input of incorrect data should be minimized to the lowest possible level

However, in order to retrieve and interconnect real data several challenges need to be overcome: (Walsh, et al., 2019)

- Inadequate human resources or time
- Cultural and linguistic difficulties
- Differences in recording of data or management records
- Academic and political worth of data
- Legal, privacy and security issues

#### 2.3.4.2 Data diversity

Apart of getting real patients' data from HIS it is also needed that CDS system leverages data from all relevant sources such as national or regional registers or clinical researches and trials. This is needed to support medical professionals in complex decisions in oncology care. According to Anca Bucur et al. (Bucur, et al., 2016) oncology needs multidisciplinary approach with coordination across clinical specialties and access to large volumes data. Additionally, most CDS systems in 2016 were unable to support all complex decisions required for personalized care.

#### 2.3.4.3 Integration

For successful introduction of CDS system to clinical practice it is required that used health information systems and clinical decision support systems either allow seamless integration using standardized API or CDS is used as a part of HIS.

### 2.3.5 Conclusion

Despite the fact that CDS systems are already used in medical practice and help to improve patients' outcomes and reduce overall costs there is still a room for an improvement. These improvements can include better access to medical data from various sources and utilization of big data, machine learning and natural language processing to improve recommendations in complex oncology cases.

## 2.4 Telemedicine

### 2.4.1 Introduction

Telemedicine is an interdisciplinary approach to provide health care and health care related services remotely. Telemedicine is used in several clinical practices and its common features include transfer of information, remote monitoring, remote therapy, remote consultancy and tele-conference. (Středa & Hána, 2016)

There are two types of communications. The first type is asynchronous and not in real time and is called store and forward. This type of communication is used in information transfer and sometimes in remote monitoring when the results are not immediately processed by a medical professional. Real-time communication is used in remote monitoring when the immediate response of a medical professional in case of need is expected, in remote therapy and in tele-conference. (Středa & Hána, 2016)

#### 2.4.1.1 Current state

Nowadays remote consultancy and tele-conference is predominately used in tele-oncology at global level. Oncology patients from rural areas have bigger issues accessing specialized oncology care because it is often concentrated in bigger cities. Patients often need to travel long-distances just because of a short consultation. Sometimes they even have to move to the city where the oncology care is provided. This can be particularly exhausting for patients undergoing chemotherapy or patients with an advanced stage of cancer. To mitigate these problems there have been several solutions in different countries. Patients in Australia living in rural areas can use tele-consultancy and video-conferences. There is Midwest Cancer Alliance in United States which provides various oncology care related services. They include tele-consultancy, education and research and technology related consultations. (Středa & Hána, 2016)

### 2.4.2 Technologies

It is possible to use various technologies and methods to deliver remote care to the patients which range from phone calls to wearables.

Nathan A. Pennell et al. (Pennell, et al., 2017) argues that telemedicine can be used in several ways. Examples of the use are educational, documentation, patient monitoring, nursing and imaging applications. Other examples include wearable sensors, data entry applications for monitoring mood and stress levels, symptoms and quality of life.

#### 2.4.2.1 Mobile health

According to World Health Organization (World Health Organization, 2011) mobile health is a medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants and other wireless devices. Mobile health involves use of several mobile functionalities raging from SMS to mobile applications while using several technologies such as GPS, Bluetooth and mobile data.

According to Christine Tran et al. (Tran, et al., 2017) mobile health technology allows patients and providers to foster collaboration. Tran et al. states that there is a study showing that half of the participants wanted their doctor or nurses to send them a health reminder thus engaging patients in their own care. They also argue that aggregated data collected by mobile applications and sensors can be turned into actionable information by supporting drug adherence, reducing medical errors, saving time during emergencies, foster self-management and improve clinical decisions.

A survey regarding attitudes of medical professionals towards telemedicine, mHealth and oncological apps showed (Kessel, et al., 2016) 88.9% of asked professionals considered telemedicine useful and 84.3% supported the idea of an oncological application which would be complementary to classical treatment. The most important features for them were automated reminders, timetables and assessment of side effects and quality of life during therapy. They also stated negatives such as medical responsibility and data privacy.

Also, Bradford Hesse et al. (Hesse, et al., 2016) states that mHealth is a relatively novel practice which needs unique considerations apart of assessment of effectiveness. There are also issues which must be resolved such as confidentiality, privacy, legal and ethical issues.

### 2.4.2.2 Mobile applications

Since the widespread of smartphones, there have been numerous mobile applications created which are related to health care and healthy lifestyle. Mobile applications as a part of mobile health have possibility to play a major supporting role in oncology care and provide functions such as symptoms management, providing information about cancer, showing reminders, improving patient adherence, providing remote monitoring and remote consultation. (Tran, et al., 2017)

### 2.4.2.3 Wearables

Wearable technology is a part of mobile health and it is an umbrella term for electronic devices that can be worn on or close to the human body. There are several types of wearables such as:

1. Wrist-worn sensors measuring physical activity and intensity
2. Rings
3. Glasses
4. Textiles or fabrics with embedded sensors to monitor heart rate and temperature
5. Implantable microchips

Increasing adoption of wearables by consumers and increased size of generated health data could help monitoring progress of treatment of cancer patients as well as help in oncology research. They could help capture dietary and physical activity data which are otherwise difficult to capture by more traditional ways like questionnaires.

Physical activity, for example, belongs to important factors in cancer treatment, and its tracking can help improve quality of life and symptoms management. Additionally, it may also improve patient's ability to tolerate cancer treatment by improving fatigue and quality of life. On the other hand, wearable technology could be also used by patients who would be otherwise unable to self-report symptoms. Data provided by wearables could be used for interventions during treatment that would not be possible without real-time continuous monitoring. Another example of use could be a use of wearables monitoring cardiovascular functions while undergoing treatment using cardiotoxic chemotherapeutics.

Since usage of wearable technology in health care and especially in oncology is in early stages, there is a limited evidence of its benefits. It is not also clear which data are the most important to improve symptoms, quality of life and overall health outcomes. (Fisch, et al., 2016)

## 2.4.3 Use-cases

### 2.4.3.1 Prevention

When it comes to prevention, mobile applications can indirectly help by promoting healthy lifestyle, assisting with tobacco cessation or providing cancer related education so they have capacity to improve cancer prevention, however little research was conducted regarding this matter. Researchers found 295 smartphone applications in 2016 related to the cancer. 46% of applications were regarded to cancer in general, while the rest were focused on awareness, education information, early detection, social support and fundraising. (Hesse, et al., 2016)

#### 2.4.3.2 Patient adherence

Patient adherence to treatment in oncology is critical as studies show that decreased adherence leads to worse outcomes and decreased survival. Most notable non-adherence can be seen in oral chemotherapy where it ranges from 11% to 50% depending on definition of adherence and methodology. (Tran, et al., 2017)

There are also data from studies of infused therapies which show that partial adherence in adjuvant chemotherapy delivered to patients with breast cancer resulted that their survival was equivalent to patients who received no adjuvant chemotherapy at all. (Pennell, et al., 2017)

The consequences of non-adherence not only negatively affect patients and their outcomes but also negatively affect medical spending in forms of avoidable hospitalizations and medication waste. (Wicklund, 2019) Adherence to a medical treatment may be improved through a software application developed for a mobile phone platform to support regular and correct drug intake, also leading to better disease management. (Nasi, et al., 2015)

#### 2.4.3.3 Symptom management and remote monitoring

Although symptom management is important in every stage of cancer continuum, it can be said it is mostly important during a treatment that involves several side effects such as chemotherapy or in advanced stages of cancer and in palliative care. When it comes to pain management, for example, one study found that nearly one-third of patients reported that their pain progressed between the start of treatment and a first follow-up visit. (Hesse, et al., 2016) It can be said that symptoms management and their reporting should be more frequent than follow-up visits during treatment or in later stages of cancer.

When it comes to symptoms management during chemotherapy there are several studies suggesting usefulness of mHealth in assessing less common symptoms (Nasi, et al., 2015) and even prolong lives of people with cancer (Guthrie, 2017)

Other study shows high level of acceptance for the mobile surveys and better quality of life in an intervention group. (Pennell, et al., 2017)

As it was said symptom management and remote monitoring is also useful in advanced stages of cancer and palliative care. According to Christine Tran et al. (Tran, et al., 2017) mHealth can reduce the need of emergency services, improve assessment and control of symptoms through early interventions.

### 2.4.3.4 Tele-consultancy

Remote consultancy is especially useful for patients living in more distant areas who would need to travel long distances just to receive a short consultation. According to Richard J. Boxer (Boxer, 2017) rural patient can mostly benefit from it while increasing quality of care and decreasing costs by unnecessary emergency department visits and reducing readmissions. Remote consultancy can also mitigate disparities caused by uneven distribution between locations of medical professionals and patients.

## 2.4.4 Case studies

### 2.4.4.1 Monitoring and management of symptoms during chemotherapy

In a randomized trial the efficacy of an automated symptom management system was tested to determine if the chemotherapy related symptoms were reduced. From 358 patients 158 were assigned to an experimental group and 178 were assigned to a control group. Participants received automated self-management telephone follow up for nurse practitioner for poorly controlled symptoms. All individual symptoms except diarrhea were lower in experimental groups. (Mooney, et al., 2017)

### 2.4.4.2 Symptoms management during chemotherapy in UK

The aim of this feasibility study was to assess acceptability of using mobile devices as a symptom management and assessment tool during chemotherapy treatment. A small sample of patients (n=18) and health professionals (n=9) in a Scottish cancer center were used for this study. Despite the fact of a small number of participants, this study showed that patients believed that their symptom management was improved, and they were comfortable using the tool. Also, medical staff found this tool helpful in assessing and managing patient's symptoms. (Kearney, et al., 2016)

### 2.4.4.3 Evaluation of a mobile symptom management system

The aim of this study was to study the impact of a mobile phone based, remote monitoring, advanced symptom management system on the incidence, severity and distress of six chemotherapy related symptoms (nausea, vomiting, fatigue, mucositis, hand foot syndrome, diarrhea) in patients with lung, breast or colorectal cancer. There were 112 people participating in the study who were evenly distributed to the intervention and control group.

The study demonstrated that the advanced symptom management system can support the management of symptoms in patients with breast, lung and colorectal cancer and provide more accurate reflection and monitoring of chemotherapy related toxicity with a potential to decrease chemotherapy related morbidity. (Kearney & Taylor, 2008)

### 2.4.4.4 Feasibility of smartphone application to increase adherence

During the past 30 years, adolescents and young adults with cancer have experienced less improvement in survival than children or older adults with cancer. It was found out that partial adherence to oral cancer therapy has been a key to nonoptimal cancer outcomes in this group. Reasons for partial adherence to oral medications include factors such as side effect, frequent and difficult dosing, forgetting, lifestyle disruptions and lacking physical and social support. In this experiment, participants (n=23) were asked to use the application for eight weeks. Feasibility was assessed through participants' usage and responses. Acceptability was assessed through perceived ease of use and usefulness.

The experiment showed that almost all participants used the application at least once. More than half reported they took medications as soon as they were alerted. Participants also stated that the application was easy to use and useful. To draw definitive conclusions, the report says, larger and more diverse intervention group is needed. (Wu, et al., 2018)

### 2.4.4.5 Effect of smartphone application on oral chemotherapy adherence

Another research team conducted a trial to determine the effectiveness of a smartphone application and to evaluate its impact on patients' adherence who take oral chemotherapy. Study took place in Boston and included 181 adult cancer patients with various types of cancer. The study did not find significant differences in adherence, symptoms and side effects, quality of life, urgent care visits and treatment satisfaction between intervention and control group. Results showed, however, that patients who reported poor medication adherence, had high anxiety, or were older than 55 may benefit from a smartphone application. Researchers also say future research could use different study settings or more diverse patients. (Greer, 2018)

### 2.4.4.6 Fitness wearables in oncology care

llian Gresham of the Samuel Oschin Comprehensive Cancer Institute at Cedars-Sinai Medical Center in Los Angeles, California, and Johns Hopkins Bloomberg School of Public Health in Baltimore, Maryland, and others undertook a study to determine the feasibility of using wearables to monitor activity of patients with advanced cancer. The device used was the Fitbit Charge HR which tracks step and stair counts, heart rate, calories and sleep patterns. The study enrolled 37 patients, 20 men and 17 women, with a median age of 62.

It was found out that the more active the patients were, the better their disease course was. An average increase of one thousand steps correlated with a significantly lower risk for hospitalizations, adverse events and increased survival. Patients who walked fewer than one thousand steps per day survived on average two months, while patients who walked more survived on average five and half months.

Their prior study was conducted to evaluate whether the fitness tracker could predict the likelihood of hospitalization in 38 patients undergoing radiation and chemotherapy. The study found out that patients who walked an average of 5103 steps per day with an increase of 1000 steps per day had a 38% reduced risk for hospitalizations.

Although this study shows promises of usage of wearables in oncology care, researchers call for larger clinical trials to explore all possibilities of wearables in this area. (Kaplan, 2018)

#### 2.4.4.7 Usefulness of fitness monitoring in cancer treatment

It was found out in a pilot study of older cancer patients that they were willing to wear devices for physical activity monitoring for 10 weeks or more and used them correctly. This study included 24 patients who were treated for variety of cancers. Data from physical activity monitors correlated with clinical assessment of patient status, researchers found. They said that adding objective data from physical activity monitors could help oncologists to fully assess their patients. It is important, because evaluation of patient's functional status is a part of clinical encounters and affects treatment decisions. Researchers hope that wearable technology will be used in larger clinical trials to determine the true effect of different cancer treatments on patients' physical activity. (UT Southwestern Medical Center, 2018)

### 2.4.5 Conclusion

The purpose of telemedicine and especially mHealth in oncology is to improve symptoms management and quality of life through continuous monitoring and early interventions, monitor patient's activity to determine if they are at risk of hospital readmission, provide remote consultation services, improve treatment adherence and enhance engagement of patients in their treatment.

Some forms of tele-oncology such as remote consultancy are well established around the globe, the rest however need more time in order to fully assess their capabilities. The conducted studies regarding usefulness of mHealth in oncology show mixed results. Majority of studies show user acceptance of mHealth and its usefulness but some of them show no effect on patient outcomes and quality of life. It can be said that studies including larger and more diverse group of people are needed to fully assess benefits of mHealth in the field of oncology.

# 3 Assessment of technologies

The purpose of this chapter is to fully evaluate technologies described in the previous chapter and create a proposed multi-criteria model of information technologies in accordance with the aim of this thesis. The mentioned model consists of these parts:

- Capabilities of technologies by cancer stage
- Use-cases by technology and actors
- Degree of impact of a technology capability

## 3.1 Cancer stages

In order to assess the technologies in different stages of cancer it is needed to define them. Various authors and publications use different diagrams to depict cancer continuum. Hesse at al. (Hesse, et al., 2016) use circle to show that cancer stages are interconnected. The model used in this thesis is inspired by the mentioned model but adds some new stages while omitting others and depicts exact relationships among the cancer stages.

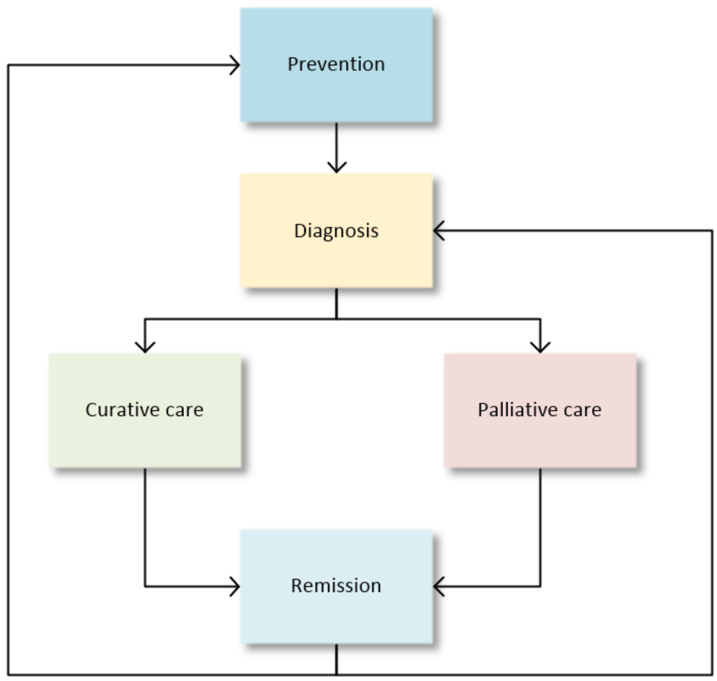


Figure 9: Cancer stages and their relationships

## 3.2 Cancer types

In order to define the impact of technologies based on type of cancer it is needed to define them in the first place. There are many approaches to divide cancer into categories. The following model is based on the first chapter of this thesis.

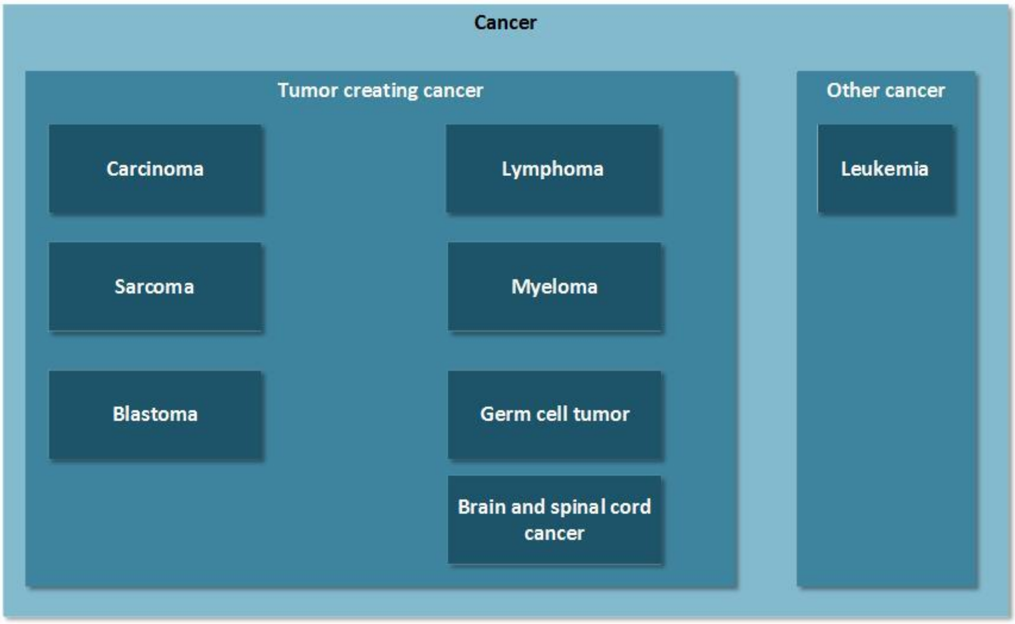


Figure 10: Cancer types

## 3.3 Technology capabilities by cancer stage

This chapter assesses technologies based on stage of cancer. As it can be seen some technologies overlap in cases, such as artificial intelligence and data analysis and CDS systems, because as it was stated before, both can be used to similar purposes. Artificial intelligence and data analysis are technologies which can serve to several purposes and CDS systems can leverage several technologies to provide adequate support to a health care professional.

| | Health information systems | Artificial intelligence and data analysis | Clinical decision support systems | Smartphones | Wearables |
|---|---|---|---|---|---|
| Prevention | Prevention through early interventions on certain types of patients | | | Applications promoting healthy lifestyle, helping with tobacco cessation and providing | |

| | Health information systems | Artificial intelligence and data analysis | Clinical decision support systems | Smartphones | Wearables |
|---|---|---|---|---|---|
| | | | | information about cancer | |
| **Diagnosis** | | Image analysis support in radiology, support in decision making in therapy, determining patient prognosis | Support in decision making, determining patient prognosis | | |
| **Curative care** | | Support in image analysis in radiology, therapy planning in radiotherapy, support in decision making, determining patient prognosis | Support in decision making, determining patient prognosis | Symptoms management, patient adherence, remote consultation | Symptoms management and remote monitoring |
| **Palliative care** | | Support in decision making, determining patient prognosis | Support in decision making, determining patient prognosis | Symptoms management, patient adherence, remote consultation | Symptoms management and remote monitoring |
| **Remission** | | Determining patient prognosis | Determining patient prognosis | | |
| **All stages** | Error reduction, decision support via holistic approach, patient engagement via connected patient portal | | | | |

Table 1: Use-cases by technology and cancer stage

## 3.4 Technologies by cancer type

It is not feasible to categorize technologies and their possible impacts or capabilities by a type of cancer. It is assumed that technologies and their impacts are agnostic to a type of cancer. This assumption is based on the fact that these technologies are meant to impact oncology in general. Also, there is no literature supporting an assertion that a technology can be used only when a certain type of cancer is present.

## 3.5 Use-cases by technology and actors

This chapter describes possible use-cases which are associated for the suggested capabilities of each respective technology described in chapter 2 and do not cover all possible features of these technologies. These use-cases are depicted in the chapters below and they are divided into four categories:

- Health information systems
- Artificial intelligence and data analysis
- Clinical decision support systems
- Telemedicine and more specifically mHealth which comprises both smartphones and wearables

These use-cases are later used in the multi-criteria model. These use-cases can have two actors:

- MP (medical professional)
- Patient

### 3.5.1 Hospital information systems

Medical professional can leverage health information systems to make informed and less error-prone decisions by having a holistic view on a patient using his or her EHR. In case the health information system is connected to a patient portal, then it is possible to engage patient by allowing them to view medical results, arrange meetings and send messages.

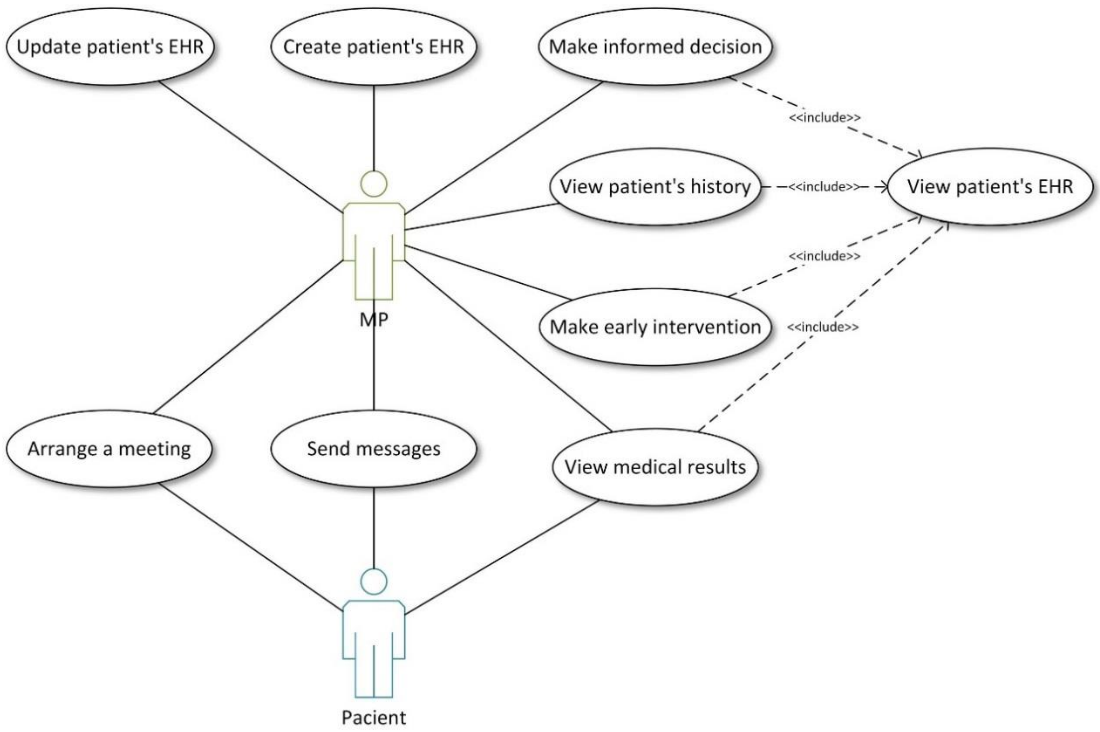


Figure 11: Use-cases for health information systems

### 3.5.2 Artificial intelligence and data analysis

Big data and AI technologies can help in complex cases based on clinical data and other sources if they are incorporated into CDS systems. AI technologies can further help in radiotherapy, for example in preparation of a therapy plan and contouring and help in image analysis in radiology.

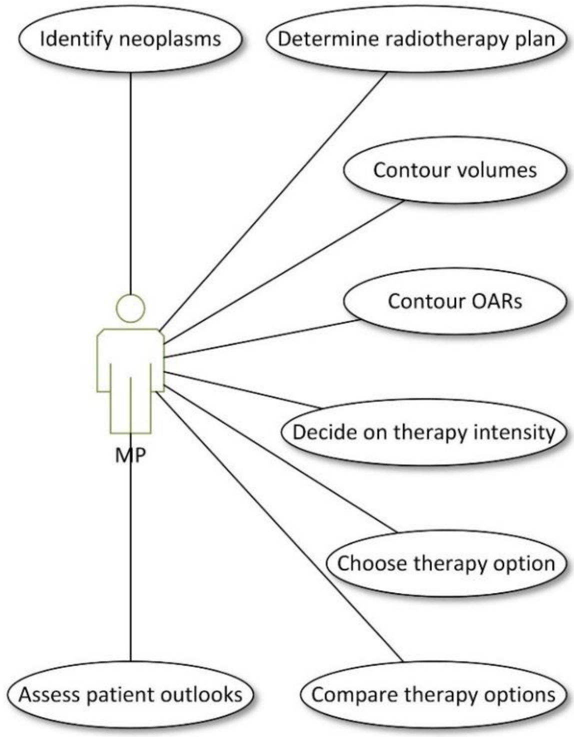


Figure 12: Use-cases for AI and data analysis

### 3.5.3 Clinical decision support systems

Medical professional can further use CDS to help them determine prognosis and make decisions related to the therapy. CDS can use big data and AI technology to provide help in complex cases based on clinical data, clinical guidance materials or other sources.

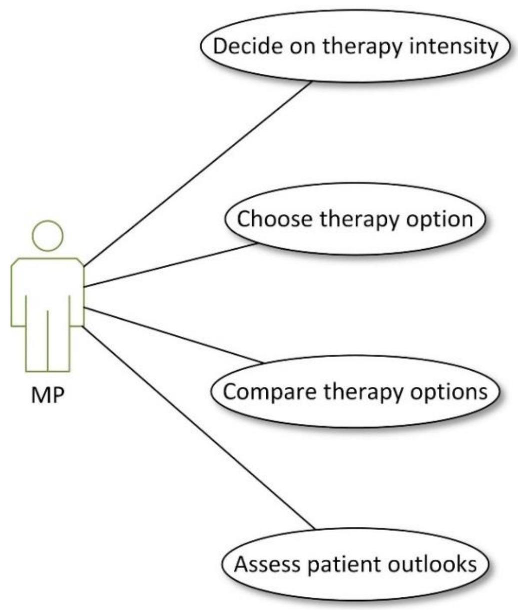


Figure 13: Use-cases for clinical decision support systems

### 3.5.4 Mobile health

As it can be seen in the following use-case diagram, patient can manage symptoms and/or be monitored remotely by using sensors (wearables) to collect data or use smartphone to fill out the questionnaire about their current state or report new or worsening symptoms. All these activities can trigger medical alerts which are delivered to a medical professional who can receive them, view patient's activity and send treatment related alerts back to the patient. Both sides can also take part in a remote consultation session. Additionally, the patient can receive information about the illness and/or healthy lifestyle and set goals for example in smoking cessation.

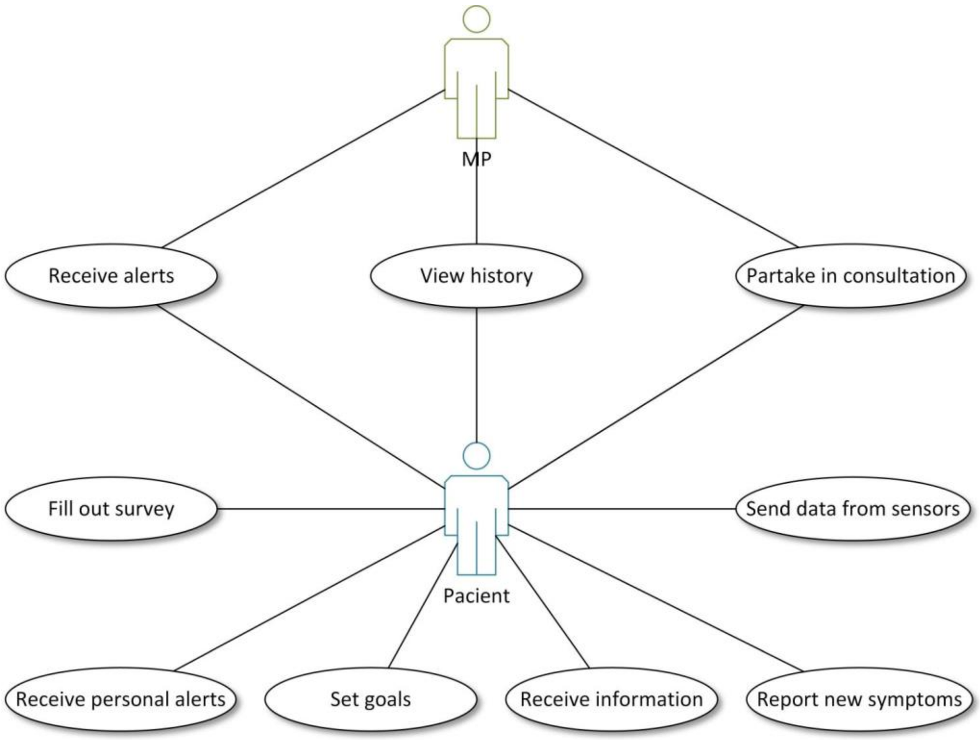


Figure 14: Use-cases for mobile health

## 3.6 Maturity and usability of technologies

Maturity and usability of the majority of proposed technologies cannot be fully assessed as they are not widely used in the health care system of the Czech Republic. This can be, however, done in the future when the mentioned technologies are more commonly used as it is more described in chapter 7.

## 3.7 Degree of technologies' impact

It is also needed to measure the degree of impacts presented by several technologies on oncology care. Following table was created based on a Likert scale (Jamieson, 2017) and technologies are assessed by this scale in the validation phase of this thesis. The assessment is based on interviews with medical professionals who are later described in the chapter 4.3.

| Degree name | Degree of impact | Explanation |
|---|---|---|
| None | 1 | Technology has no effect on oncology care. |
| Minimal | 2 | Technology has minimal to none effect on oncology care. Data from technology might be however used in the future to improve it. |
| Supporting | 3 | Technology has minimal effect on improvement of patient outcomes, but it might improve patient's comfort and quality of life and reduce costs. |
| Potentially relevant | 4 | Technology improves patient's quality of life and comfort and might be used to improve patient outcomes in oncology care. |
| Relevant | 5 | Technology improves patient's quality of life and comfort and can be used to improve patient outcomes in oncology care. |

Table 2: Degree of technologies' impact

## 3.8 Multi-criteria model

The multi-criteria model consists of four parts:

1. Technology: Each technology is described in Chapter Technologies2
2. Capability: Each technology is composed of several capabilities which can improve patient outcomes and/or quality of life.
3. Use-cases: Each capability contains of several use-cases (1: n relationship) which contains actors and the description. The possible actors are patient (blue color) and a medical professional (green color)
4. Cancer-stage: This part of the model shows the list of cancer stages where the capability is put to the best use. Stages of cancer for the model purposes are described in chapter 3.1.

According to Voříšek et al. (Voříšek & al., 2012) the purpose of the generic MBI (management of business informatics) model is to improve the performance of business IT and more specifically to improve quality, availability, performance and efficiency of information services in organizations where information technologies are not their main specialty. The dominant object of the MBI model is a task which describes how to proceed in solving a certain problem in the business informatics.

The multi-criteria model can serve to define a task and key activities as it is specified in MBI meta model (Voříšek & al., 2012) so it can serve as a basis to create a specific eHealth model in the field of oncology. The model could also include roles, factors, relationships to other fields of IT management and metrics to create comprehensive guide in the development of information services in oncology. In other words, it can be seen that multi-criteria model does not exist in vacuum but can be integrated with or used in other existing models or frameworks. It should be noted that specific model still needs to be adjusted to the needs of a particular health care institution as it can be seen in the figure below.

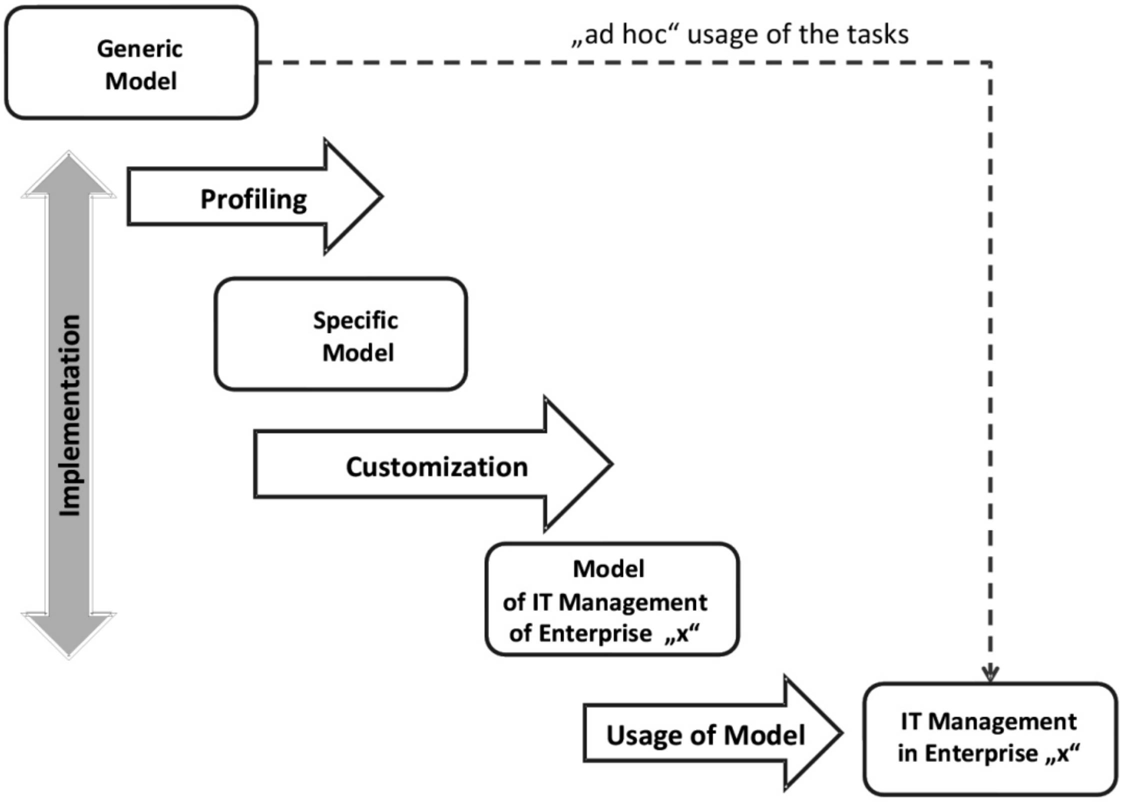


Figure 15: MBI models (Voříšek & al., 2012)

| Technology | Capabilities and their use-cases with actors | | Cancer stages |
|---|---|---|---|
| Health information systems | Error reduction | View patient's EHR; Update patient's EHR; Create patient's EHR | All cancer stages |
| | Decision support via holistic approach | Make early intervention; Make informed decision; View patient's history | All cancer stages |
| | Patient engagement via connected patient portal | Arrange a meeting; View medical results; Send messages | All cancer stages |
| Artificial intelligence and data analysis | Image analysis support in radiology | Identify neoplasms | Diagnosis, palliative and curative care |
| | Planning support in radiotherapy | Determine plan; Contour OARs; Contour volumes | Palliative and curative care |
| | Decision making support using EHR data | Decide on therapy intensity; Choose therapy option | Diagnosis, palliative and curative care |
| | Determining patient prognosis using EHR data | Compare therapy options; Assess patient outlooks | Diagnosis, palliative and curative care |
| Clinical decision support systems | Decision making support using medical guidelines and/or EHR data | Decide on therapy intensity; Choose therapy option | Diagnosis, palliative and curative care |
| | Determining patient prognosis using medical guidelines and/or EHR data | Compare therapy options; Assess patient outlooks | Diagnosis, palliative and curative care |
| Smartphones (mHealth) | Promoting healthy lifestyle, tobacco cessation, providing information about cancer | Receive personal alerts; Set goals; Receive information | Prevention |
| | Patient adherence | Receive alerts; View history | Curative and palliative care |
| | Remote monitoring and symptoms management | Report new symptoms; Fill out survey; Receive alerts; View history | Curative and palliative care |
| | Remote consultation | Partake in consult-ation | Curative and palliative care |
| Wearables (mHealth) | Remote monitoring and symptoms management | Send data from sensors; Receive alerts; View history | Curative and palliative care |

Figure 16: Multi-criteria model of technologies in oncology

# 4 Current state in Czech Republic

## 4.1 Cancer statistics

According to the statistics (Národní onkologický program, 2018) every third person in the Czech Republic gets cancer and every fourth person dies because of it. In 2016 there were 96 500 persons diagnosed with a malign neoplasm. In the same year, there were around half a million people in the country who had been diagnosed with cancer. When it comes to mortality 27 261 people died because of cancer that year. The most common types of cancer were melanoma, prostate, intestinal, breast and of respiratory system.

Statistics from 2011 (Dusek, et al., 2014) show that the Czech Republic belongs to the countries with the highest cancer incidence and mortality rates in Europe and worldwide. According to these statistics, incidence rate of neoplasms (tumors) reached almost 802 cases per 100 000 men and 681 per 100 000 women. Neoplasms are the second most common cause of death in the Czech Republic.

| Parameter | Males | Females | Total |
|---|---|---|---|
| population size | 5,158,210 | 5,347,235 | 10,505,445 |
| fertility rate | – | – | 1.427 |
| age (2011) | | | |
| mean/median (years) | 39.6/38.5 | 42.5/41.5 | 41.1/40.5 |
| 25–75$^{th}$ percentile (years) | 23.5–56.5 | 24.5–60.5 | 24.5–58.5 |
| > 50 years (in %) | 32.4% | 38.2% | 35.3% |
| life expectancy at birth (years) | 74.7 | 80.7 | – |
| annual overall mortality | 54,141 | 52,707 | 106,848 |
| causes of death (%) | | | |
| diseases of the circulatory system (I00–I99) | 44.6% | 54.3% | 49.3% |
| neoplasms (C00–D48) | 28.0% | 23.4% | 25.8% |
| injury, poisoning and certain other consequences of external causes (S00–T98) | 7.7% | 3.5% | 5.6% |
| diseases of the respiratory system (J00–J99) | 6.0% | 4.6% | 5.3% |
| diseases of the digestive system (K00–K93) | 4.7% | 3.7% | 4.2% |
| endocrine, nutritional and metabolic diseases (E00–E90) | 2.2% | 3.0% | 2.6% |
| other causes | 6.8% | 7.4% | 7.1% |

Figure 17: Demographic characteristics of the Czech Republic (Dusek, et al., 2014)

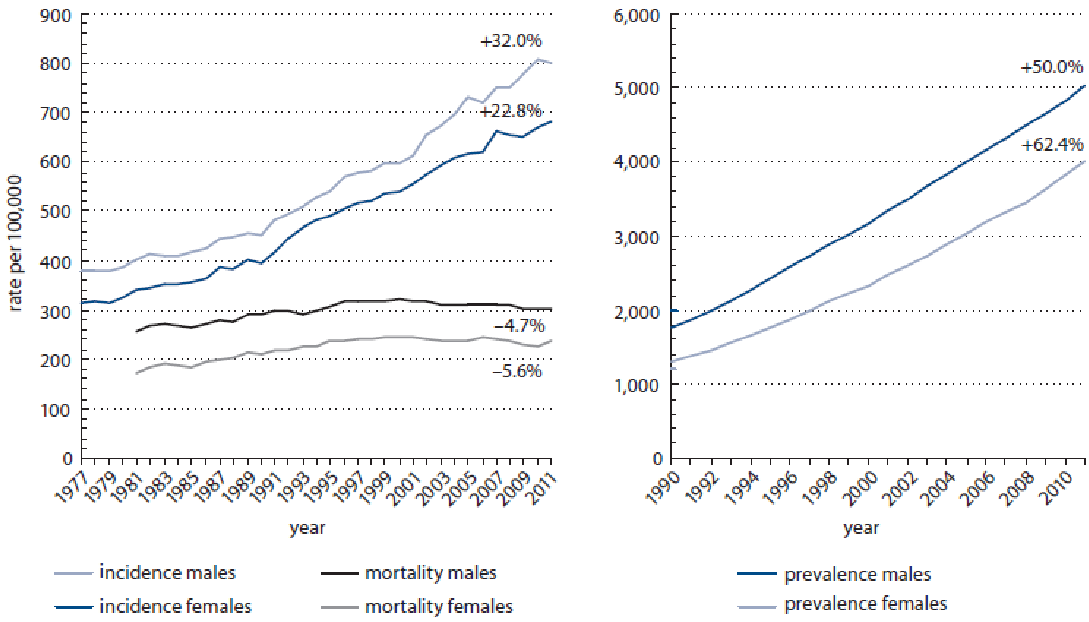


Figure 18: Cancer incidence, prevalence and mortality rates in the Czech Republic (Dusek, et al., 2014)

As it can be seen in the graph above, while the incidence rates have been increasing, the mortality rates were stabilized and have even slightly decreased. This has resulted in higher number of cancer survivors thus increasing the overall cancer prevalence.

According to Czech National Cancer Control Program (Czech Society for Oncology, 2014) this was possible to achieve thanks to the improvements in oncology care as well as modern cancer treatment methods. On the other hand, this resulted in higher costs, since these newer methods are usually more expensive. They argue that there must be an effort to diagnose cancer patients in early stages, thus decreasing treatment costs and improve patient prognosis.

## 4.2 Cancer care in the Czech Republic

### 4.2.1 Overview

There is a network of health care facilities which consist of comprehensive cancer centers, district hospitals, health centers and other facilities. There are also National Cancer Centers which serve as scientific and research institutes and also cooperate internationally with other cancer care centers. (Czech Society for Oncology , 2019)

### 4.2.2 Comprehensive Cancer Centers

There are currently fifteen comprehensive cancer centers (CCC) in the Czech Republic which fulfil the technological and organizational criteria (Czech Society for Oncology , 2008) Each center contains of multidisciplinary teams to provide personalized oncology care to patients and also coordinates and organizes oncology care in the respective region.

Additionally, the highly specialized care, educational activities and assessments of quality and outcomes are in the competence of a center. There are also regional cancer groups which consists of CCCs, providers of inpatient cancer care and other related facilities. (Czech Society for Oncology , 2019)


Figure 19: Map of CCC in Czech Republic (Czech Society for Oncology , 2019)

## 4.3 Interviews

All fifteen complex oncology centers (KOC) in the Czech Republic were contacted in order to arrange an interview with a medical professional in the field of oncology or related technology fields which were mentioned in this thesis.

It was not possible to get a comment from three hospitals and four of them refused to participate. An interview was arranged in eight hospitals with the following results:

1. Together nine interviews were conducted with medical professionals from the field of oncology and experts related to telemedicine using the dramaturgical model explained in the chapter Methodology
2. Eight interviews were done in person, whereas one respondent was interviewed via phone call
3. Two interviews were joint were two people participated at once.

The usual structure of interviews was the following:

- Introduction to the topic
- Discussion about the current state and how the proposed technologies could affect it
- The participants were also asked to grade the impact of capabilities of the proposed technologies using a Likert scale as it was described in the chapter Degree of technologies' impact.

All participants got a questionnaire (Attachment A) which contains a set of questions and a table to grade the impacts of proposed technology capabilities. These questions or their modifications were then used during an interview. The purpose of these interviews was to evaluate and enhance the created artifact, the multi-criteria model, in accordance with the DSR approach.

## 4.4 Health information systems

All hospitals have implemented a cross-department health information system, but these systems vary in overall functionality and the level of integration with other components such as radiology. They, however, provide cross-department EHR so it is possible to have a holistic view on a patient. On the other hand, majority of the hospitals do not have extra-institutional EHR, so the patient data are stored and accessible only in one particular medical facility. Two oncology care departments share EHR data with its subsidiaries in the region, so it is possible to view patient's EHR with some limitations from several related facilities.

### 4.4.1 Usability

When it comes to overall HIS usability, the majority of interviewees found their HIS either user-friendly or had neutral attitude towards its usability. Two interviewees described their HIS as not user-friendly at all because of lack of complete and up-to-date information, missing functionalities such as alerts and the obsolete user-interface.

According to the one interviewed radiation oncologist, the health information systems are not really suitable for oncology, because medical records are created as an unstructured text. This results in missing clinical statistics about quality of care and patient prognosis. He argued that a HIS should be more "parametrized" which means that selected characteristics of a patient and selected treatment should be inserted using a standardized form instead of an unstructured text. This is, according to him, the most crucial thing which should be implemented in HIS because it enables institutions to continuously assess the clinical results.

### 4.4.2 Data quality and other problems

Three interviewees described that there are technical problems with their HIS from time to time such as:

- Instability in case of higher demand
- Occasional problems with data loss and corruption during migration
- Problems with electronic prescriptions (SÚKL, 2018)

Three interviewees think that there is a problem when medical professionals copy parts of records to reuse them again in patient's EHR. This can result in data duplication, where old reports are unnecessarily duplicated, or even insertion or duplication of wrong information in a patient's EHR. However, majority of asked medical professionals think that the quality of patient records has increased since the area of paper medical reports. According to one radiation oncologist this is because the previous paper reports were quite brief and did not really follow standards. Nowadays, medical reports are more comprehensive and of higher quality despite the possible increase of errors. On the other hand, according to one oncologist, use of HIS created a new problem despite the increase of quality and possibility to view older records easily. The administrative burden has increased since the adoption of HIS, since oncologists have to do almost everything themselves and the creation and update of patient records and related activities are slower.

### 4.4.3 Provider-agnostic electronic health record

Two interviewees found the absence of provider-agnostic EHR as a major problem, because they do not know all information about a patient and cannot see the related documentation if a patient does not mention it. According to one clinical oncologist, *"this is a major problem which lowers the overall effectivity of a system".* Another two medical oncologists find this idea attractive, in case the patient receives treatment in several medical facilities in the area. On the other hand, they are quite concerned about privacy and access to EHR. In other words, there should be some checks so the *"doctor from the other side of the republic cannot see patient's EHR without a valid reason".* One oncologist had grave concerns about privacy and confidentiality. Another radiation oncologist welcomed this idea, but he did not believe that it would work in a near future. According to another radiation oncologist, the shared EHR could reduce disparities among health care facilities and would lay grounds for big data.

### 4.4.4 Conclusion

All health information systems support holistic view on a patient in oncology care despite the lack of extra-institutional EHR and functional disparities. The views on error reduction as one of the proposed capabilities differ from person to person as it usually depends on an individual who inserts new information into a patient's EHR and there is really no validation of inserted data. No hospital has implemented a comprehensive patient portal which is connected to HIS and EHR to foster patient engagement in their care.

## 4.5 Artificial intelligence and data analytics

The methods of creation of statistics vary in the hospitals. While some HISs support creation of basic statistics automatically, in other hospitals the data have to be extracted manually. However, the vast majority of hospitals does not reuse patient clinical data for further analytics to improve cancer care and get new insights.

There are some hospitals which and health information institutions which cooperation has resulted in a pilot project which fuses payer's data to create statistics which could be used for clinical purposes. These statistics include financing, costs, quality comparativeness and patient prognosis. These statistics omit certain patient characteristics, however, such as genomic data and others, so there is a space to make them more thorough. However, the technologies used in this project were not disclosed in the interviews.

It was confirmed in several hospitals that patient data in radiotherapy planning systems are either reused or plan to be reused in the preliminary computation of radiation plans in IMRT and related therapies which require inverse planning. The mentioned treatment planning system uses machine learning to learn from previous radiation plans and prepares the preliminary plan for the patient with similar characteristics such as location and type of neoplasm. These preliminary plans serve as a starting point in the plan preparation since they require a manual intervention in order to adjust DVH and other parameters, but they save time and improve quality. Another radiation oncologist would implement the mentioned feature in his hospital in order to *"reduce the plan variances"*. On the other hand, three radiation oncologists expressed a negative opinion towards it since they find every patient too unique to use these tools.

When it comes to automatic or semiautomatic OAR and volume segmentation using AI, two medical professionals expressed negative attitudes towards it as they do not find these systems to be mature enough to be used in clinical practice. According to one radiation physicist these systems produce poor results, so they are not usable.

The majority of asked health care professionals could not express their opinion on the use of big data and machine learning to process patient data to get a new intelligence. According to one radiation oncologist it is not currently possible because of data quality variance, missing standards and problems with data categorization.

## 4.6 Clinical decision support systems

None of the mentioned hospitals use CDS systems as standalone components or as a part of HIS or plan to use them in the near future. According to one radiation oncologist the clinical guidelines regarding treatment and diagnosis are usually stored in form of official documents. Some interviewees are aware of online decision support systems as Adjuvant Calculator (ONCO Assist, 2018) and similar tools. The opinions on these systems ranged from finding them as a promising and interesting tool to be a tool with mediocre results at best. However, they could all agree on a few things such as these systems are not really ready to be used in everyday clinical practice since it is not possible to capture all patient characteristics and they are problematic from the legal point of view.

According to one radiation oncologist, learning CDSs could be helpful within ten years when there will be fewer doctors and there will be a bigger demand on effectivity. These CDSs could help doctors with decisions upon first patient admission.

As it was stated before, one of the problems with learning CDSs is in the structure of EHRs. According to one oncologist these records are like "essays" so he could not imagine how they could be analyzed properly. On the other hand, more formalized EHR would take more time to create and update and would increase administrative burden.

## 4.7 Telemedicine

All hospitals are connected to ePACS network (ePACS, 2019) so medical professionals are able to send and receive medical images from all connected medical institutions. When it comes to teleconferences, the responses differed from person to person:

- One institution used to have tele-conferences but did not prove to be useful
- Six institutions use tele-conferences mostly on educational and research purposes

One hospital has started a pilot project and it is connected to the European Reference Networks for Rare Adult Solid Cancers ( ERN-EURACAN, 2019) This network involves health care providers across Europe and its aim is to get an specialized advice in the case of complex and rare oncology case. An oncologist inserts patient's information to the system and awaits responses from medical professionals from connected health care institutions.

According to one interviewee from the telemedicine field, it can help to save patient's time and travel expenses, as there are reduced visits of doctor's office. According to their calculations for cardiology, heart failures more specifically, telemedicine can also increase cost-effectiveness, increase quality and decrease mortality. Telemedicine is already being used in these fields as the telemonitoring in cardiology is covered by General Health Insurance Company and there is a telemonitoring program for gestational diabetes (diaBetty, 2019)

In the oncology, however, the situation is more difficult. There are quite small distances between a complex cancer care centers and patients. Additionally, doctors generally prefer personal contact. In the United States, however, tele-consultancy is more popular because of bigger distances and a lower price for a payer. According to the interviewee, telemedicine could be used for tele-monitoring of body temperature during chemotherapy and for educational purposes.

## 4.8 Mobile Health

When it comes to proposed mobile health technologies, no hospital uses them in clinical practice nor has started or plans to start pilot projects concerning these technologies. Majority of asked medical professionals do not see mHealth or doctor-patient telemedicine as something that would be really needed in oncology. The opinions on the remote monitoring and other proposed capabilities were the following:

- Patient is educated and should call in case of problems during chemotherapy, so the monitoring does not make sense.
- Relying on patient provided data on adherence could be dangerous.
- Some proposed capabilities could be useful for some patient groups, but the emphasis should be put on education of a patient and their relatives and the personal approach.
- Acquired data cannot express the overall state of a patient in oncology

- Realtime remote monitoring could create unnecessary alerts and burden medical staff
- Implementation of mHealth in oncology could be sloppy and create unnecessary administrative burden with little to none added value
- Systematic collection of patient symptoms could improve the quality of life and affect clinical decisions but only in case it would be used to addition to standard examinations.
- There are quite small distances in Czech Republic, so patient's visits are preferable.
- Remote consultations were found useful by two oncologists in case where there is an established relationship between an oncologist and a patient.
- Medicine reminders should be in competence of a patient
- Using a smartphone to promote patient adherence could be useful for some patient groups since some medicine require more complex dosage
- According to three interviewees, an acquisition of objective data using sensors could be useful during chemotherapy such as body temperature or physical activity.
- One oncologist expressed a positive attitude towards doctor-patient telemedicine as it could be promising in oncology.

## 4.9 Assessment of technologies

### 4.9.1 Impact of technology capabilities

As it was stated in the chapter Degree of technologies' impact interviewees from the oncology field were asked to rate the impact of technology capability using a Likert scale which is described in the chapter 3.7. The following table shows rounded mean values of data acquired during interviews. The detailed responses can be seen in the Attachment B.

| Technology name | Example of use | Level of impact |
|---|---|---|
| Health information systems | Error reduction | 3 |
| | Improved decision making by having all information about a patient | 3 |
| | Patient engagement via connected patient portal | 5 |
| Artificial intelligence and data analysis | Support in decision making | 3 |
| | Support in therapy planning in radiotherapy | 4 |
| | Support in image analysis in radiology | 3 |

| Technology name | Example of use | Level of impact |
|---|---|---|
| | Determining patient prognosis | 3 |
| Clinical decision support systems | Support in decision making | 3 |
| | Determining patient prognosis | 3 |
| Smartphones (mHealth) | Symptoms management and remote monitoring | 3 |
| | Patient adherence | 4 |
| | Remote consultation | 4 |
| | Promotion of healthy lifestyle, helping with tobacco cessation and providing information about cancer | 3 |
| Wearables (mHealth) | Symptoms management and remote monitoring | 4 |

Table 3: Mean rounded values of technology capability impacts

### 4.9.2 Multi-criteria model

The multi-criteria model introduced in chapter 563.8 is here enriched with the level of impact for each technology capability. The impact of a capability is depicted on the model using a heat-map.

| Degree name | Degree of impact | Heat map color |
|---|---|---|
| None | 1 | |
| Minimal | 2 | |
| Supporting | 3 | |
| Potentially relevant | 4 | |
| Relevant | 5 | |

Table 4: Heat-map of capability impact

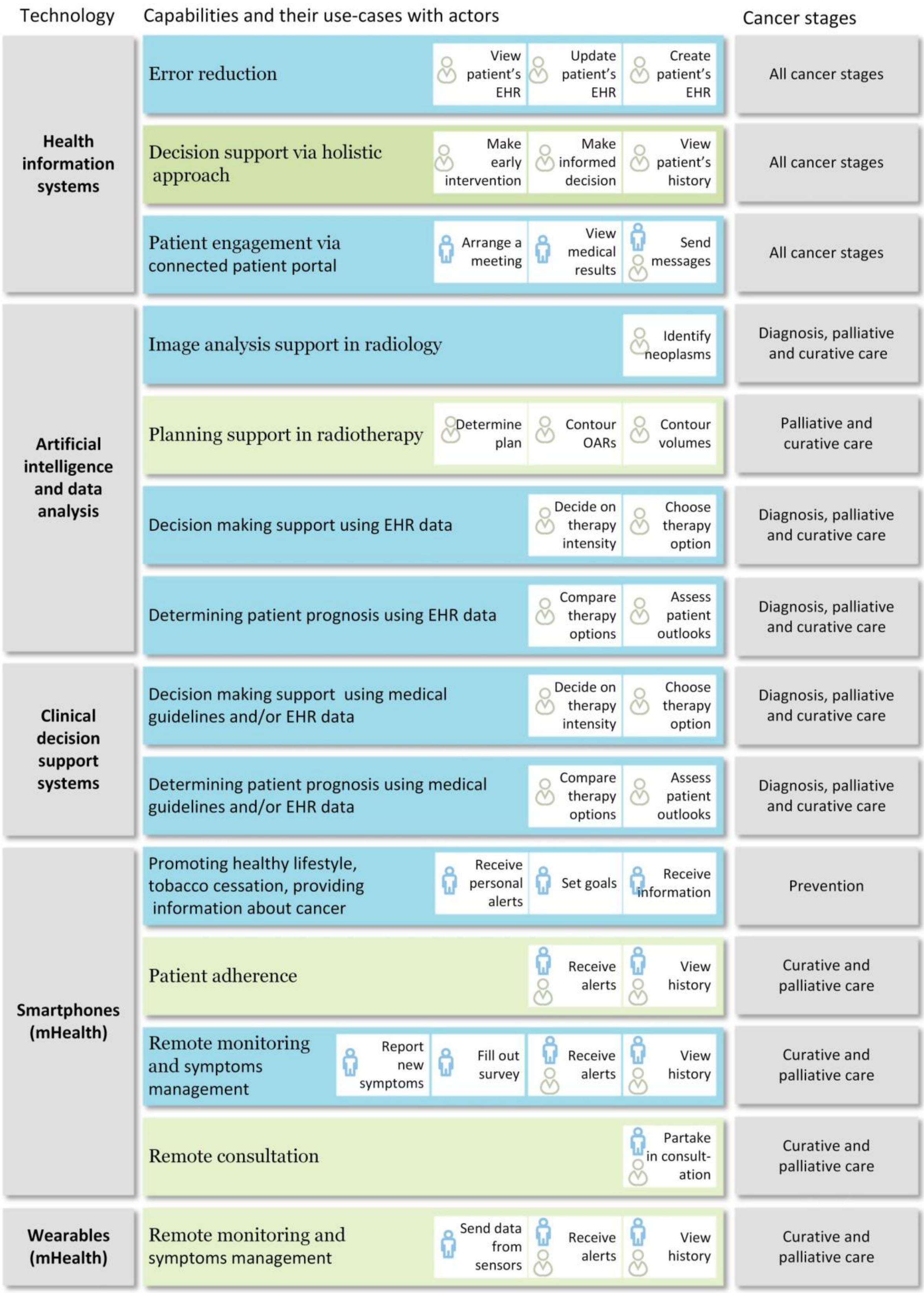


Figure 20: Multi-criteria model with capability impacts

# 5 Current state in United States

This chapter describes cancer statistics and state of oncology care from the technology viewpoint in the country. The outcomes of this chapter do not have impact on the final multi-criteria model. This is because its main purpose is to highlight differences in use of technologies and their capabilities presented in the mentioned model.

## 5.1 Cancer statistics

According to National Cancer Institute (National Cancer Institute, 2019) the cancer statistics are the following:

- The most common cancers are breast cancer, lung and bronchus cancer, prostate cancer, colon and rectum cancer, melanoma, bladder cancer and others
- Cancer incidence is 439 per 100 000 men and women
- Cancer mortality is 164 per 100 000 men and women
- Cancer mortality is higher among men (197 to 140 per 100 000)
- There were around 15.5 million cancer survivors in the country. The number is expected to rise to 20.3 in 2026.
- Estimated national expenditures for cancer states in 2017 were 147.3 billion USD

According to (Cronin, et al., 2018) cancer incidence rates (Figure 23) decreased among men, but the number is stable among woman. There is a decline in cancer death rates, but there are some exceptions for example when it comes to liver and uterus cancer as it can be seen in the Figure 21 and Figure 22.

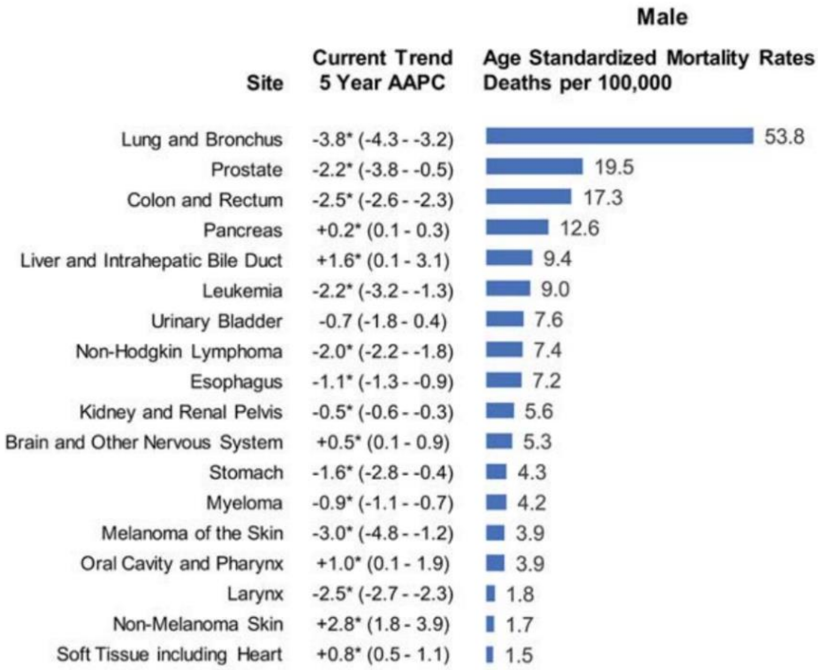


Figure 21: Death rates among males in the United States in the years 2011-2015 with annual percent change (AAPC) (Cronin, et al., 2018)

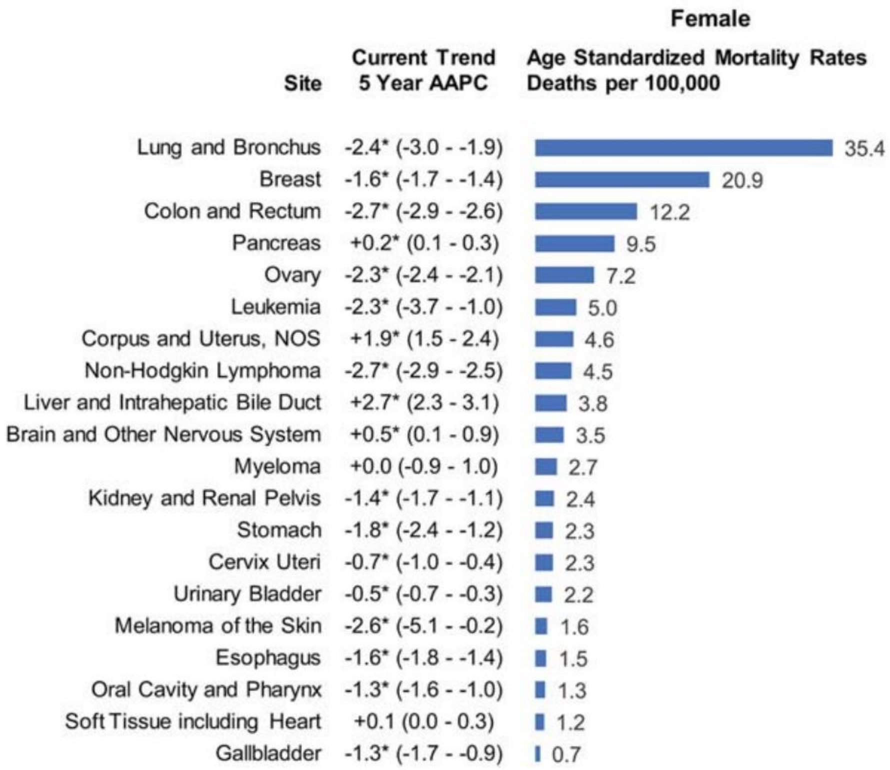


Figure 22: Death rates among females in the United States in the years 2011-2015 with annual percent change (AAPC) (Cronin, et al., 2018)

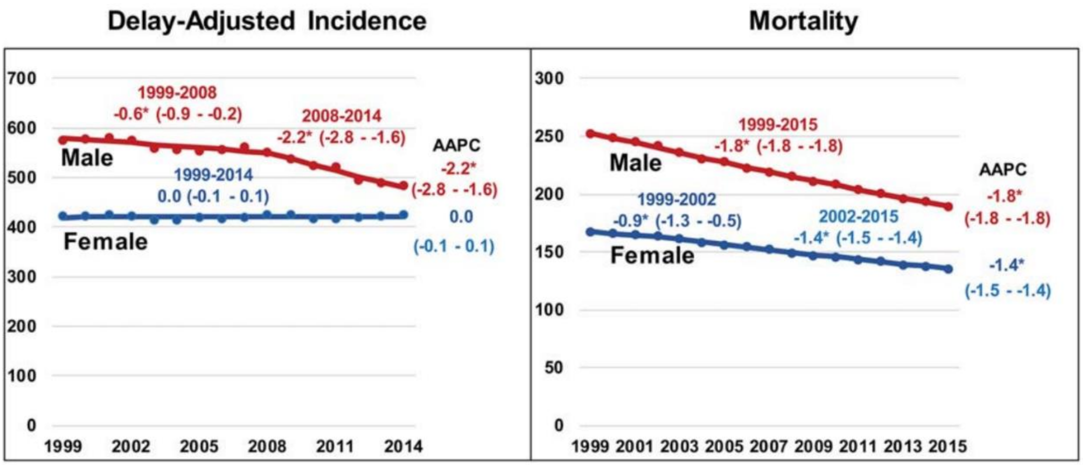


Figure 23: Cancer incidence and mortality rates in the US (Cronin, et al., 2018)

## 5.2 Interviews

Two interviews were conducted for the purpose of this chapter. One interview was done via e-mail correspondence with a senior program coordinator and a clinical oncologist, members of an organization dealing with cancer care and the second one was done via phone call with an oncologist and associate professor from one university hospital. The purpose of these interviews was to highlight differences and similarities in use of technologies in oncology care and present them to the reader.

The usual structure of interviews was the following:

1. Introduction to the topic
2. Discussion about the current state and how the proposed technologies could affect it

### 5.2.1 Health information systems

According to the interviewed oncologist, there are some benefits connected to the use of EHR systems which are:

- Interconnection with other practices: for example, when patient is undergoing chemotherapy elsewhere, it is possible to see its results. This way it is easier to see the whole picture of a patient.
- Better organization of information: the patient documentation is clearer and easier to understand when compared to era of paper documentation.
- “Pharmacy electronic ordering”: EHR system can recommend a dosage based on patient characteristics such as weight. Some errors regarding a wrong dosage can be averted this way.

Overall, there is an increase in quality of data, however, there are some issues connected to the use of EHR system:

- Copy and paste problem: It is easier to reproduce an error, since there are parts of a patient documentation which are usually copied. In other words, the problem is magnified.
- Administration: There is an increase in administration burden. A lot of administration was shifted to doctors since the implementation of EHR systems. There is also so-called “EHR burnout” which corresponds with increased stress and responsibility connected with use of an EHR system.

According to the second interviewee, there is a problem with a general interoperability of EHR systems, because some of them cannot accept any patient information from other practices. Another problem is that patient data are less organized and many critical oncologic variables such as cancer stage or biomarkers are not stored in discrete fields.

### 5.2.2 Artificial intelligence and data analysis

There are several HIT platforms mentioned in a chapter 2.2.4. According to the first interviewee, their common theme is that they use data aggregation to overcome challenges to interoperability by normalizing data to a common data model and then using that to gain new insights. For some of them, the main purpose is to improve quality of care. This can be done by presenting dashboards and reports of the performance of connected practices and how they are doing against established standards. These platforms are all sources of “real-world data” (RWD). These data can show what happens in the clinical practice as opposed to the situations created for the purpose of clinical trials which can lack diversity in terms of patient characteristics and the comorbidities. In other words, these data allow a patient and doctor to see characteristics and outcomes of similar patients. Although the EHR data are the primary source of data, there are other sources such as cancer registries, claims data and death data which can enrich them and fill in important gaps.

As it was mentioned in previous chapter, there is a problem with unstructured data in EHR systems. The first interviewee argues that many of the most important data elements such as staging, biomarkers, adverse events and progression are documented in an unstructured way, so their retrieval and normalization is a very difficult thing. The lack of a common data model which could solve these problems is an important shortcoming.

### 5.2.3 Clinical decision support systems

According to the second interviewee, there is no CDS system in their hospital. Clinical guidelines are not integrated to EHR system and they are usually in a document form. When it comes to learning CDS systems, they would be really helpful as they would enable to see the efficiency of several therapy options for a patient and provide better decision support. When it comes to the current use of clinical data to this purpose, he says that “*we are not doing a good job in learning from data*”.

### 5.2.4 Telemedicine and mobile health

According to the second interviewee, the remote consultation is really helpful because of the huge distances in the country. It is a waste of time for a known patient to drive all the way to the hospital just to find out everything is all right. When it comes to periodic and continuous collection of patient symptoms and state, they are another data source which is not used and could be really helpful. The hospital started to collect PROs for research purposes, but these data are not yet integrated with an EHR system. The second interviewee argues that there is a lot of interest of incorporating patient-generated data into oncology HIT platforms. These data include PROs and data from wearables and sensors. There are many unanswered questions because of the fact that it is still unclear to what extent these data can improve patient outcomes. According to the first interviewee the use of smartphones to improve adherence is not widely used but it seems to be viable option to increase it since more and more older people start using smartphones. He argues that this is quite an important problem and there should be a search for novel practices to mitigate it.

# 6 Feasibility of the model in the Czech Republic

This chapter describes the implementation feasibility of the Multi-criteria model introduced in the chapter 4.9.2. This is intended to be done in form of project proposal based on project solution of eHealth implementation according to MBI (Potančok & Vondrová, 2019) which belongs to group of application projects in the management of development of business informatics (Voříšek & al., 2012). MBI and the type of a project were chosen because of its focus (described in chapter 3.8) and the connection to eHealth.

This project can be divided into four stages:

1. Preparation of the initial study
2. Design and analysis
3. Implementation
4. Migration and deployment

Only the two first parts of the project will be used to demonstrate which technologies and their capabilities of the multi-criteria model are currently feasible to implement in the health care system of the Czech Republic. Since the main purpose of this project proposal is to demonstrate feasibility of the model, some parts of the proposal such as vendor selection and detailed financial plan are omitted. For this purpose, a sample comprehensive cancer center (CCC) is used. The current state of this sample CCC is the following:

- The CCC has implemented a comprehensive HIS which is integrated with other components such as radiology and PACS. EHRs in this HIS are shared across the hospital departments. Cooperating health care providers in the regional cancer group (RCG) do not have access to this EHR so there is a certain disconnection between medical facilities caring for the same patient.
- It is assumed that HIS provides API for integration purposes.
- EHRs are usually in unstructured form.
- There is no patient portal which would support appointment system, viewing medical results and communication with a doctor.
- CDS system is not used.
- The data of oncology patients are not used for analysis and benchmarking to provide decision support and prognosis analysis to oncologists.
- The mentioned HIS supports creation of managerial statistics.
- There are attempts to use patients' radiotherapy plans for pre-computation of future radiotherapy plans.
- There is no mobile health implemented.

## 6.1 Initial study

### 6.1.1 Scope of the project

It is important to define a scope of the project. In other words, the questions “Why?” and “What” need to be answered. It needs to be determined, what is in the scope of the project, if it is feasible in the current state of the health care in the Czech Republic.

#### 6.1.1.1 EHR sharing between facilities

Despite the fact that current HIS supports holistic view on a patient, this is only possible inside the medical facility. In other words, EHR is provider-centric not patient-centric. Health records from other facilities are needed to be obtained manually. This can be done by several ways:

- EHR integration with other health care providers in RCG using an API of all affected information systems
- Remote access to health information system in CCC using technologies such as remote desktop connection
- Postpone this step and wait for Ministry of Health to finish “Infrastructure and management of electronic health care” (Ministry of Health of Czech Republic, 2018). The purpose of this project is to create an infrastructure for exchange of EHRs and specification of legislative, technical, security and other standards needed to realize a shared EHR (Ministry of Health of Czech Republic, 2017). In this case, the state will guarantee EHR sharing via “Indices of health documentation” document “Strategy of Computerization of Health Care in the years of 2016-2020” (Ministry of Health of Czech Republic, 2016) (further as SCHC)

It is needed to be determined which way should be used in order to achieve this goal.

In the first scenario it is required that all information systems in RCG can be connected to CCC’s HIS. Since all mentioned information systems are heterogenous an integration layer is needed to accomplish this goal which makes this option more expensive. Additionally, health information systems will need to be connected to this integration level which amounts to more work and additional costs.

The second scenario is less expansive and easier to implement and can serve as an interim solution until the concept of a shared EHR is implemented on a national level.

#### 6.1.1.2 Error reduction

Although the quality of medical records has increased since the era of paper records, there is still a room for improvement. Current health information system partially supports this capability since the information are accessible up-to date and to the right people but does not support validation. As it was mentioned before, health records are not parametrized and are in an unstructured form, so they are not standardized and there is a certain level of variance in a quality of health records. In other words, there is a room for possible errors in form of redundant or incorrect information. This problem could be mitigated by a creation of more formalized (parametrized) user interfaces in HIS. This is, however, out of scope of this project because several questions must be answered:

1. Does current HIS support parametrization of EHR?
2. If the current HIS does not support it, how can be this solved? Possible scenarios are these:
    1. Migration to different HIS
    2. Implementation of standalone module for oncology in a form of TASW or IASW
3. Will the perceived outcomes improve error reduction enough to justify the costs?
4. Which processes will be affected by this change? In other words, how will this affect the administrative burden of medical staff?

Standardization of health documentation is supported by SCHC with the measure 3.3.2 called "Support of standardization of medical documentation and therapeutic procedures". According to this document, there is a big variance and latitude in the use of terminology and abbreviations. This lowers validity and readability of medical documentation which can sometimes results in fatal outcomes.
The authors of the mentioned document argue that these steps need to be done to standardize medical documentation:

- Standardization of therapeutic procedures
- Formalization and creation of software tools which would help medical professionals to adhere to these procedures
- Use of internationally recognized clinical terminology (SNOMED-CT)

These are, according to the authors, the requirements to achieve international interoperability, reduce quality variance and enable analytical processing of a medical documentation. On the other hand, the eHealth strategy describes this problem on a high-level and does not provide currently any roadmap for this measure.

### 6.1.1.3 Patient portals

The main goals of a patient portal are to provide a patient with the following features:

1. Online appointment scheduling system
2. Possibility to view patient's EHR and connected medical results (e.g. laboratory results)
3. Send messages to a medical provider

Creation of the mentioned patient portal is fully supported by SCHC with the following measures:

1. Electronic order of a medical service (Measure 1.1.2): This should improve the accessibility of medical care, mitigation of medical risks and negative economic impacts because of delays and unnecessary long waiting times.

2. Easy access to personal medical record (Measure 1.2.1): The patient could see information about their medical status, recommendations, active medical regimens and list of prescribed medication. This should improve patient engagement, adherence, overview of health state and reduce redundant examinations.
3. Distant electronic consultation of health status (Measure 1.1.3): There is currently no standardized system which would guarantee secured communication between a patient and a doctor. This measure should guarantee that authenticated patients can send comments, notes and messages to the doctor.

#### 6.1.1.4 Artificial intelligence and data analysis

These technologies are out of scope of this project due to the following reasons:

- It is not possible to analyze patient records due to their variance and unstructured form as it is described in the chapter Error reduction.
- Many of the proposed capabilities are not yet ready to be used in clinical practice which are image analysis in radiology and contouring in radiotherapy.
- It is assumed that provider-centric EHRs will not provide enough data needed to build an actionable intelligence.
- The creation of a tool which would analyze EHRs and data from other sources is supported with the measure 2.2.3 “Creation of dynamic tool for an assessment of quality of health care system” which states that “there are potentially interesting data generated in the health care which can be used to support evidence-based medicine”. On the other hand, this measure is not really specific as there is no legislative support, specific steps needed to achieve this measure and no timeline available.

However, the hospital continues in their attempts to put into use existing functionalities of radiotherapy planning systems and make them learn from previous treatment plans.

#### 6.1.1.5 Clinical decision support system

This technology is out of scope for all types of CDS systems (knowledge base, AI based or mixed). These reasons are stated in chapters Artificial intelligence and data analysis and Error reduction.

#### 6.1.1.6 Mobile health

Although the mobile health is an interesting topic in the oncology, there are several problems connected to this:

1. It is not certain which capabilities of mHealth are really useful to the oncology as there is no clinical experience in the Czech Republic.
2. There are no signal codes published by insurance companies so telemedicine in oncology is not covered by the public insurance.
3. How the current processes will be affected by implementation of mobile health?

The implementation of telemedicine and mHealth is supported by SHC with the specific goal 3.1 called "Telemedicine and eHealth" which states that *"systematic and conclusive collection of indicators of patient's health status using a secure and precise remote connection will increase efficiency of health care delivery"* and *"this way it is possible to secure a sustainable development of the entire system"*.

However, this specific goal also states that it is required to define areas where telemedicine can be used, specify target patient groups and diseases, technical requirements, verify its impact and resolve reimbursement of related expenses.

The following mHealth capabilities with the highest impact score will be implemented in the scope of this project:

1. Improvement of patient adherence
2. Remote consultation
3. Remote monitoring and symptoms management using wearables

There are following assumptions connected to this step:

1. The implementation of mHealth is a pilot project and it is not intended for a mass use. Target patient groups will be selected by oncologists and related medical staff.
2. Integration with HIS is not in the scope of this pilot.

### 6.1.2 Project goals

The goal of the project is to implement:

1. Patient portal
2. Make CCC's HIS accessible to all related medical facilities in RCG
3. Pilot project in mHealth

The goal of this project is to improve patient's outcomes in oncology in terms of improving their quality of life and medical outlooks. All these partial goals support the project outcome.

### 6.1.3 Funding

This project can be divided into two parts:

1. Development of additional features and accessibility improvement of the health information system
2. Mobile health

These two parts require different sources of funding, but they could be:

1. Hospital's own resources
2. EU structural funds which are European Regional Development Fund and European Social Fund (European Commision, 2019)
3. Other grants to support implementation of mHealth

### 6.1.4 Stakeholders

There are several stakeholders in this project which are depicted in the table below.

| Name | Involvement |
|---|---|
| Management | Its role is to secure the funding for this project and make sure that project outcomes are consistent with the project (customer) intent. |
| IT department | Its role is to make sure infrastructure can handle all system components implemented in this project and also is an integral part in the project handover to production. |
| Vendor | It is assumed that vendor will cover all project phases. |
| Customer | The founder of this hospital is the region, so it is required that management activities are in accordance with its instructions. |
| End-users | The end-users of the project outcomes will be medical staff and patients. It is therefore required that they are involved in this project, so the risks connected with an improper usability and resistance to adoption are mitigated. |

Table 5: Project stakeholders

### 6.1.5 Project plan

The project will be implemented using a waterfall methodology and will be delivered in two drops. Each drop consists of several steps with an expected timeline and is depicted in the tables below.

#### 6.1.5.1 Health information system

The scope of the first drop is to implement a patient portal and create a remote access to CCC's health information system.

| | Q3 2019 | Q4 2019 | Q1 2020 | Q2 2020 | Q3 2020 | Q4 2020 |
|---|---|---|---|---|---|---|
| Requirements analysis | | | | | | |
| Design | | | | | | |
| Implementation | | | | | | |
| Verification | | | | | | |
| Maintenance | | | | | | |

Table 6: Expected timeline for the first project drop

### 6.1.5.2 Mobile health

The scope of the second drop is to implement features that will support following capabilities of mHealth:

1. Improvement of patient adherence
2. Remote consultation
3. Remote monitoring and symptoms management using wearables

It is expected to start this drop later because of the missing experience with mHealth in oncology so there are issues which need to be resolved and they are mentioned in chapter 6.1.1.6.

| | Q1 2020 | Q2 2020 | Q3 2020 | Q4 2020 | Q1 2021 | Q2 2021 | Q3 2021 |
|---|---|---|---|---|---|---|---|
| Requirements analysis | | | | | | | |
| Design | | | | | | | |
| Implementation | | | | | | | |
| Verification | | | | | | | |
| Maintenance | | | | | | | |

Table 7: Expected timeline for the second project drop

## 6.2 Design and analysis

According to eHealth implementation project solution based on MBI (Potančok & Vondrová, 2019), the purpose of this phase is to define the required functionality of the parts of eHealth which are defined in the scope of this project. For the purpose of this project proposal, the high-level component diagram has been created (Figure 20). Darker blue components need to be developed from scratch, while the lighter blue components represent an existing software which needs to be adjusted and/or deployed for the purposes of this project. Grey components represent software which is freely available or already preinstalled on end-user devices. When it comes to use-cases connected to the proposed functionalities, they are already mentioned in the chapter 3.5Use-cases by technology and actors.

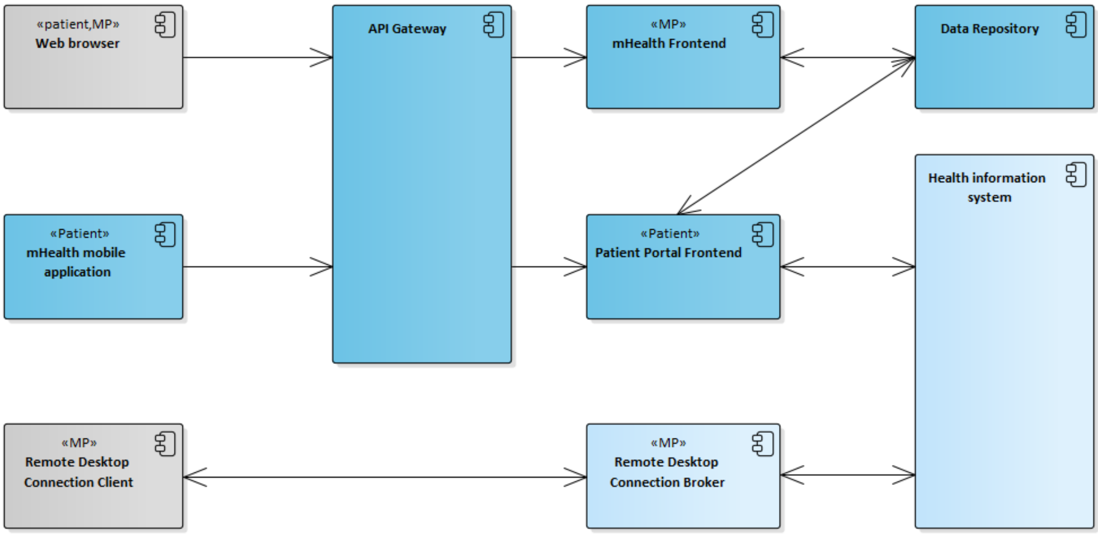


Figure 24: High-level component diagram of proposed technologies

- Patients use a web browser to access patient portal which is integrated with health information system to manage appointments and to enable to look into their EHR.
- Medical professionals use a web browser to view patient-generated data from their mHealth mobile application.
- Medical professionals from medical facilities in the region use remote desktop connection to access their patients' EHR
- Since both patient portal and mHealth support messaging between a patient and a doctor, these components share a data repository for these purposes.
- API Gateway is used for communication orchestration, API mapping, logging, authorization and authentication purposes.

# 7 Conclusion

The aim of this thesis is to create a multi-criteria model of information technologies and assess their impact on patient outcomes in oncology in the setting of health care system in the Czech Republic. Each technology is assessed by several criteria such as their capabilities by cancer stage, their use-cases and level of impact of technology capability.

Realization of the specified objectives which are creation of creation of multi-criteria model based on literature research, evaluation of this model by assessing the current situation in the Czech Republic and confronting this model with professionals related to this field, enhancement of the multi-criteria model of technologies with acquired information from these interviews and evaluation of feasibility of the model by creating a project proposal for a comprehensive cancer center can be also seen as successful.

The chapter Technology showed that there are many interesting technologies which can and could help improve patient outcomes in oncology and that they are all part of eHealth ecosystem. The third chapter contains more detailed decomposition of a multi-criteria model to show what it consists of and the multi-criteria model itself. The fourth chapter shows that cancer is a widespread disease in the Czech Republic and also describes the interviews with professionals. It can be interesting to see that views on some technologies differ from person to person and there is a different perception of the problems connected to oncology and use of information system. The fifth chapter shows that although there are initiatives which start to use patient data to improve oncology care, it can be seen that there are problems which are common with the clinical practice in the Czech Republic. This chapter also contains the multi-criteria model with perceived impacts of technology capabilities. The sixth chapter shows the implementation feasibility of proposed technologies in the multi-criteria model. It can be seen, unfortunately, there are several prerequisites which have to be fulfilled in order to be able to implement the most of multi-criteria model in practice.

## 7.1 Limitations

Some capabilities of the proposed technologies are not yet suited for everyday clinical practice because of the lack of standardized data or they are not perceived to be mature enough. The typical example of this issue is the use of machine learning in radiology and segmentation in radiotherapy. There are also issues with consensus with benefits of some technologies such as mobile health, as it is not yet fully established what capabilities are the most important for improving patient outcomes.

Since the majority of proposed technologies are not yet used in the Czech Republic it is not possible to analyze their usability and maturity for example using HIMMS Maturity and Usability model. The second problem is that the interviews were focused more on oncology practice and patient outcomes, so it is not possible to fully evaluate the maturity of existing technologies, since the mentioned model requires a lot of parameters.

## 7.2 Statement of usefulness

The thesis can be useful for medical professionals, hospital management, eHealth experts and other people who are interested in the oncology care and eHealth. The aim of the multi-criteria model is to show how technologies can improve patient outcomes and their quality of life. Other intended purposes are to promote the use of the technologies to reduce disparities between recent technological advances and clinical practice, improve patients' care by leveraging patient and other clinical data and their engagement in oncology care.

The model can be used standalone or can be part of a framework or a model as it is explained in the chapter 3.8.

## 7.3 Application of the thesis

The multi-criteria model can be used by any hospital which is interested in improving oncology care by using information technologies and it can serve as a guideline to determine which technologies are the most relevant to address their issues.

When it comes to research, this model can serve as a starting point to perform more detailed analysis of the proposed technologies using for example quantitative data or to determine their maturity and usability. Another possibility would be to use this model to perform more interviews which would involve several stakeholders of a typical oncology care department. The last possibility of application is to make a pilot project using a selected technology to assess its usefulness and/or usability in a clinical practice. It should be noted that it would be interesting to revisit this model in several years to determine the progress of use of information technologies in oncology care in the Czech Republic.

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# Attachments

## Attachment A: Questionnaire for medical professionals in the Czech Republic

The following questionnaire was sent to medical professionals when asking for an interview. This questionnaire is in the Czech Language due to the fact it was sent to the medical professionals in the Czech Republic.

### 1. Úvod

Tento dokument představuje diplomovou práci, která se jmenuje "Multi-criteria model of information technologies and their impact on patient outcomes in oncology" (Multikriteriální model informačních technologií a jejich dopad na pacienta v onkologii).

Její cílem je porovnat moderní informační technologie z vícero úhlů a vytvořit vícekriteriální model, který by byl vhodný v prostředí zdravotnictví České republiky.

Součástí práce je zhodnocení dosavadní situace v České republice a zároveň dostat zpětnou vazbu na navrhované technologie a jejich využití od odborníků z praxe.

V podstatě se jedná o zhodnocení NIS, datové analytiky, rozhodovacích systémů, telemedicíny – konkrétně mHealth nositelné elektroniky v onkologii z pohledu lékaře. Na základě literární rešerše byla vytvořena matice technologií a stadia rakoviny a předpokládaných přínosů dané technologie.

### 2. Otázky

1. Některé nemocniční informační systémy přinášejí vícero benefitů a některé se také dají propojit s portálem pro pacienty anebo zobrazit upozornění, pokud nějaký pacient patří do rizikové skupiny. Používáte tyto systémy? Jaké?

2. Jaké benefity nebo komplikace Vám výše uvedené systémy přinesly?

3. Myslíte si, že správně zavedený NIS (nemocniční informační systém) je předpokladem pro další technologie jako systémy pro podporu rozhodování, analytiku pomocí Big Data a umělé inteligence (strojové učení) a telemedicínu?

4. Používáte nějaké systémy pro podporu rozhodování u složitých případů v onkologii?

5. Pokud ano, tak jak byste je popsali z hlediska efektivnosti a přínosů?

6. Používáte nějaké nástroje na analýzu pacientových dat v NIS?
7. Používáte nějakou formu telemedicíny v onkologii?

8. Pokud používáte nějakou formu telemedicíny tak jak byste jí ohodnotili?

9. V České republice existují pilotní programy v telemedicíně například pro diabetické pacienty a některé z nich jsou hrazeny pojišťovnami. Chystá se něco podobného i v onkologii?

10. Myslíte si, že používaní telemedicíny na sledovaní pacientova stavu a kvality života mezi návštěvami ordinace je může zlepšit?

11. Myslíte si, že používaní telemedicíny na systematický sběr pacientových symptomů může zlepšit kvalitu jeho života a ovlivnit rozhodnutí týkající se jeho/její léčby?

12. Myslíte si že mobilní aplikace pro chytré telefony, které slouží ke zlepšení dodržování léčebního režimu pacientem (například pomocí upozornění), ho mohou pozitivně ovlivnit?

13. Myslíte si, že nositelná elektronika (wearables) je vhodná možnost jako neustále monitorovat pacienta například během chemoterapie?

## 3. Užitečnost technologií a jejich využití v onkologii

Použijte prosím následující tabulku na ohodnocení užitečnosti technologií a jejich využití v druhé tabulce. Pokud jsi nejste jistí, tak nechte políčko prázdné.

| Název úrovně užitečnosti | Úroveň užitečnosti | Vysvětlení |
|---|---|---|
| Žádná | 1 | Technologie v tomhle využití nemá žádný efekt na pacienta. |
| Minimální | 2 | Technologie v tomhle využití má minimální nebo žádný efekt pro pacienta. Je možné ale, že získaná data se využijí v budoucnu pro zlepšení péče. |
| Podpůrná | 3 | Technologie v tomhle využití má minimální nebo žádný efekt pro pacienta. Technologie ale může zlepšit kvalitu života a komfort pacienta a snížit náklady. |
| Potencionálně užitečná | 4 | Technologie v tomhle využití má potenciál zlepšit kvalitu života a komfort pacienta a potencionálně může mít pozitivní dopady na léčbu pacienta. |
| Užitečná | 5 | Technologie v tomhle využití má potenciál zlepšit kvalitu života a komfort pacienta a má pozitivní dopady na léčbu pacienta. |

Table 8: Likert scale to assess technology capabilities

| Název technologie | Příklad využití | Úroveň užitečnosti |
|---|---|---|
| NIS | Snížení chybovosti | |
| | Zapojení pacienta přes pacientské portály | |
| | Zlepšení rozhodovacího procesu díky kompletním informacím o stavu pacienta | |
| Datová analytika (umělá inteligence a Big data) | Rozhodování v léčbě | |
| | Určení prognózy pacienta | |
| | Identifikace novotvarů v radiologii | |
| | Podpora plánování léčby a plánu v radioterapii | |
| Systémy pro podporu rozhodování | Rozhodování v léčbě | |
| | Určení prognózy pacienta | |
| Chytré telefony | Řízení symptomů a vzdálené sledování | |
| | Zlepšení dodržování léčby pacientem | |
| | Vzdálená konzultace | |
| | Podpora zdravého životního stylu, podpora ve skončení kouření a poskytovaní informací o rakovině | |
| Nositelná elektronika (wearables) | Řízení symptomů a vzdálené sledování | |

Table 9: Assessed technologies and their capabilities

# Attachment B: The evaluation of impacts of technology capabilities

The following two tables show the perceived impacts of the proposed technology capabilities in the multi-criteria model. If a comprehensive cancer center is there twice it means that two medical professionals from the same institution were asked to fill out the table.

| | Health information systems | | | Artificial intelligence and data analysis | | | |
|---|---|---|---|---|---|---|---|
| | Error reduction | Patient engagement via connected patient portal | Improved decision making by having all information about a patient | Support in decision making | Determining patient prognosis | Support in image analysis in radiology | Support in therapy planning in radiotherapy |
| CCC 1 | 2 | 2 | 3 | 4 | 4 | 4 | 4 |
| CCC 2 | 3 | 2 | 5 | 4 | 4 | 3 | 3 |
| CCC 2 | 2 | 4 | 3 | 3 | 2 | 3 | 5 |
| CCC 3 | 3 | 4 | 4 | 3 | 3 | 2 | 4 |
| CCC 3 | 5 | 5 | 5 | 5 | 4 | 3 | 4 |
| CCC 4 | 4 | 1 | 5 | 2 | 2 | 5 | 2 |
| CCC 5 | 2 | 4 | 5 | 1 | 2 | 4 | 3 |
| CCC 6 | 3 | 3 | 4 | 1 | 3 | | 5 |
| CCC 7 | 4 | 4 | 5 | 2 | 2 | 2 | 5 |
| TOTAL | 3 | 3 | 5 | 3 | 3 | 3 | 4 |

Table 10: Perceived impacts of health information systems and AI and data analysis

| | Clinical decision support systems | | Wearables (mHealth) |
|---|---|---|---|
| | Support in decision making | Determining patient prognosis | Symptoms management and remote monitoring |
| CCC 1 | 4 | 3 | 4 |
| CCC 2 | 4 | 4 | 3 |
| CCC 2 | 3 | 3 | 3 |
| CCC 3 | 3 | 3 | 2 |
| CCC 3 | 3 | 3 | 5 |
| CCC 4 | 2 | 2 | 5 |
| CCC 5 | | 2 | 5 |
| CCC 6 | 2 | 3 | 3 |
| CCC 7 | 4 | 4 | 4 |
| TOTAL | 3 | 3 | 4 |

Table 11: Perceived impacts of CDS systems and wearables

| Smartphones (mHealth) | | | | |
|---|---|---|---|---|
| | Symptoms management and remote monitoring | Patient adherence | Remote consultation | Promotion of healthy lifestyle, helping with tobacco cessation and providing information about cancer |
| CCC 1 | 4 | 4 | 4 | 4 |
| CCC 2 | 3 | 4 | 4 | 3 |
| CCC 2 | 3 | 4 | 4 | 3 |
| CCC 3 | 2 | 2 | 4 | 2 |
| CCC 3 | 5 | 5 | 5 | 5 |
| CCC 4 | 1 | 5 | 5 | 5 |
| CCC 5 | 4 | 5 | 4 | 4 |
| CCC 6 | 1 | 1 | 4 | 4 |
| CCC 7 | 3 | 3 | 4 | 1 |
| TOTAL | 3 | 4 | 4 | 3 |

Table 12: Perceived impact of smartphones