Design of a Human-Machine Interface to Enhance Multi-Criteria Decision Analysis for Healthcare Professionals with a Mock-Up Design Focusing on Colorectal Cancer Screening

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Abstract

Healthcare professionals are often challenged with highly complex situations when multiple aspects must be considered. The benefits offered by human-machine interfaces combined with procedures like multi-criteria decision analysis can significantly improve a healthcare worker's everyday life.

The design science research method by Alan R. Hevner was used to develop a human-machine interface that supports multi-criteria decision analysis for shared decision-making (SDM) in colorectal cancer screening. A systematic literature review was conducted to create a knowledge base. Critical aspects of multi-criteria decision analysis (MCDA), human-machine interfaces, and shared decision-making were identified and extracted. In addition, further information about the topics clinical decision support (CDS), electronic health records (EHR), and the MCDA technique analytic hierarchy process (AHP) were included in the research.

The HMI designed within this paper is based on the conducted research and was not field-tested. More evaluation and developing iterations are needed to gain more value of the HMI.

Nevertheless, the developed design provides a solid foundation that already delivers value for future iterations and can even serve as a base point for different use-cases.

1. Introduction

People that work in the healthcare industry must deal with a lot of data in complex situations. This circumstance can result in a) inefficient and potentially wrong decision-making due to a lack of concentration and b) overwhelming situations for workers in health care. Wrong decisions in healthcare can have life-threatening consequences. Using clinical decision support combined with multi-criteria decision analysis embedded in increasingly used electronic health records has already led to better healthcare outcomes for patients [1, p. 2]. In addition, a more detailed look at the patient data and essential information is provided in EHR. Enhancing CDS leads to better clinical management and cost containment [1, pp. 2-5], less workload and higher efficiency [2, p. 37]. However, it can be complicated to implement CDS that is easy to use and accepted by healthcare professionals [3, p. 1203]. Obstacles can include fragmented workflows, inappropriate alerts [1, pp. 6-7], inconsistent design concepts and visualization, inflexible interaction, poor presentation [3. pp. 1206-1207] and a bad HMI design [4, p. 388].

To answer the research question “How should a human-machine interface be designed to support and enhance the usage of multi-criteria decision analysis for healthcare workers?”, a solution that integrates MCDA in a human-machine interface to enhance the decision-making process of healthcare workers was developed by using the design science research methodology by Alan Hevner.

There are a variety of different instances where MCDA is making an impact by supporting healthcare professionals making difficult choices [5, pp. 4-5]. While developing the prototype, a particular focus was set on shared decision-making in colorectal cancer screening using AHP. SDM in healthcare describes patients' treatment choices in agreement with their physician [6, p. 1].

This paper will provide multiple mock-ups to assess cancer screening alternatives in the context of SDM while removing the related obstacles to gain a higher acceptance for CDS and enhance the use of MCDA. Even though the HMI represents cancer screening, it should be adaptable for different kinds of shared decision-making use-cases in the healthcare sector.

First, information about MCDA (and the AHP technique), SDM, and colorectal cancer screening will be provided to build a frame of reference. Secondly, DSR will be introduced to develop an artifact (HMI) for solving the problems healthcare workers are confronted with in cancer screening and the requirements to be met in the design process are listed and explained. Then, the artifact will be presented as a frontend solution and lastly, the conclusion will demonstrate limitations and future outlooks will be discussed.

2. Foundations

According to Jitesh J. Thakkar (2021), multi-criteria decision analysis, also known as multi-criteria decision making (MCDM), focuses on “[…]various alternatives and scenarios for “what-if” analysis.“ [7, p. 1]. He describes it as a “systematic approach of evaluating, prioritizing and selecting the most favorable alternative from a set of available ones.” [7, pp. 5]

Generally, MCDA describes a mathematical procedure that weights multiple conflicting criteria to assess the most suitable option(s) later. When conducting a MCDA, it is essential to structure the given problem properly by pointing out all the crucial alternatives and criteria. It is vital to consider the complexity of trade-offs between conflicting criteria, which are weighted differently [7, p. 2]. The solution(s) achieved through MCDA should be seen as a guideline; therefore, the final decision should be acceptable for each stakeholder [7, p. 4]. Stakeholders in this context are those who provide the preferences used to conduct the MCDA, and the decision-makers make the final decision by figuring out the most suitable alternative considering the data provided by the MCDA [5, p. 3]. It is important to understand that the stakeholders can differ from use-case to use-case and can even reflect the general public [8, p. 20].

Through MCDA, a significant impact can be achieved by revealing important, unseen information and enabling the stakeholders to solve fundamental conflicts and the decision-maker to follow the most suitable strategy [7, p. 4]. MCDA should be considered an extension of other methods used to make a decision [6, p. 1].

Generally, MCDA methods are divided into multi-objective decision making (MODM) and multi-attribute decision making (MADM) models. In contrast to MADM models, the different alternatives of MODM are not fixed and can be continuously expanded or decreased. Furthermore, there are three main categories in which a MCDA technique can be classified. The first is the “value measurement models” (e.g. AHP, MAUT, etc.), where a complete aggregation occurs. A partial collection is given in the “outranking models” (e.g. ELECTRE), and the “goal, aspiration or reference level models” (e.g. TOPSIS) focus on local aggregation [9, pp. 33-34]. The classification is also shown in Mühlbacher and Kaczynski 2015 [9, p.34]. A copy of the figure is provided here in Figure 1.

ISPOR’s (International Society for Pharmacoeconomics and Outcomes Research) second task force report of 2016 presented good practice guidelines for conducting a multi-criteria decision analysis as shown in Table 1.

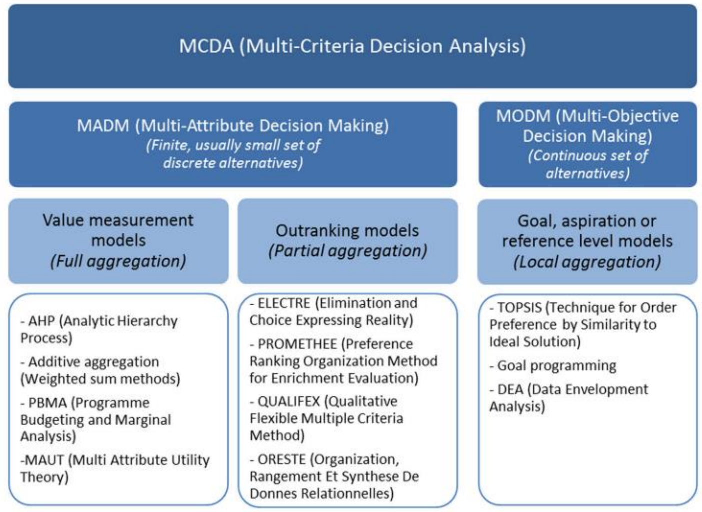

Figure 1 provides an overview of the various MCDA approaches

The MCDA process is usually divided into eight steps. The first is the “definition of the decision problem”. Afterward, the criteria need to be selected and structured. The third step covers the “measuring performance”, which describes data collection about the alternatives and performance of criteria and summarizing them inside a “performance Matrix”. Next, the alternatives need to be scored and the criteria weighted by considering the stakeholder’s preferences. What follows is the calculation of the aggregated scores to get the final rank of the alternatives. The next move would be to perform an uncertainty analysis. The last step describes the “reporting and examining of [the] findings” [5, p. 8]. At each step, validation should be conducted to ensure the relevant “design, input and outputs are plausible and consistent with decision maker objectives and stakeholder preferences” [10, p. 126]. For more specific information regarding the different steps and validation, ISPORS’ first and second Taskforce Report is recommended.

As already mentioned, various MCDA techniques exist, with each having different possible applications. This paper will focus on the Analytic Hierarchy Process approach. Due to its mathematical and structural simplicity, the AHP technique is used in various sectors, including healthcare. One advantage of AHP is the pairwise comparison (usually on a scale from one to nine) between two criteria or alternatives. This makes it easy for decision-makers to contribute to the outcome of the MCDA process and make the final ranking more relatable. One feature that stands out is the hierarchical structure of the technique [7, p. 33]. The different criteria, sub-criteria (and sub-sub

Table 1 – ISPOR MCDA Good Practice Guidelines Checklist.

MCDA step	Recommendation
1. Defining the decision problem	a. Develop a clear description of the decision problem
	b. Validate and report the decision problem
2. Selecting and structuring criteria	a. Report and justify the methods used to identify criteria
	b. Report and justify the criteria definitions
	c. Validate and report the criteria and the value tree
3. Measuring performance	a. Report and justify the sources used to measure performance
	b. Validate and report the performance matrix
4. Scoring alternatives	a. Report and justify the methods used for scoring
	b. Validate and report scores
5. Weighting criteria	a. Report and justify the methods used for weighting
	b. Validate and report weights
6. Calculating aggregate scores	a. Report and justify the aggregation function used
	b. Validate and report results of the aggregation
7. Dealing with uncertainty	a. Report sources of uncertainty
	b. Report and justify the uncertainty analysis
8. Reporting and examining of findings	a. Report the MCDA method and findings
	b. Examine the MCDA findings

MCDA, multiple criteria decision analysis.

criteria, etc.) are all arranged at different levels and can therefore be analyzed separately as a problem on each level. Afterwards, the results can be aggregated to one final solution/option for the given problem [8, p. 10-13]. The exact procedure and steps of AHP are described in the book "Multi-Criteria Decision Making" by Jitesh J. Thakkar [7, pp. 33-62].

Given limited resources and multiple conflicting objectives, multi-criteria decision analysis is becoming more common in healthcare [11, p. 269]. The use of MCDA can spread from macro- to micro-level applications [6, p. 1]. Among other things, it is used in health technology assessment, benefit-risk assessment, shared decision-making, and many other use cases [5, pp. 4-5].

Typically, those affected by healthcare decisions (e.g. patients in hospitals, budget negotiations) have very little influence on the chosen procedure and must rely on the competence of experts (e.g. physicians). There are a few areas in healthcare where it makes sense that the stakeholders can actively influence the decision-making process. Recent developments in healthcare services show an increase in shared decision-making and the consideration of patients' preferences [9, p. 30].

The preferences vary depending on the circumstances or stakeholders, making it hard to decide whose preferences are more important. In the case of shared decision-making (SDM), the patient's preferences are highly relevant [8, p. 20]. SDM describes the interaction process between a patient and a doctor to support the decision of treatment choices [6, p. 1]. It is getting more common to include the patient's preferences in the healthcare decision process [9, p. 30].

Usually, healthcare decisions are classed as opaque [9, p. 29], but thanks to MCDA's transparency [11, p. 270] and ability to include patients' views in the decision process [9, p. 31], massive support has been found in the shared decision-making process. Some steps of the multi-criteria decision analysis are still conducted analogously (e.g. "collect the preferences of the participants"), leading to inefficiency and difficulties in executing the MCDA. Software supporting MCDA already exists, but to successfully use it in the healthcare sector, it needs to be altered to the needs of the stakeholders/ decision-makers, namely healthcare workers [11, p. 270]. One reason for the lack of MCDA software implementation is the lack of know-how regarding the appropriate MCDA technique for the different healthcare fields [9, p. 29].

There are a variety of different MCDA techniques, and most can be altered to a healthcare use-case. Here, the focus was set on colorectal cancer in the context of cancer screening and shared decision-making [5, p. 6].

The American Cancer Society defines cancer as "a group of diseases characterized by the uncontrolled growth and spread of abnormal cells that can result in death if not treated." [12, p. 1] They estimate that "106,180 cases of colon cancer and 44,850 cases of rectal cancer will be diagnosed in the US, and a total of 52,580 people will die from these cancers" in 2022 [12, p. 14]. Colorectal cancer can develop in any person, but the risk increases with age [12, p. 1]. In addition, smoking, obesity, alcohol consumption, and unhealthy eating habits can increase cancer risk [12, p. 2]. Colorectal cancer has multiple symptoms, including rectal bleeding, blood in the stool, changes in bowel habits, and more. However, in the early stages, it usually does not cause these symptoms. Therefore, it is important for patients to do a screening to catch cancer early [12, p. 15].

The screening process describes the search for cancer in an asymptomatic person. The screening method chosen is not as important as the screening itself [13, p. 8]. Screening is essential for cancer detection and can prevent early death. Even if screening results in cancer detection, it can lead to more effective treatment methods that increase the patient's chance for survival [12, p. 15]. Various screening options exist for patients, each with its own benefits and limitations [13, pp. 14-16]. They are usually divided into "Stool-based tests" which are more convenient, and the more intense "Visual (structural) exams" [13, p .8].

Colorectal cancer screening presents an opportunity for patients to include their preferences in the final screening decision, which will increase the likelihood of patients coming to the recommended follow-up meeting. Studies have shown that patients are likely to change their opinion when presented with more information about the different screening options [14, pp. 1-2]. In the information exchange between physician and patient, the physician is required to provide the relevant information about the various screening options, and the patient contributes with his preferences regarding the different criteria involved in the different cancer screening alternatives [15, p. 1]. The shared decision-making process consists of multiple steps which can lead to higher patient satisfaction [15, p. 2].

First, the patient needs to be invited to participate in the decision-making process where the different alternatives are presented. Afterwards, the information exchange as mentioned above takes place. That is also the point where the MCDA will be conducted. This process should lead to a simplification in the decision-making. Lastly, the physician should support the patient in following through with the chosen screening option [15, p. 4].

The following paragraph will display a brief introduction to the topics EHR/CDS and HMI.

EHR has a variety of definitions. For example: EHR is "[…]a repository of patient data in digital form, stored and exchanged securely, and accessible by multiple authorized users" [16, p. 554]. The definitions are true for the initial concepts of EHR from the 1990s. But since then, the content, structures, and technologies have changed and the EHR is constantly adapting [17, p. 320]. Nowadays, to achieve meaningful use, EHRs have functions that go far beyond storing and sharing data [18, p. 319]. The analysis of data and the support based on it have taken a central role in EHRs. CDS with integrated MCDA can be used for this process. The CDS software, where patient information gets entered and interpreted, can be integrated during the development of an HMI. HMIs are "[...] hardware or software through which an operator interacts with a controller.

An HMI can range from a physical control panel with buttons and indicator lights to an industrial PC with a color graphics display running dedicated HMI software" [19, B-7]. An HMI provides an interface between a human and a machine and supports the user in interacting with it, without having to know the machine language that lies behind it. In this, the HMI is a color graphics display that runs software that provides value to healthcare workers. The benefit of the HMI depends strongly on how it is designed. A vast literature on design principles explains how HMI should be designed to support user interaction with the machine.

3. Methodology

For developing a human-machine interface that supports multi-criteria decision analysis for choosing a colorectal cancer plan, the design science research method by Alan R. Hevner [20] was applied. Design science research is used to develop an artifact, a technical solution for a research problem, in an iterative procedure.

The environment represents the problem area and consists of affected people, organizations, and used technology. In the case of SDM, the people affected are the doctors and patients who need to decide which treatment to implement (e.g. choose a cancer screening alternative).

Information system research is the developing area where theories or artifacts get built and evaluated iteratively. The goal is to develop a human-machine interface (artifact) that helps the affected people from the environment in shared decision-making using multi-criteria decision analysis. The evaluation was conducted by comparing the design principles mentioned earlier with the actual HMI developed in the process of DSR.

The knowledge base consists of foundations, methodologies and design requirements that are applied to the development process in the information system research area. The foundations, methodologies and design requirements are the results of the conducted literature review on multi-criteria decision analysis, human-machine interface in a healthcare context, and more specific cancer screening alternatives.

A literature review was conducted in the databases Google Scholar, PubMed, WebOfScience, and ScienceDirect. Two reviewers independently extracted information in the research areas: HMI, MCDA, AHP, SDM, CDS, EHR, DSR, IS, healthcare, and colorectal cancer screening. In total, 94 papers were selected from the databases for further examination. Of the 94 papers, 62 stem from the area of healthcare and MCDA. Eighteen papers dealt with the topics HMI, CDS, and HER. An additional fourteen included the subjects DSR and IS.

The final paper selection was conducted in three steps. First, the papers in the databases were screened by the titles. Second, the abstracts were taken into account. Finally, the remaining papers were reviewed in detail and the critical information extracted. The search strategy identified 24 studies that were used in this paper.

The requirements that resulted from the literature review were applied to the design process. We used the following eight design requirements, which were composed of the literature [3, pp. 1205-1208], [21, pp. 99-103], [22, p. 96], and [23, p. 264].

A) Starting point: It should be easy for users to identify how to run an interaction with the system. Having an obvious starting point should a) lead to a better understanding of beginning a task and b) provide better navigation inside of the system. An overview frame like a home screen works well.

B) Reverse options: This is not only about getting back to the starting point but having the option to reverse the last step, save the current state, or discard the complete process. This interaction should have no effect on the system. The reverse option takes away the fear of damaging something or information loss in the system. This encourages the user to experiment with the system and get familiar with it.

C) Consistency logic: A consistent logic is required for the user to know what to expect when interacting with the system. For example, every box that represents a button should have rounded corners. The user will understand very fast that rounded boxes are buttons. Boxes with regular corners can be used to provide information without interaction capability. This kind of consistency helps to reinforce the learning process because the user already knows what to expect when clicking on rounded boxes and does not have to "try it out." Consistency logic helps shorten the required time to finish a task and lowers the cognitive effort.

D) Feedback and support: Providing informative feedback to the user is very important, so the user is informed and confident that the interaction with the system has an effect. In our case, feedback should include support for the user. For example, the user could be informed that important information is missing or that a request needs attention. Feedback could also include an alert about something he needs to take care of, which must be implemented, so the user does not get distracted.

E) Customization and adaption: A user should be able to customize entries due to their preferences and needs. Moving regularly needed information to the top, for instance, can allow the user to quickly find crucial details, which helps better integrate the system into their workflow. Not only should the positions and amount of information be customizable, but the appearance of them should be as well. For example, users with poor eyesight can adapt the font size.

F) Visualization of information: Understanding and memorizing data can be supported by visualizing information. Presenting the same information requires more cognitive effort, and the user cannot concentrate for a long time. Visualization helps to minimize the memory load.

G) User-control: The user needs to develop a feeling of control over the system's interface. Physicians, in particular, might have a hard time handing over the responsibilities to a computer. Enhancing the user-control helps to improve trust in the system.

H) Colors, highlights, and fonts: The interface should use collocations of colors that are easy to distinguish so everything is easy to read. It is essential to keep colors, highlights, and fonts basic to ensure the user's attention gets drawn to the desired scenario when it is really needed. The interface can use psychological indicators to catch the user's attention. For example, this can be accomplished by using green or red colors.

4. Results

Figures 3, 4, 5, 6, and 7 represent the HMI created to support healthcare workers and enhance the usage of MCDA by focusing on the AHP technique in connection with colorectal cancer screening. A specific use case (colorectal cancer screening) was chosen to illustrate the design principles from above. The developed HMI serves as a first mock-up to base future research on.

Having the data of patients easily accessible helps the user know which patient he is dealing with at any given moment. The personal data of the patient currently selected is provided in a section in the top left corner of every interface. Furthermore, the interface provides buttons to get to the home screen, save changes, undo the last step, and open the settings. A search bar helps to find information—e.g. medications or treatments. Lastly, in every frame, there is a feedback bar at the bottom.

The user has an integrated calendar at the bottom left of the home screen, which shows patient-specific appointments sorted by time as well as prioritization of other upcoming meetings and deadlines. On the right side is a visualization of all diseases of the patient. The user can get detailed information by clicking on the marked areas. In the middle, the user can customize how the overview information of the patient should be presented.

Figures 4 and 5 ("Input of Preferences for Cancer Screening") present the beginning of the cancer screening plan and decision application. As shown in the "value tree" in figure 2 [24, p. 3], the hierarchical structure of AHP consists of three levels.

The first level contains the main criteria: "test effectiveness", the "screening plan", and "features of the test". On the second level, the sub-criteria are organized: the "follow-up possibility" and "frequency of testing" are two sub-criteria of the "screening plan", and the criteria "features of the test" is divided into the four sub-criteria: the "possibility of complications", "convenience", "preparation", and "procedure". On the third and last level, the selected screening alternatives for colorectal cancer are positioned: the "fecal immunochemical test" (FIT) [frequency: every year], the "computed tomography colonography" (CTC) [frequency: every 5 years], the "colonoscopy" [frequency: every 10 years] [12, pp. 14-16].

The AHP method was altered to fit the requirements of SDM better. The questions for the patient were reduced by a) excluding the pairwise comparison of alternatives based on a criteria/sub-criteria and b) by implementing the "enforce the consistency ratio to zero" button (Figures 4 and 5).

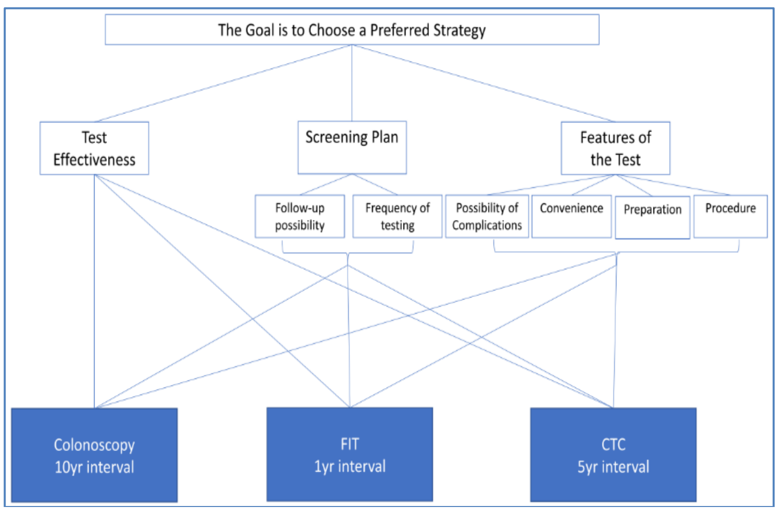

Figure 2 AHP value tree for colorectal cancer screening

a) An example of an excluded question is as follows: "How would you evaluate the alternatives below based on (criteria/sub-criteria)?"

- FIT vs. CTC
- FIT vs. Colonoscopy
- [CTC vs. Colonoscopy]

The reason for excluding these questions is that patients are usually not experts on healthcare topics and thus cannot appropriately answer the questions. This simplification reduces the number of questions from 31 to 10. The comparison in the square brackets disappears if the consistency ratio button is activated.

b) The consistency ratio describes the transitivity rule. For example, if "effectiveness" is two times more important to a patient than "convenience" and the "possibility of complications" is two times more important than "effectiveness", a patient should value "possibility of complications" four times more than "convenience".

To avoid inconsistency, the checkbox "Force Consistency Ratio to 0.0" should always be preselected and active during the weighting process (Figure 4). This also reduces the number of questions from 10 to 6 (compare Figures 4 and 5). The remaining pairwise comparisons are shown below:

Level 1: Main criteria

- Test Effectiveness vs. Screening Plan
- Test Effectiveness vs. Features of the Test
- [Screening Plan vs. Features of the Test]

Level 2.1: Sub-criteria – Screening Plan

- Follow-up Possibility vs. Frequency of Testing

Level 2.2: Sub-criteria – Features of the Test

- Possibility of Complications vs. Convenience
- Possibility of Complications vs. Preparation
- Possibility of Complications vs. Procedure
- [Convenience vs. Preparation]
- [Convenience vs. Procedure]
- [Preparation vs. Procedure]

The weighting for the AHP respectively for the different criteria will be done in consultation with the physician. The patient will compare the criteria pairwise and can decide which criteria are most important. When the patient finished the questionnaire, the answers can be submitted by pressing the corresponding button ("Submit").

Next to a suggestion for the cancer screening plan, which is highlighted in blue, the decision output of the framework provides a visualization of the evaluated criteria of the screening plans as well. By clicking on one of the criteria, the user gets more detailed information about its particular criteria and can compare the alternatives. On the bottom left, the user can decide which cancer screening plan to use. It can be the same as the decision of the MCDA, or he can choose an alternative in consultation with his doctor.

The next section explains the derived design principles, based on the design requirements in section 3.

<u>A) Starting point:</u> The home screen was designed to reflect a comfortable user environment. The operator can decide whether he/she just wants to get an overview of the selected patient or start an application, such as a cancer screening evaluation.

<u>B) Reverse options:</u> The interface was designed so that users always have the option to reverse an action or to return to the home screen. A "safe" button was integrated to enable the user to skip the application currently running and return later without

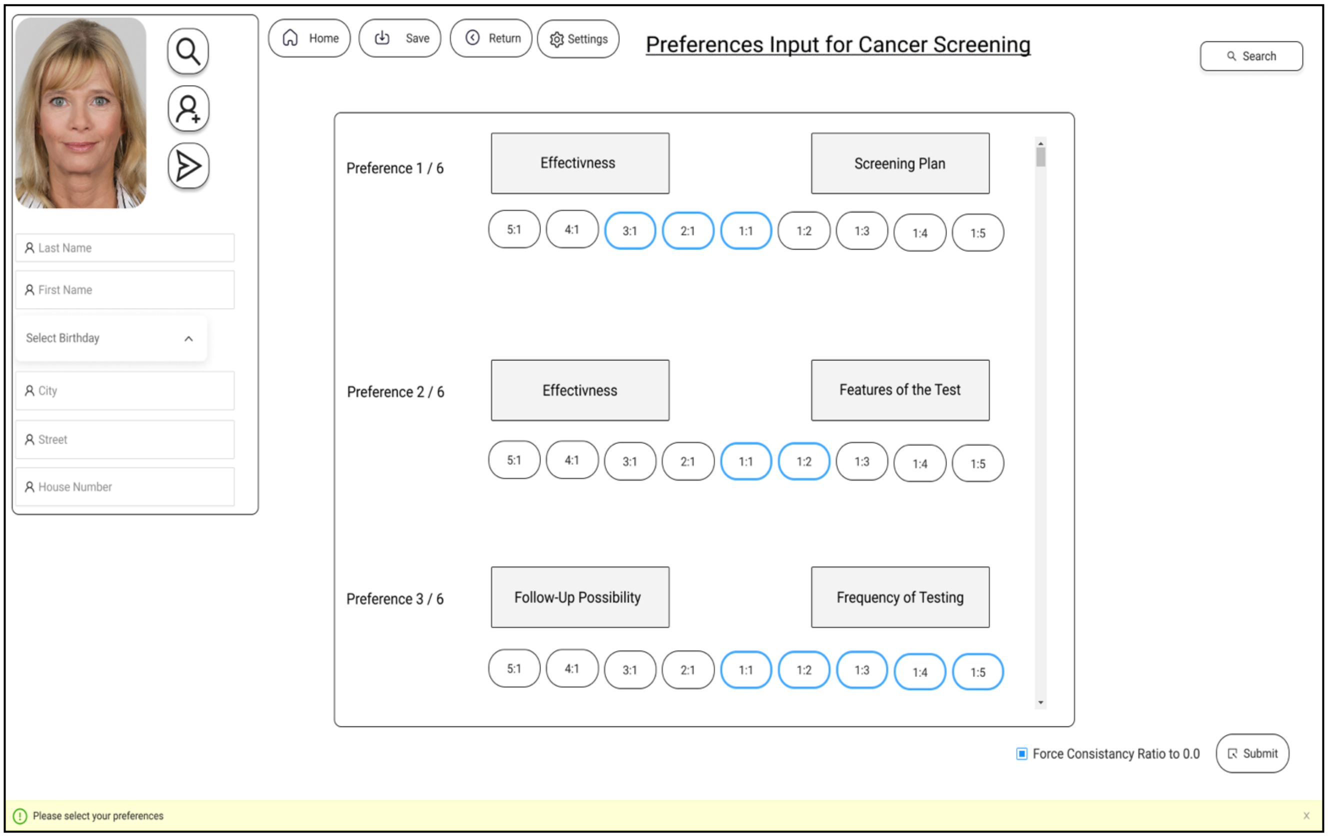

Figure 4 – AHP use case for cancer screening (All mock-up designs are located in the appendix)

memory loss. In the case of an emergency or an undelayable appointment, the user is always able to restore the saved state and continue working on the task.

C) Consistency logic: To make buttons easier to identify, all were designed with rounded corners. Information is displayed in squared boxes and editable text fields are represented the same way, except for a grayed-out indication of what should be written inside.

To maintain consistency, other factors also need to be considered. For example, the home button should remain even if the user is on the home screen. This helps ensure the user that the order of the buttons remains the same, helping him/her to easily adjust to the interface.

D) Feedback and support: The interface has a variety of feedback options that can support the user without being too distracting. Feedback, support, and warnings will deploy on the bottom of the screen. The user can continue his/her work but still be informed.

E) Customization and adaption: On the home screen (Figure 3), in the middle frame, the patient's overview information is displayed and can be customized to the desired structure of the operator. If information about allergies is referenced frequently, it can be moved to the top to reduce the search time. In addition, the user can filter and sort his calendar to prioritize his appointments and deadlines by his needs. In the settings, the display options can be altered if the user has poor eyesight or color vision. These features can contribute to a pleasant work experience by making the interface customizable to an individual's needs.

F) Visualization of the information: The patient's illnesses are visualized on the right side of the home screen. The pictorial representation of information makes it easy for the user to get an overview. If more detailed information is needed, the user can click on the highlighted areas. The elements of the different screening plans are displayed in a column diagram, on the screen "Cancer Screening Decision" (Figures 6 and 7). These elements are normalized to a scale of 10, to provide better comparability of the characteristics.

If the user is interested in the "complications" of the screening plans, the corresponding columns can be compared with each other. This enables the user to get a more complete picture of the different alternatives. More detailed information about certain properties is displayed by clicking on the desired one.

G) User-control: The recommended cancer screen plan is highlighted on the screen "Cancer Screening

Decision" (Figures 6 and 7). However, the doctor can still decide in cooperation with the patient which cancer screen plan to use. This way, the control remains with the user.

H) Colors, highlights, and fonts: The interface uses color highlights and fonts very sparingly. This makes it easier to guide the user to an important intervention. Feedback is divided into three different options and is therefore separated by color. This makes it easier for the user to identify if it is a) normal feedback, b) support or c) a warning.

Normal feedback was displayed in blue and support in yellow. For warnings, the color red was chosen. People associate this color with danger and therefore perceive it faster. Red is also used if the consistency ratio during the MCDA gets greater than 0.1. In the black boxes, which contain detailed information, important words and differences are highlighted in bold.

5. Conclusion and Outlook

The conducted research has shown that there is a demand for an HMI solution that supports healthcare workers to deal with different challenges. One of these challenges describes the shared decision-making process in cancer screening. Patients are more and more interested in contributing to the final decision. They are more likely to follow up with important appointments if their interests and preferences are integrated into the decision-making process. This can result in early cancer detection and therefore to more effective treatments and a higher life expectancy for the patients. The human-machine interface was designed to make this exchange between physician and patient easier and to help healthcare workers to handle overwhelming situations.

To integrate this process in the human-machine interface, the AHP technique was used. During the developing process of the interface, different design principles were incorporated. It is important to note that the interface wasn't evaluated yet and is based on the aforementioned design principles, as well as the MCDA framework research. More evaluation and developing iterations are needed to assess the value of the human-machine interface. For the evaluation, interviews with healthcare workers and existing patients are recommended. Later the mock-up designs should be field-tested by integrating them into a real application that the physicians use in their daily work routine. Nevertheless, the developed design with a solid foundation already delivers value for future iterations and can even serve as a base point for different use-cases in the healthcare industry.

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<u>Tables:</u>
Table 1: [10, p. 127]

<u>Figures:</u>
Figure 1: [9, p. 34]
Figure 2: [24, p. 3]
Figure 3, 4, 5, 6, 7: Nico Muñoz and Ndricim Smakolli, "Healthcare Mock-Ups", Darmstadt, June 2022

<u>Graphics:</u>
Graphic 1:
https://online.visual-paradigm.com/app/diagrams/#infoart:proj=0&type=GroupedColumnCharts&gallery=/repository/598bbc09-82aa-470c-8871-c78c119351af.xml&name=Grouped%20Column%20Chart, used in Figure 4 and 5
Graphic 2:
https://www.vecteezy.com/vector-art/418279-human-body-outline-in-three-colors, used in Figure 3
Graphic 3:
https://0e10dcc0-a-62cb3a1a-s-sites.googlegroups.com/site/mpwebshop2013/diverses/erika%20mustermann.jpg?attachauth=ANoY7crTkkUEJbHke1I6DzeTr17eN2u_B0u8wwOCBLuO2cNOnNkXVQntVu9LZDX_8yyAO-U4qm-yy3pf9wKpx-c-I2_QRuFeM7kOxcIkfNBhskS6ojRjll7Cv0HxDWgQCrT2lbWbzDAJEWIHUaiuei-xfHxB8JnTXssI-h6C-qeMZTEgsbq6hfvvNriKIrKWGsaU9bNabW54mc2ixNTdqTEXyYQ6xaQHOGBTx1lsWBVX5q_ho6XUDQw%3D&attredirects=0, used in Figure 3 to 7

Abbreviations	
MCDA	multi-criteria decision analysis
MODM	multi-objective decision making
MADM	multi-attribute decision making
AHP	analytic hierarchy process
HMI	human-machine interface
DSR	design science research
IS	information systems
CDS	clinical decision support
EHR	electronic health records
ISPOR	International Society for Pharmaco-economics and Outcomes Research
SDM	shared decision-making
FIT	fecal immunochemical test
CTC	computed tomography colonography

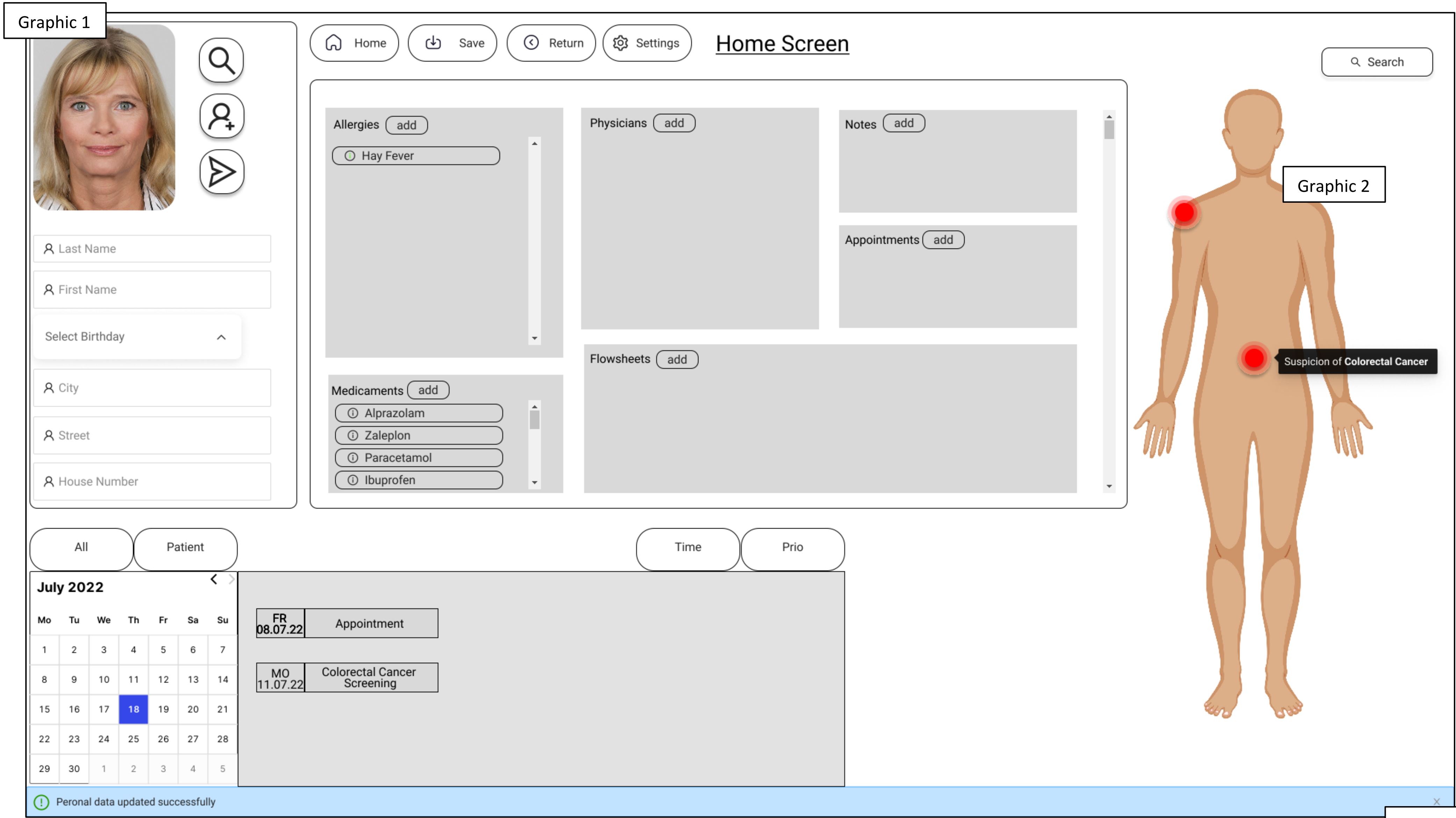
Graphic 1
Home
Save
Return
Settings
Home Screen
Search
Allergies add
Hay Fever
Physicians add
Notes add
Appointments add
Medicaments add
Alprazolam
Zaleplon
Paracetamol
Ibuprofen
Flowsheets add
Graphic 2
Suspicion of Colorectal Cancer
Last Name
First Name
Select Birthday
City
Street
House Number
All
Patient
Time
Prio
July 2022
Mo Tu We Th Fr Sa Su
FR 08.07.22 Appointment
MO 11.07.22 Colorectal Cancer Screening
Peronal data updated successfully

Figure 3

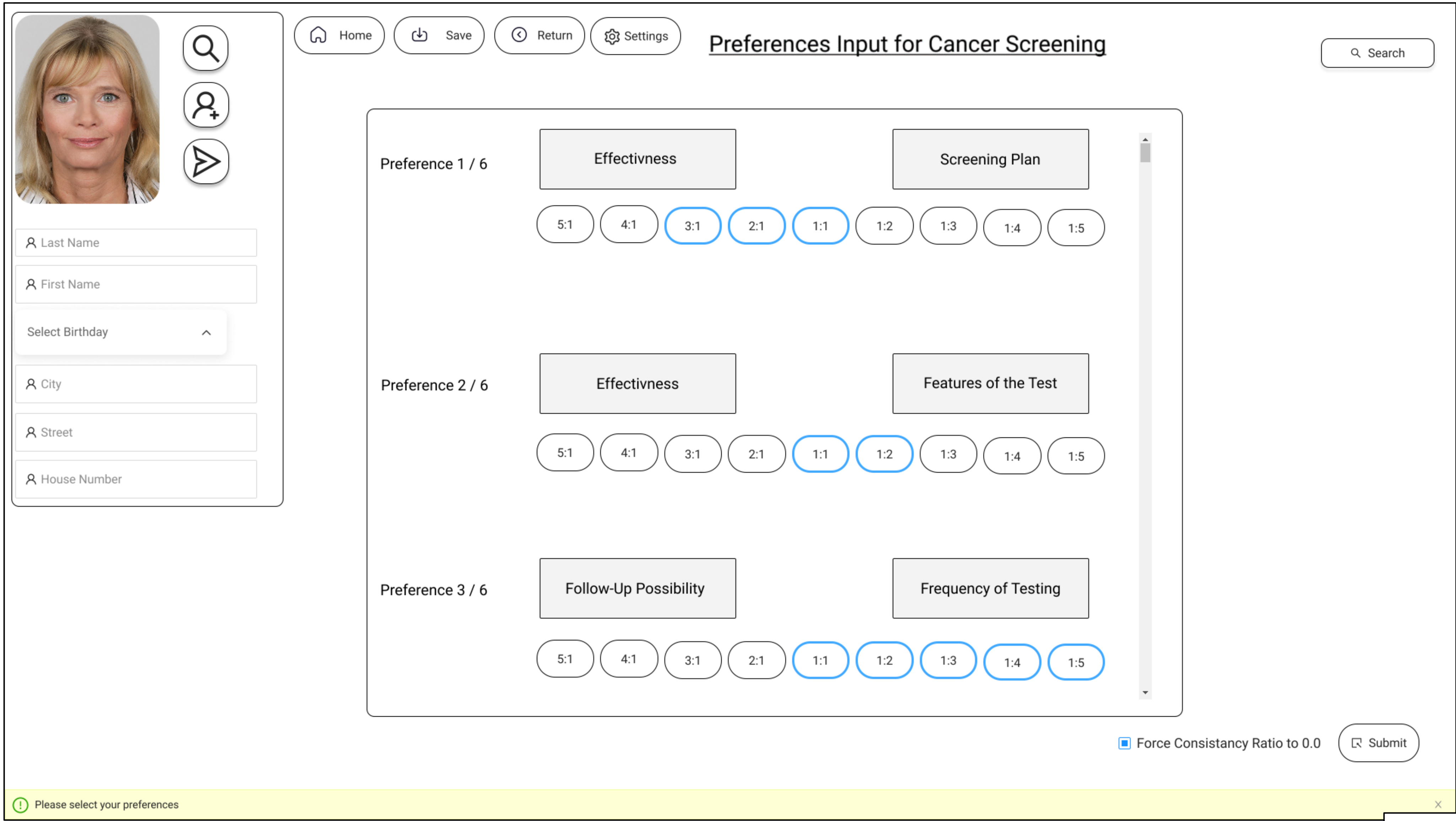
Home
Save
Return
Settings
Preferences Input for Cancer Screening
Search
Last Name
First Name
Select Birthday
City
Street
House Number
Preference 1 / 6
Effectivness
Screening Plan
5:1
4:1
3:1
2:1
1:1
1:2
1:3
1:4
1:5
Preference 2 / 6
Effectivness
Features of the Test
5:1
4:1
3:1
2:1
1:1
1:2
1:3
1:4
1:5
Preference 3 / 6
Follow-Up Possibility
Frequency of Testing
5:1
4:1
3:1
2:1
1:1
1:2
1:3
1:4
1:5
Force Consistancy Ratio to 0.0
Submit
Please select your preferences

Figure 4

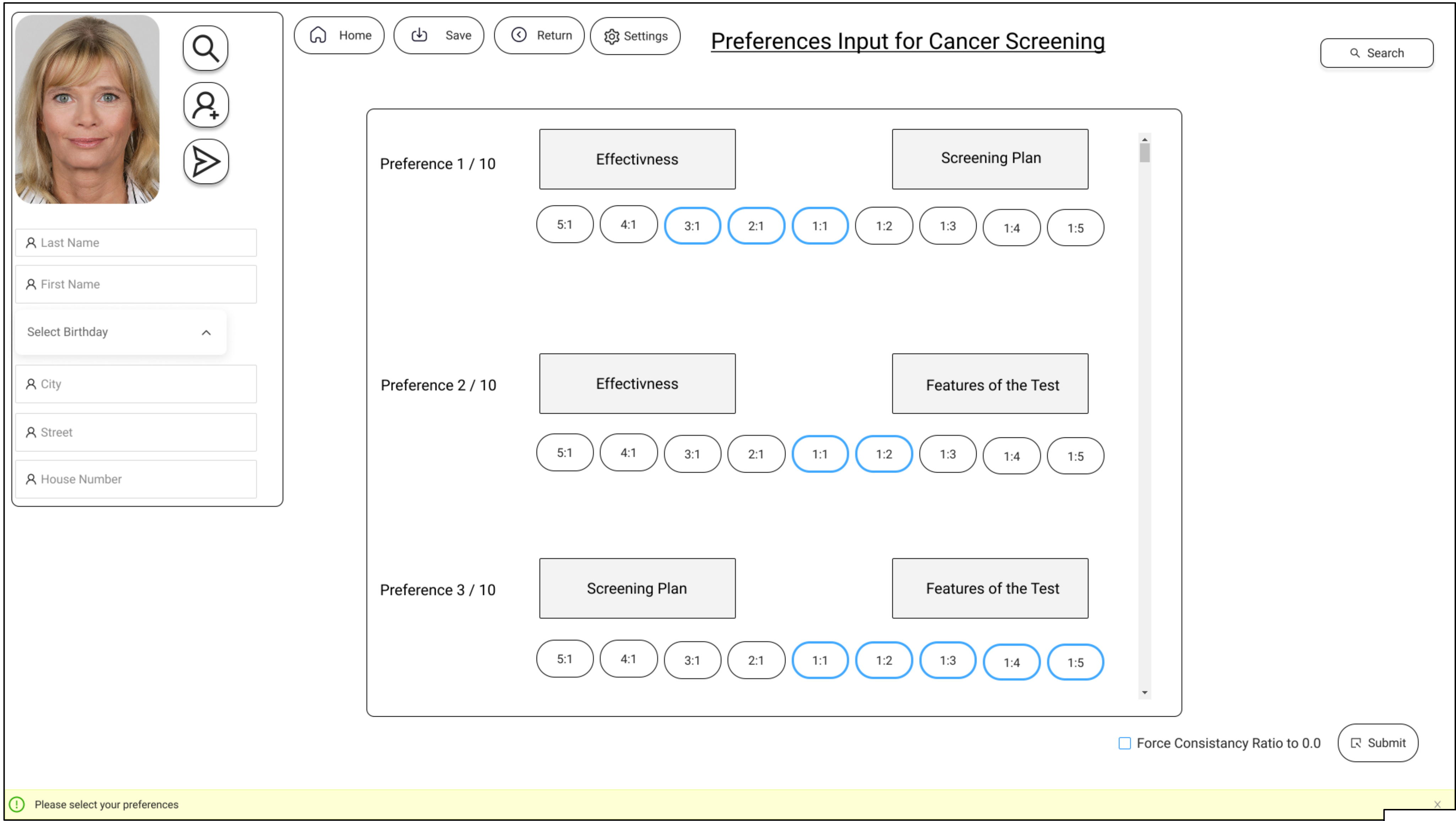
Home
Save
Return
Settings
Preferences Input for Cancer Screening
Search
Last Name
First Name
Select Birthday
City
Street
House Number
Preference 1 / 10
Effectivness
Screening Plan
5:1
4:1
3:1
2:1
1:1
1:2
1:3
1:4
1:5
Preference 2 / 10
Effectivness
Features of the Test
5:1
4:1
3:1
2:1
1:1
1:2
1:3
1:4
1:5
Preference 3 / 10
Screening Plan
Features of the Test
5:1
4:1
3:1
2:1
1:1
1:2
1:3
1:4
1:5
Force Consistancy Ratio to 0.0
Submit
Please select your preferences

Figure 5

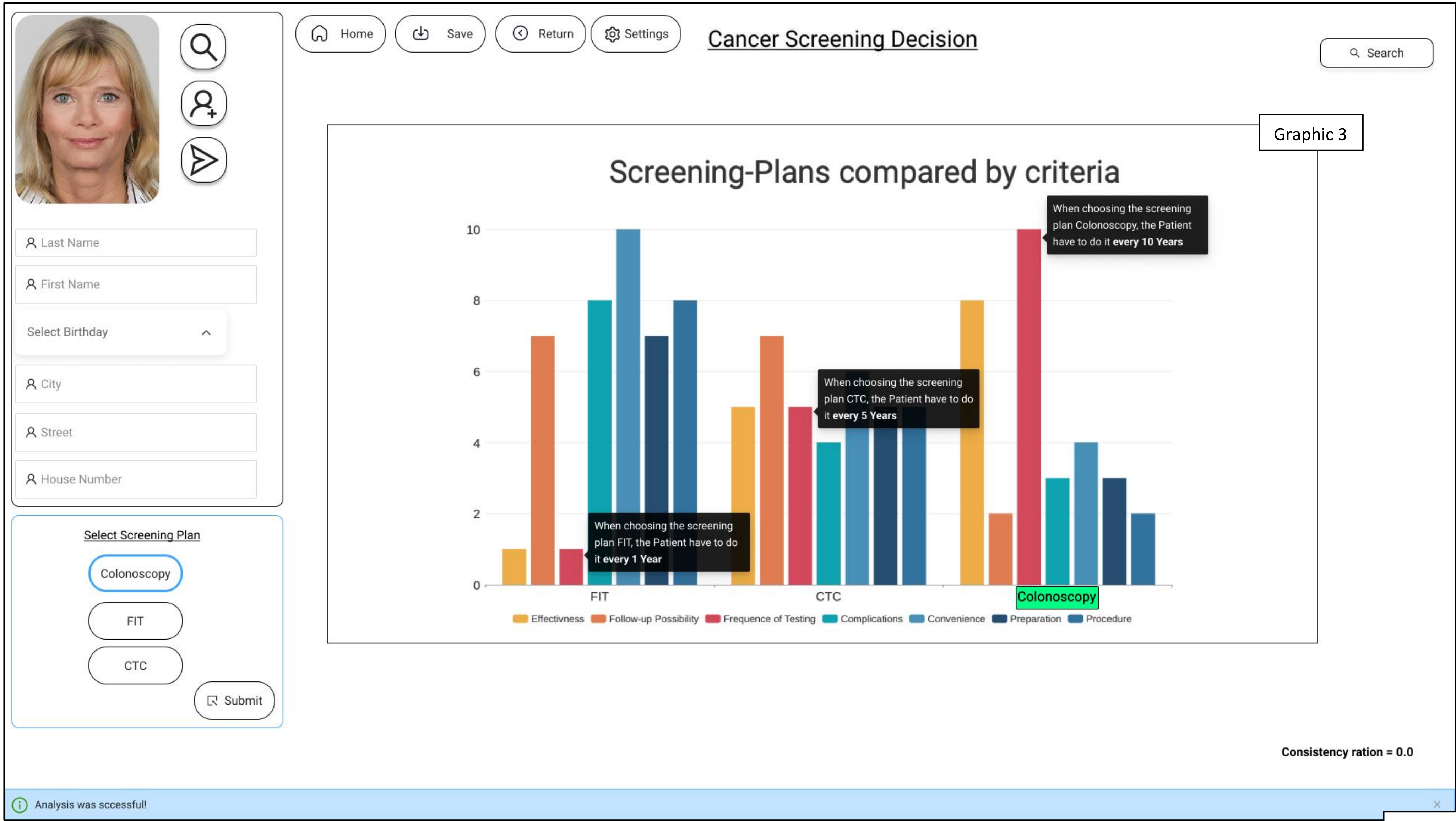
Home
Save
Return
Settings
Cancer Screening Decision
Search
Last Name
First Name
Select Birthday
City
Street
House Number
Select Screening Plan
Colonoscopy
FIT
CTC
Submit
Graphic 3
Screening-Plans compared by criteria
When choosing the screening plan Colonoscopy, the Patient have to do it every 10 Years
When choosing the screening plan CTC, the Patient have to do it every 5 Years
When choosing the screening plan FIT, the Patient have to do it every 1 Year
10
8
6
4
2
0
FIT
CTC
Colonoscopy
Effectivness
Follow-up Possibility
Frequence of Testing
Complications
Convenience
Preparation
Procedure
Consistency ration = 0.0
Analysis was sccessful!

Figure 6


Home
Save
Return
Settings
Cancer Screening Decision
Search
Last Name
First Name
Select Birthday
City
Street
House Number
Select Screening Plan
Colonoscopy
FIT
CTC
Submit
Screening-Plans compared by criteria
When choosing the screening plan Colonoscopy, the Patient have to do it **every 10 Years**
When choosing the screening plan CTC, the Patient have to do it **every 5 Years**
When choosing the screening plan FIT, the Patient have to do it **every 1 Year**
10
8
6
4
2
0
FIT
CTC
Colonoscopy
Effectivness
Follow-up Possibility
Frequence of Testing
Complications
Convenience
Preparation
Procedure
Consistency ration = 0.4
Consistency ratio is too high! Intensive evaluation needed.

Figure 7