Combining hospital pathways modeling with value-based healthcare: Building methods for care improvement at IPO-Lisboa

Nelson Filipe Magalhães Bento

Thesis to obtain the Master of Science Degree in Biomedical Engineering
Instituto Superior Técnico, University of Lisbon, Portugal

Abstract: Hospitals are faced with pressure to improve their patient's clinical pathways and to involve hospital stakeholders in such improvements. This work aimed to develop a novel approach to assist IPO-Lisboa health professionals in improving hospital pathways, combining a simulation model with value-based healthcare instruments. For this purpose, a socio-technical approach was developed in which a discrete event simulation model is integrated with a multicriteria evaluation model built with the MACBETH method. Regarding the social component of the approach, different hospital stakeholders, namely physicians and administrative staff members, participated in the construction and validation of the models developed. The models helped simulating the pathways taken by breast cancer patients from their first consultation to the performance of surgeries, as well as analyzing how it is possible to generate added value improvements to the pathways. Through the application of this approach, it was analyzed not only the current breast cancer pathway but also the impact of improvement actions on the pathway. Subsequently, and considering the view of different healthcare professionals, it was possible to reach a consensus on which improvement actions have the highest value for money. Moreover, discussions and reflections concerning possible ways to implement those actions were promoted. Participants provided positive feedback regarding the approach, suggesting its potential use in future studies, for instance in combining clinical pathways from different pathologies.

Keywords: Clinical Pathways; Value-Based Healthcare; Discrete Event Simulation; MACBETH; Process Improvement.

1. Introduction

According to the International Agency for Research on Cancer, breast cancer is the most common type of tumor in women and the second most frequent worldwide [1]. In 2018, about 2.1 million new cases of breast cancer were recorded, and more than 626 thousand deaths occurred worldwide. In Portugal, in that same year, more than 6800 new cases of breast cancer and around 1700 deaths from this cause were identified [2]. Time is known to be a critical factor for breast cancer patients, as delays in detection, diagnosis, and treatment can lead to decreased survival and lower probability of curative treatment.

Thus, health professionals are under daily pressure to improve healthcare delivery, that is, to make improvements along the pathways that patients pass through. Also, it is important to note that oncological pathways are particularly complex, as they involve many processes, multidisciplinary teams, and require combinations of different health technologies [3]. Further to organizational and efficiency issues, pathways need to be aligned with the delivery of value-based healthcare (VBHC), taking into account the impact on patients and the views of hospital stakeholders. In this way, the delivery of care must involve coordination and collaboration across professionals, a shared accountability for optimizing health, continuous relationships with patients over time, and the delivered care should be centered on patients and tailored to their needs, preferences and concerns [4].

IPO-Lisboa is considered a national reference center in the delivery of healthcare in the oncological area [5]. Moreover, it is an institution that is concerned with constantly updating the clinical pathways of its patients to improve their experience in the hospital environment. In this way, it becomes necessary to use tools capable of modeling hospital pathways, analyzing them, and understanding how these processes can be improved.

Simulation techniques are widely used in several areas, such as industrial management and manufacturing, when it is intended to model and analyze a complex process [6]. Furthermore, the current proliferation of the utilization of simulation models in the field of medical research and healthcare service management is evident [6]. This growth has happened due to the capacity these models have in addressing complex problems, allowing to evaluate the efficiency of the practices used in the management of healthcare delivery, as well as carrying out analyzes that compare different situations, where it is possible to identify bottlenecks existing in hospital pathways, discover approaches capable of reducing waiting times, improving the usage of human resources and equipment involved [6]. However, to implement changes to clinical pathways, it is necessary to take into account the opinion of health professionals, as well as to use instruments to consensualise the value, which wrongly is not a very common practice [7]. These health professionals are those who choose the most attractive improvements to be implemented, that is, those that have the highest value. Thus, it is necessary to create tools to be used in decision-making processes, which need to be able not only to model the hospital processes that are intended to be improved but also to discover how added value is generated.

This work aims to develop methods for assisting the decision-makers (DMs) of IPO-Lisboa to improve hospital pathways, more specifically the pathways used in the delivery of

healthcare to breast cancer patients. Also, it has the objective of combining clinical pathways modeling with VBHC instruments so that IPO-Lisboa can identify value-based improvements in the delivery of care.

In this study, a novel methodological approach was developed that uses the combination of two techniques: one used for pathways modeling and the other for value modeling. For the pathways modeling task, the discrete event simulation (DES) method was used [8], and for the value modeling task, a multicriteria decision analysis (MCDA) approach was applied: the MACBETH method [9]. This technique has the potential to develop an evaluation model based on qualitative judgements and to support complex decision situations, and allows considering the multiple criteria that are relevant in the decision-making process. In the specific case of this study, it was possible to build multicriteria evaluation models that reflect how value is generated by IPO-Lisboa activities from the point of view of different health professionals.

2. Literature review

Clinical pathways can be defined as structured and multidisciplinary care plans that detail the essential steps in providing care for a patient who has a specific clinical problem. These plans aim to build the link between the best evidence available and clinical practice, providing recommendations, processes, and frameworks for the management of medical conditions or specific treatments with optimized clinical outcomes, which maximize clinical efficiency [10]. They describe the complete journey of a patient and not only the contribution of each independent specialty sector. Thus, they prevent the management of patients from becoming chaotic and inconsistent, contribute to reduce length of stay and hospital costs, improve the communication between team members, and enable health professionals to make their individual decision when justified, as there is always variability among patients.

On the other hand, the pathways should be centered on patients [11]. However, the idea behind patient-centered delivery care is difficult to integrate into a patient's entire journey since there is a wide range of clinical pathways. Furthermore, the pathways involve different stages and sectors, the services involved are diverse, the diseases are complex and with heterogeneous outcomes, besides the multiple treatment strategies.

Considering what is currently done in the development of clinical pathways, it is, therefore, possible to highlight some factors that are lacking and that need to be considered so that they would be more patient-centered, and able to integrate the VBHC concept, aiming to improve the quality of care by measuring outcomes that reflect value. In this way, the following recommendations can be made [12]: (1) engagement of patients with health providers and with developers of clinical pathways; (2) improved interoperability and integration between the pathways' IT infrastructures and patients' electronic medical records to facilitate communication between patients and providers; (3) improvement in the integration between pathways and monitoring of outcomes or evaluation of effectiveness, accuracy, quality, and appropriateness of the care delivered to patients.

Thus, it is important to build a bridge between classical methods used to model the clinical pathways in order to improve them, being aligned with the delivery of VBHC. Thus, to realize how value is added to a healthcare system, health stakeholders have to be active participants to discover their objectives, concerns, and preferences.

2.1. Simulation methods to model clinical pathways

Simulation techniques can be utilized for clinical pathways modeling, namely DES. This is a method of simulating the behavior and performance of a real-life process, having been currently applied in healthcare services [8]. Moreover, DES is a modeling approach that has a stochastic nature, being quite suitable for queuing network systems, where state changes occur at discrete points of time. The entities that populate the model move stochastically along with the queuing system and activities, whose durations are sampled from probability distributions. Lorenz & Jost (2006) stated that it can capture "detail complexity" [13], "the system behavior that results from the possible combinations of many random processes, coupled with the system structure, leading to interconnection effects".

DES models are those that stand out the most, being cited as "the most powerful and intuitive tool for the analysis and improvement of complex healthcare systems" [14]. However, depending on the complexity of these systems, further analysis may need to be performed about their behavior. These systems can involve many elements and variables that interact with each other simultaneously, and therefore, it is necessary to observe and evaluate several decision criteria, which deal with multiple objectives [15]. Thus, another decision support methodologies can be incorporated, as is the case of MCDA, expanding the capacity of DES, and thus creating a decision support system (DSS) that combines these two methodologies.

2.2. MCDA in healthcare systems

MCDA is a structured DSS technique used to deal with problems, in which multiple and complex criteria influence the decision process, allowing the visualization of the logical/rational structure of the problem, representing and quantifying the importance of its elements, relating them according to the general objectives, and allowing the execution of tradeoff studies [15]. Several studies use this approach to successfully address highly complex problems, which have multiple objectives. Oliveira et al. (2012) built a multicriteria model, using a socio-technical approach, where decision conferences and the MACBETH method were used to choose which programs should be invested by healthcare centers in Portugal. Also, it was taken into account the existence of a limited budget to cover such programs. In this study, it was possible to conclude which programs should be funded, that is, which are the ones that present a cost-benefit ratio that fits with the objectives of health centers, and that respect the financial constraints [16].

2.3. Combining DES with MCDA

Considering the aspects observed in this literature review, it is possible to conclude that different techniques are suitable to use when clinical pathways are attempted to be modeled.

However, the literature does not provide many studies where MCDA is combined with other Operational Research and Management Science methods [17]. Furthermore, it was possible to conclude through the previous sections that while DES is a tool that discovers alternatives that fit in a satisfactory way with the needs of users, MCDA allows quantifying the importance of the multiple elements, which are part of the different alternatives [15]. In this way, it should be seen as an integral part of problem-solving methodologies. For example, combining simulation with MCDA allows to obtain the performance of a system in different situations and also to convert this performance into value scores. Moreover, this integration enhances greater engagement with the final user.

3. Methodological approach

This section presents the methodological approach developed to complete the objectives of this article, combining two different techniques. Fig. 1 illustrates the main three steps that constitute this methodology. It is important to note that each of its steps includes a technical and a social component.

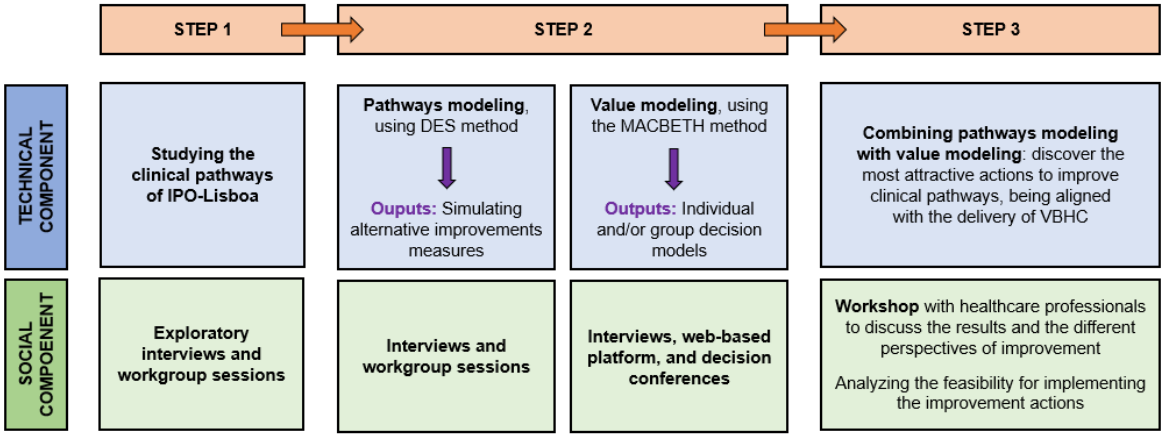

Fig. 1. Methodological approach steps. Each step of the methodological approach includes a technical and a social component.

3.1. Studying clinical pathways of IPO-Lisboa

Firstly, if the objective of this study is to create tools to improve the clinical pathways used in breast cancer healthcare delivery, they need to be studied. Through exploratory interviews with physicians and administrative staff members, it is possible to discuss the current situation of the pathways. Furthermore, as a way to understand which are the positive and negative aspects, data from previous projects should be examined. Thus, and with the participation of different stakeholders, it is possible to realize how to improve the delivery of care at this hospital.

3.2. Pathways modeling, using DES method

Then, a simulation model needs to be created for modeling the clinical pathways. In this way, it is possible to identify which are the points that need to be improved and understand how changes in elements of this process impact the entire system [14]. Frequently, healthcare DMs use subjective information provided by staff members, providers, and other stakeholders so that decisions are made in order to improve hospital processes. However, changes made both at the structural level and at the level of processes, are attempts to improve the current system, which can often be demonstrated costly in terms of time and capital.

In this sense, DES emerges as a valuable tool, as it is a low-risk and low-cost method to develop strategies, test assumptions, and observe potential outcomes. Thus, DMs can use computational methods and make decisions before their implementation [14].

Regarding the social component presented in this step of the approach, different stakeholders must participate in order to collect the necessary data for the construction of the model, as well as its validation. Also, it must be discussed with them how the clinical pathways could be enhanced, through the proposal of alternative improvements.

When a system is modeled using a DES approach, this process contains the following steps [8]: (1) defining objectives for the simulation; (2) process mapping; (3) data collection and analysis; (4) constructing the base simulation model; (5) sensitive analysis with simulation scenarios; (6) results analysis; (7) designing and planning decisions.

3.3. Value modeling, using the MACBETH method

In the health sector, decision-making is usually a complex task that involves confronting tradeoffs between multiple objectives, which can often be conflicting [18]. In this sense, it is crucial to develop models capable of measuring the value of the options involved in the decision-making process to discover which of them are the most attractive for the DMs. Thus, it is necessary to build a multicriteria decision model, which is based on the fact that different concerns can be grouped into a single model, in an understandable and flexible way, in which its construction includes the collection of qualitative judgements [19]. This type of approach allows the simplification of a complex problem into several smaller ones, which are analyzed independently and then integrated into a global analysis.

Also, an MCDA has a social component. Firstly, it is very important to develop a clear description of the problem at hand, defining which are the objectives of the DMs, by doing interviews with them [19]. Then, it is necessary to carry out meetings that count on the participation of key players who wish to solve important problems that are occurring in their

organization. These meetings are attended by a facilitator, an expert in decision analysis, who works as a consultant of the process, using a model that has relevant data, which were collected in a first phase, as well as judgements created on-the-spot, which assist the DMs to be able to think more clearly about the problems at hand [18].

Through this procedure the individual or group multicriteria evaluation models are created. To build individual models, structured interviews are conducted, allowing to solve the problem rapidly and efficiently. On the other hand, decision conferences must be carried up when group models are intended to be built, enabling a greater sharing of knowledge and opinions to make higher quality decisions with a higher degree of acceptance [20].

Regarding the technical component of an MCDA, it is necessary to use a method capable of responding to the problems at hand. As it is referred to in the literature, a popular method to perform this type of analysis is MACBETH (**M**easuring **A**ttractiveness by a **C**ategorical-**B**ased **E**valuation **T**ec**h**nique) [16]. Bana e Costa et al. (1994) described this as an interactive approach that requires only qualitative judgements on the part of the DMs in order to measure the attractiveness of the existing options in the decision process [21]. For the application of this method, it is required to use a user-friendly software named M-MACBETH, which allows the implementation of the entire multicriteria model. By using this software, for each time the judgements are expressed, their consistency is verified automatically, suggesting changes that must be made in the judgement matrix when inconsistencies arise [15].

The MACBETH is a non-numerical method that generates numerical scores based on the qualitative judgements of the DMs. For each criterion, its value score is multiplied by its weighting coefficient. By aggregating this multiplication in an additive way to all criteria, an overall score is calculated for a given option, which reflects its attractiveness for the DMs [19]. The weighting coefficients, k_j, allow each partial value unit, v_j, to be converted to a global value unit, V. Then, one can mathematically determine the global value for each alternative, a, through the following additive model:

$$V(a) = \sum_{j=1}^{n} k_j v_j(a), \qquad (1)$$

where $V(a)$ represents the overall value of option a, $v_j(a)$ the partial value of option a in terms of criterion j and k_j is defined as the weighting coefficients of criterion j [19]. The additive value model must meet the following conditions:

$$\sum_{j=1}^{n} k_j = 1 \text{ and } k_j > 0 \text{ with } j = (1,2,\dots,n);$$
$$\begin{cases} v_j(target_j) = 100, \ \forall_j \\ v_j(current\ state_j) = 0, \ \forall_j \\ V(target\ overall) = 100 \\ V(current\ state\ overall) = 0 \end{cases} \qquad (2)$$

To develop a multicriteria model, is necessary to identify the factors that interfere with DMs' choice, defining and clarifying the criteria considered relevant, which are also named Fundamental Points of View (FPV) [19].

For each criterion, a descriptor of performance must be associated or constructed so that the criterion becomes intelligible [9]. This descriptor consists of a set of impact levels, ordered by preference, and serve to objectively describe the impacts of alternatives concerning a criterion, which can be done either quantitively or qualitatively. Moreover, the model also uses two reference levels for each descriptor, representing the "target" that DMs want to achieve, and the "current state" of performance [19].

After defining the criteria and their descriptors of performance, and by using the M-MACBETH software is possible to obtain value functions and weighting coefficients, which must be validated and adjusted by DMs [9].

3.4. Combining pathways modeling with value modeling

By using a simulation technique (namely the DES) to model hospital pathways, it is possible to obtain alternative improvement measures. On the other hand, with this information, the multicriteria model is able to assess the impact of improvement measures on the criteria that are considered. Basically, from the outputs of the simulation model, inputs are obtained for the multicriteria model, which will be able to identify which improvement alternatives are most attractive to the stakeholders involved in the study.

The combination of these techniques is responsible for promoting discussion and reflection about the different perspectives of improvement. Also, it is crucial to highlight that the feasibility of implementing the improvement actions must be analyzed to complete the decision-making process.

The implementation of this methodological approach (particularly its second step) in the case study will be presented in the next section.

4. Implementation of the methodological approach

4.1. Pathways modeling

In this study, the objective is to model the clinical pathways traveled by breast cancer patients at IPO-Lisboa, using the DES method to create a simulation model. Thus, it is necessary to complete several steps in order to develop this model correctly. Through this model, it is possible to analyze the impact caused by changes in the pathways when improvement alternatives are simulated.

4.1.1. Process mapping

Having in mind the objectives of the model development, it was necessary to map the process that was going to be simulated. Through interviews with different stakeholders (namely, 5 physicians and 3 administrative staff members), it was possible to realize there was a particular interest in analyzing the clinical pathway in a specific time interval, that is, from the first consultation at the multidisciplinary breast clinic (MBC) to the performance of the surgery.

As was discussed with the different physicians and administrative staff members involved in this study, the provenance of the patients who enter this pathway can be diversified. For instance, they can be referred from healthcare centers to this

hospital for the first time, or they can already be IPO-Lisboa patients. However, the different origins of the patients were not considered, being defined that all of them begin the clinical pathway with the first consultation at the MBC, followed by a biopsy (at the radiology service). After this first exam, patients are submitted to three different exams: MRI and CT, both performed at the radiology service, and bone scintigraphy, performed at the nuclear medicine service. During the performance of these exams, patients also need to attend subsequent consultations so that physicians at the MBC can assess the situation state of these patients.

After all these exams and subsequent consultations, a surgical decision consultation (SDC) is carried out. This consultation aims to decide whether the patient will undergo surgery or not. According to data provided by IPO-Lisboa, in 2018, 69.9% of patients underwent surgery after SDC, with the remaining 30.1% beginning to start neoadjuvant chemotherapy treatment before any surgery. It should also be noted that these two alternatives are the result of the choice of a multidisciplinary team from the MBC in order to adapt the clinical pathway to the patients' needs. For the purpose of the simulation model, neoadjuvant chemotherapy was considered as an exit point from the analyzed process since the main objective of the pathway modeling was to examine the journey from the first consultation until the surgery was performed.

4.1.2. Data collection and constructing the simulation model

To build and run the simulation model, it was then necessary to collect data to populate it. Thus, interviews were conducted with healthcare professionals from the MBC, the radiology service, and the nuclear medicine service. The data collected were all from 2018, which were the following: (1) number of breast cancer patients who traveled through the pathway; (2) number of physicians who performed consultations at MBC; (3) number of consultations performed by a given physician at MBC; (4) number of exams performed per day; (5) waiting time for scheduling exams and waiting time for obtaining their results; (6) number of surgeries performed per month; (7) percentage of patients who underwent surgery after SDC; (8) waiting time between the first consultation and the SDC, waiting time between the SDC and the surgery, and waiting time between the first consultation and the surgery (average and maximum values).

Fig. 2 illustrates how the model layout was implemented in the SIMUL8 software, which represents the pathway of breast cancer patients at IPO-Lisboa. Through this user-friendly DES package, it was possible to create a visual model of this pathway by drawing different objects directly on the screen. Once the activities are carried out in different hospital services, three colored rectangles have been drawn, delimiting the main services.

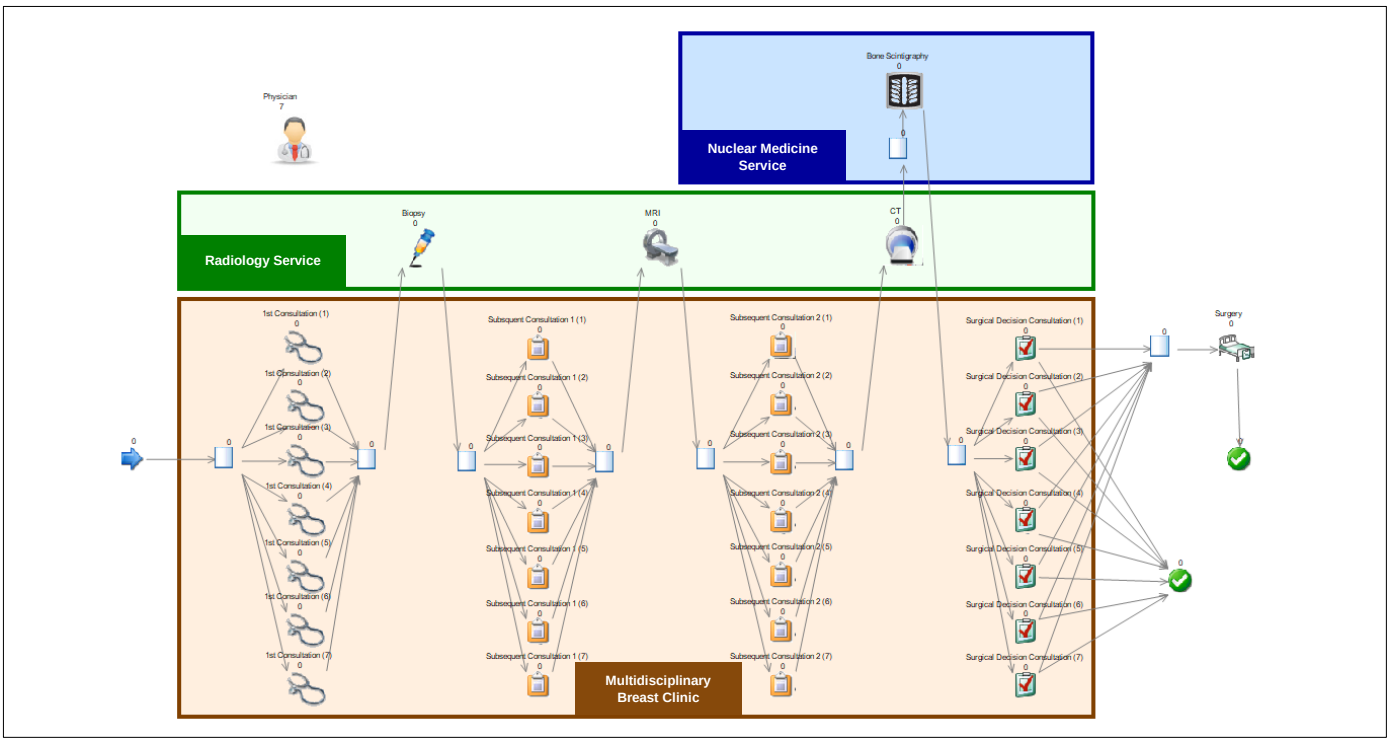

Fig. 2. Computational implementation layout of the breast cancer patients' clinical pathway at IPO-Lisboa, using SIMUL8.

4.1.3. Validation of the simulation model

After constructing the simulation model, it is necessary to proceed with its validation. Thus, it was run to simulate the period of one year, more specifically the year 2018. However, at the beginning of the simulation, the system is empty, which does not correspond to reality, as this was not the opening year of the hospital. Thus, a warm-up period of 90 days was used since this is the average time a work item takes to go through the entire system. Therefore, the use of a warm-up period helps the model to be calibrated, creating realistic starting conditions [8].

When running the simulation model, the results summarized in Table 1 were obtained. It is observed that the waiting times between the first consultation and the SDC, the waiting times between the SDC and the surgery, and the waiting times between the first consultation and the surgery are very similar

to the times recorded in the real system when both the average values and the maximum values are compared.

Thus, it was possible to validate the simulation model since it is able to produce a very approximate representation of the real situation. These results were also presented to the stakeholders involved in the study, all of whom have revealed a high level of confidence about the built model. In this way, when using it to simulate hypothetical alternatives, one has the confidence that the obtained results can, in fact, represent a hypothetical reality [14].

Table 1. Comparison between data from the real situation at IPO-Lisboa and outputs of the simulation model.

	Real Situation	Simulation
Number of patients	1468	1475
Number of days btw. first consultation and SDC (avg.)	51	52.19
Number of days btw. first consultation and SDC (max.)	68	62.38
Number of days btw. SDC and surgery (avg.)	46	46.57
Number of days btw. SDC and surgery (max.)	74	79.33
Number of days btw. first consultation and surgery (avg.)	103	95.56
Number of days btw. first consultation and surgery (max.)	134	137.76

4.1.4. Simulation of improvement alternatives

After the construction of the simulation model, the objective was to observe what would be the impact caused by hypothetical improvements in breast cancer patients' clinical pathways. In this sense, the different stakeholders involved in the study considered that the fundamental points of change were associated with three aspects: (1) decreasing the minimum waiting time to obtain the biopsy results; (2) increasing the number of MRIs performed per day; (3) increasing the number of surgeries performed per month.

4.2. Value modeling

This study aims to create methods that assist the DMs of IPO-Lisboa in decision-making processes. As these are complex processes with multiple criteria, the construction of an appropriate multicriteria decision model is necessary [18]. In this section, it will be presented the stages that have been completed in order to develop this model correctly, using the MACBETH method. It is also important to note that this is an approach with a strong social component, thereby involving different stakeholders for constructing the multicriteria model. Exploratory interviews with healthcare professionals (namely, 5 physicians and 3 administrative staff members) were conducted for structuring the problem, defining the criteria and the descriptors of performance. On the other hand, two individual multicriteria decision models were built, one for a physician and the other for an administrative staff member. In this way, to calculate the value functions and the weighting coefficients, a web-based platform was used to collect the qualitative judgements of the health stakeholders, and structured interviews were conducted to adjust and validate the models.

4.2.1. Structuring the problem and defining the criteria

The reason behind the need to develop a multicriteria decision model is due to the fact that it is important to build tools for assessing how value is generated by the IPO-Lisboa activities, highlighting the healthcare services delivered to breast cancer patients during their journey to surgery. In this way, several interviews were carried out with healthcare professionals, namely physicians and administrative staff members, to understand their fundamental points of view when it comes to answering the question "How value is generated by the IPO-Lisboa activities?". Essentially, it was sought to obtain the necessary information in order to define the criteria of the multicriteria decision model. The interviews have addressed only topics to explore, not being restricted to a questionnaire with answer options to fill out. This approach is in accordance with the concept of value-focused thinking, originating conversations with stakeholders, in which they share their objectives and concerns. Thus, besides trying to understand how value is generated by the IPO-Lisboa activities, these interviews have also tried to comprehend how healthcare delivered to patients can be improved, as this is an institution that always considers patients as the center of their concerns [21].

The definition of these criteria was based on the fact that different stakeholders have considered as essential that the delivery of healthcare services might be accessible to all patients and that the improvement of patients' quality of life is one of the major objectives of the work carried out in this institution. Moreover, the services provided by IPO-Lisboa acquire greater value when their activities are performed efficiently. In the case of this study, breast cancer patients need to undergo several exams during their journey. Therefore, from the point of view of the stakeholders, it is important to perform these exams as soon as possible, without patients waiting for long periods. Also, the exam results must be obtained in a short period so that patients are not blocked in the system.

4.2.2. Descriptors of performance

For each of the criteria, it was necessary to associate or build a descriptor to measure its performance so that the criteria are operational. Moreover, in each descriptor, two reference levels were defined, essential to obtain the weighting coefficients. The choice of these levels was made based on the fact that the "current state" level represents the current situation in all criteria and the "target" level represents the level that the different health stakeholders intend to achieve, considering it as a satisfactory level of performance [19].

Thus, for the criterion named "Access to diagnosis", the number of days between the first consultation and the SDC was used to describe performance. To measure the performance of the criterion named "Access to surgery", the number of days between the SDC and the surgery was used as the descriptor.

For the "Quality of life" criterion, a descriptor of performance was built, which was based on the fact that it is considered that when patients perform their diagnoses and surgeries within the recommended time intervals, there is a possibility of increasing their quality of life. Thus, when the waiting time for diagnosis and surgery is within this range of values, negative

consequences for patients are not brought, in the short, and long term. However, this is just a proxy that has been used since measuring patients' quality of life is a difficult task in the context [22]. Also, many healthcare professionals, due to their high experience and long years of monitoring multiple patients with heterogeneous characteristics, may not always agree with these values that are recommended by national and European organizations [23].

For the criterion named "Efficiency in performing exams", the number of tests that need scheduling for their performance was used as the descriptor. This number can vary between 0 and 4, once breast cancer patients perform four exams during their journey to surgery. In this way, it is possible to analyze how many tests possess a waiting list associated with its performance, being that the absence of particular scheduling reveals that the number of performed exams is sufficient to cover the hospital's needs, that is, it is sufficient to cover the number of patients who need to perform that exam.

Finally, for the "Speed in obtaining exam results" criterion, the number of days required to obtain the biopsy results were used as a descriptor. During the interviews within the scope of understanding how added value is generated by IPO-Lisboa activities, the health stakeholders have reported that this is the only exam with an excessive waiting time associated with the obtention of the results, and therefore, it is the only exam to consider when measuring the performance of this criterion.

4.2.3. Constructing individual multicriteria models

After completing these steps, the multicriteria model is structured, following its construction. In this study, it was considered interesting to understand the perspectives that different types of health stakeholders had about the developed value tree. Thus, two individual models were built, one for a physician and the other for an administrative staff member. By developing individual multicriteria decision models, some disadvantages of group decision models are not faced, namely the fact of being a time-consuming task and group work conflicts that can arise [20]. Thus, with different individual models, the problem can be solved rapidly and efficiently, and different opinions and points of view are also considered.

To collect the judgements in a quick and simple way, a web-based platform developed on Google Forms was created, which presented all the questions necessary for developing the multicriteria decision model, allowing participants to answer when it was most convenient for them. The platform has two parts: one with questions necessary for making possible the calculation of the value functions, and another to calculate the weighting coefficients for each criterion. After this process, the resulting value functions and weighting coefficients were presented to DMs so that they could validate them, making adjustments when necessary [15].

After obtaining all the value functions and weighting coefficients, the model is prepared to be used, that is, it is possible to acquire the overall score of an option after inserting its performance in the M-MACBETH software [19]. In the context of this study, these options correspond to improvements that can be made in breast cancer patients' clinical pathways, and some of their parameters correspond to the performance obtained by using the simulation model built.

In the next section, the results obtained when combining these two models will be presented, where the outputs of the simulation model are used as inputs of the decision model.

5. Results

5.1. Results of the methodological approach

As described in the previous section, the simulation model is able to measure the impact caused by changes in the system. In this way, it was discussed with the stakeholders which are the main points that need to be analyzed in the breast cancer pathways, in order to improve them.

Table 2 presents the performance of these improvement proposals when compared to the simulation of the current situation, that is, the situation corresponding to the year 2018. This table presents the time intervals between the first consultation and the SDC, the waiting time between the SDC and the surgery, and the time interval between the first consultation and the surgery. All these outcomes are exposed both on average and in their maximum values. The table contains the input parameters of the improvement measures.

After analyzing all the improvement proposals' performance, it is important to make a decision about which one generates more value from the perspective of the stakeholders, remembering that the breast cancer patients' pathway must be aligned with the delivery of VBHC. In other words, it is time to combine pathways modeling with value modeling. In this part, it was verified that some of the physicians considered that the involvement of administrative staff members is more beneficial in what concerns the decisions that must be made regarding the choice of the improvement actions.

By using the M-MACBETH software, the performance of each option is converted into a score, which corresponds to the sum of the scores associated with each criterion, considering the weight coefficients previously calculated. Thereby, a table is obtained that presents the overall score for each of the seven improvement options.

In this study, as two individual multicriteria decision models were built from the point of view of two DMs, belonging to different categories at IPO-Lisboa, two tables are obtained with the overall scores of each improvement proposals, as depicted in Fig. 3 and 4.

It is possible to observe that, as the two multicriteria decision models built based on the qualitative judgements of the two DMs are different, the overall scores calculated for each improvement proposal are also different in both cases. However, it can be seen that when ordered by their overall score in a decreasing way, the sequence of the seven improvements is the same in the two cases (Imp 7; Imp 6; Imp 5; Imp 3; Imp 4; Imp 2; Imp 1), and a consensus has been reached.

Table 2. Impact of the improvement measures in terms of some performance indicators: the number of days between first consultation and SDC, the number of days between first consultation and surgery, and the number of days between SDC and surgery. For each alternative improvement it is also presented the input parameters of the simulation model: minimum waiting time to obtain the biopsy results, number of MRIs performed per day, and number of surgeries performed per month.

Performance Indicators	**Current Situation**	**Imp. 1**	**Imp. 2**	**Imp. 3**	**Imp. 4**	**Imp. 5**	**Imp. 6**	**Imp. 7**
Number of days between 1st consultation and SDC (avg.)	52.19	48.41	41.52	37.52	52.19	48.41	41.52	37.52
Number of days between 1st consultation and SDC (maximum)	62.38	58.23	43.63	39.75	62.38	58.23	43.63	39.75
Number of days between SDC and surgery (avg.)	46.57	47.69	53.47	54.78	11.01	11.01	15.64	15.65
Number of days between SDC and surgery (max.)	79.33	79.86	95.18	96.33	12.99	13.07	21.13	20.91
Number of days between 1st consultation and surgery (avg.)	95.56	92.85	95.56	92.75	63.21	59.42	58.15	54.16
Number of days between 1st consultation and surgery (max.)	137.76	134.11	137.84	134.24	73.81	69.65	63.61	59.41
Simulation Input Parameters	**Current Situation**	**Imp. 1**	**Imp. 2**	**Imp. 3**	**Imp. 4**	**Imp. 5**	**Imp. 6**	**Imp. 7**
Minimum waiting time to obtain the biopsy results	10 days	6 days	10 days	6 days	10 days	6 days	10 days	6 days
Number of MRIs performed per day	curr. number	curr. number	2×(curr. number)	2×(curr. number)	curr. number	curr. number	2×(curr. number)	2×(curr. number)
Number of surgeries performed per month	curr. number	curr. number	curr. number	curr. number	1.4×(cur. number)	1.4×(curr. number)	1.4×(curr. number)	1.4×(curr. number)

Table of scores

Options	Overall	Access to diag	Access to surg	QoL	Efficiency	Speed
Imp 1	18.60	20.43	-7.53	0.00	0.00	100.00
Imp 2	39.29	55.01	-23.72	64.00	100.00	0.00
Imp 3	60.46	82.61	-27.38	64.00	100.00	100.00
Imp 4	55.96	8.71	220.31	36.00	0.00	0.00
Imp 5	73.89	20.43	220.31	36.00	0.00	100.00
Imp 6	80.13	55.01	180.50	64.00	100.00	0.00
Imp 7	102.02	82.61	180.41	64.00	100.00	100.00
Target	100.00	100.00	100.00	100.00	100.00	100.00
Current State	0.00	0.00	0.00	0.00	0.00	0.00
Weights :		0.2500	0.2000	0.2700	0.1300	0.1500

Fig. 3. Table of scores of the proposed improvement alternatives, obtained in the M-MACBETH software, when the qualitative judgements were provided by a physician.

Table of scores

Options	Overall	Access to diag	Access to surg	QoL	Efficiency	Speed
Imp 1	21.01	29.00	-11.03	0.00	0.00	100.00
Imp 2	31.41	63.49	-34.73	69.00	100.00	0.00
Imp 3	51.91	85.89	-40.10	69.00	100.00	100.00
Imp 4	49.19	12.36	146.17	31.00	0.00	0.00
Imp 5	69.34	29.00	146.17	31.00	0.00	100.00
Imp 6	76.13	63.49	130.89	69.00	100.00	0.00
Imp 7	98.07	85.89	130.86	69.00	100.00	100.00
Target	100.00	100.00	100.00	100.00	100.00	100.00
Current State	0.00	0.00	0.00	0.00	0.00	0.00
Weights :		0.3100	0.2700	0.1900	0.0800	0.1500

Fig. 4. Table of scores of the proposed improvement alternatives, obtained in the M-MACBETH software, when the qualitative judgements were provided by an administrative staff member.

The results obtained allow to understand which actions are the most attractive to be taken, promoting the discussion, or even negotiation between the different DMs involved about the next step of the decision-making process.

Improvement 7 is the one with the highest overall score, and therefore, it is the most attractive to implement. Nevertheless, this is also the improvement that requires a greater number of actions so that it can be put into practice once it presents changes in the input parameters of the three main points of the pathway, where problems are detected. It is also important to bear in mind that there may be constraints about the number of actions that can be taken simultaneously.

Through this decision model, it is possible to answer the question: "What is the most attractive option, if one has the possibility to make only two changes to the input parameters of the activities considered?". Here, the intention is to find out which improvement has a higher overall score when there is a constraint in the number of actions that can be taken simultaneously. In this case, option 6 would be the most attractive, that is, doubling the number of MRIs performed per day and increasing the number of surgeries performed per month by 40%. Therefore, an improvement action would be taken in one activity that occurs before the SDC and in another that occurs after the SDC. Furthermore, it is observed that, if it were only possible to put into practice one of the improvement actions, the most attractive option would be improvement 4, as among options 1, 2, and 4, this is the one with the highest overall score. Interestingly, in this improvement, none of the parameters of the activities that occur before the SDC would be modified.

It is also important to note that a more detail analysis of the results can be made in future applications, performing, for instance, a sensitivity analysis by changing the weights of the considered criteria, as well as through the creation of more improvement proposals.

5.2. Workshop with health stakeholders

The combination of the two techniques allows for understanding which improvements are most attractive from the stakeholders' point of view. However, to complement the decision-making process, it is essential to realize how the suggested actions can be implemented and how feasible they are.

During workshops where the results of the approach developed were shown, healthcare professionals have reported that the decrease in the minimum waiting time for obtaining biopsy results and the increase in the number of MRIs performed per day can be achieved by increasing the number of human resources or equipment. Nevertheless, increasing the number of equipment is often a solution associated with expensive costs, thereby performing better management of human resources is

the best solution. This can be done through incentive systems, increasing the productivity of existing human resources, or hiring new professionals. Both of these solutions entail costs for the institution. However, it was pointed out by administrative staff members that the best strategy is always to increase the productivity of existing human resources since the intake of new professionals is associated with training programs, once many times these new resources may not possess the required level of expertise.

On the other hand, through the decision model, it was possible to analyze that the increase in the number of surgeries performed is the operation that must be executed first if there is a constraint of put into practice only one action. To this end, it was determined by the stakeholders involved in the study that there is a need to increase the number of blocks available for breast cancer patients. Although they can bring negative consequences for other IPO-Lisboa pathways or include expensive costs, there are three different ways to achieve this increase in the number of surgeries performed: (1) decreasing the number of blocks assigned to non-priority patients of other pathways; (2) improving the management and planning of activities performed at the hospital; (3) increasing the number of rooms of the operating theater.

During the realization of this study, changes in the hospital's infrastructures were already happening. Hence, this increase in the number of rooms was being put into practice, forecasting a major improvement in the services provided by the hospital, adding value to them.

6. Discussion

Hospitals are complex systems, where their professionals deal daily with situations of pressure given the unpredictable environment and the high patients' expectations regarding the quality of the healthcare delivery.

In the case of IPO-Lisboa, there is then an attempt to find ways to continuously improve the clinical pathways of this institution, adding value to them. Therefore, it is necessary to improve the value of the activities that cancer patients undergo throughout their pathways, keeping in mind that these are patients who travel their journeys over a long period of time, dealing with situations of stress and anxiety. For both them and healthcare professionals, it is not just the final result that must be taken into account when trying to improve the hospital pathway. Intermediate activities are also part of this process. Thus, by adding value to the hospital's activities, it becomes possible to add value to the care delivered to patients.

On the other hand, some resistance may arise from healthcare professionals regarding the implementation of improvement actions. Consequently, it is necessary to find strategies and use approaches that involve actively multidisciplinary teams that are part of these complex systems. In this way, it becomes possible to include different points of view, which are important in the decision-making processes.

6.1. Positive points of the methodological approach

The methodological approach developed allowed, when modeling clinical pathways, to identify the main bottlenecks and to analyze the main aspects that need to be enhanced. Also, it was possible to assess the impact of alternative changes in the parameters of the activities to improve this process. Thus, the construction of a simulation model, although not being familiar to healthcare professionals, left them very enthusiastic, as it presented itself as a tool with high potential to analyze the impact of hypothetical organizational changes in the pathways traveled by patients.

Moreover, the fact of this tool has been implemented in a dynamic and interactive software that allowed the graphic visualization of its functioning, through an animation of the patients' flow, contributed to their engagement.

By using the methodology, it was possible not only to gather improvement proposals but also to discover which ones have added more value to the activities of the institution, that is, which ones have presented themselves as being more attractive from the point of view of the stakeholders involved in the decision-making process. Thus, the importance of the strong social component allied with the technical component must be emphasized, which allows the information collected to be more complete, that there is a greater diversity of points of view, and a higher level of acceptance is reached, as the perspectives of the different stakeholders are considered to make a higher quality decision.

During the value modeling task, a value tree was structured, which captures the fundamental points of view that must be considered when trying to evaluate how it is possible to generate additional value to the IPO-Lisboa activities. Thus, the information collected during several interviews, in which the objectives, values, preferences, and concerns of the different stakeholders were identified, is organized in a visually intuitive way, facilitating its understanding.

When the simulation model and the multicriteria decision model were combined, it was promoted discussions and reflections regarding the different points of view, as well as it was analyzed how it is possible to implement the improvement actions, understanding how feasible their execution is.

In a nutshell, the use of the developed methodological approach allowed to complete the objectives of the proposed work, building a tool to assist the DMs of the IPO-Lisboa in decision-making processes that focus on improving clinical pathways, being aligned with the delivery of VBHC.

6.2. Limitations and points to improve

It was noted that there was a lack of familiarity on the part of some health stakeholders regarding the use of simulation models and multicriteria analysis. Thus, there were some initial doubts and hesitations concerning the implementation of the methodological approach. However, it was verified that all participants possessed a strong enthusiasm to learn, an aspect that allows overcoming this limitation.

In this study, only the clinical pathways of breast cancer patients were considered. Nevertheless, many of the activities of this journey are points where pathways of other pathologies intersect. Thus, this analysis can be considered as a piece of the puzzle that is the healthcare delivery system of the IPO-Lisboa,

which presents different clinical pathways with transversal activities that share resources among themselves.

Regarding the value modeling, only two individual multicriteria decision models were built, which ended up presenting similar responses when ordering improvement proposals according to their attractiveness. Therefore, the involvement of a small number of participants, although belonging to two different categories, was a limitation.

7. Conclusions

All the models developed during this project were validated by the different participants, who emphasized a particular interest in applying simulation models capable of analyzing the impact of changes in parameters of the activities that constitute the clinical pathways. Also, through their different perspectives, it was possible to understand how value is generated by the IPO-Lisboa activities, remembering that this is an essential concern of the healthcare professionals, as this is a hospital with a patient-centered attitude. Thus, when adding value to the pathways' activities, value is also added to the care delivered.

The novel approach developed constitutes a contribution to the literature since there is a gap in combining simulation methods with MCDA, which must be seen as an integral part of problem-solving methodologies. In the case study, through the simulation model, it was possible to discover the main bottlenecks existing in the breast cancer patients' pathways, from their first consultation to the surgery. Moreover, this model enabled the investigation of the impact caused by hypothetical changes in this system. By combining this model with the multicriteria decision model, it was possible to determine that value is added when improvement actions are integrated.

Concerning future work, it is possible to highlight the particular interest in integrating clinical pathways of different pathologies in simulation models. However, it is important to keep these models simplified so that the collection of the necessary data to populate them is performed in a timely manner, and the analysis of the results is not too complex. Furthermore, the collaborative approach can be improved through the participation of a greater number of stakeholders. Besides individual decision models, group models can also be developed, allowing a greater sharing of knowledge and opinions to make higher quality decisions. In this case, techniques such as the Delphi method can be used to handle conflict management [24].

In a world subject to constant and unpredictable changes, it is crucial to adopt quick and effective measures capable of improving and adding value to the hospital pathways, which are journeys taken every day by a wide range of patients.

Acknowledgments: This document was written as an institutional academic requirement and as part of the evaluation of the MSc thesis in Biomedical Engineering of the author at Instituto Superior Técnico. The study described herein was performed at Centro de Estudos de Gestão do Instituto Superior Técnico, University of Lisbon (Portugal), under the supervision of Professor Mónica Oliveira. The thesis was co-supervised at Instituto Português de Oncologia de Lisboa Francisco Gentil by Doctor Júlio Pedro. This work was also developed within the scope of the MEDI-VALUE project (Developing HTA tools to consensualise MEDIcal devices' VALUE through multicriteria decision analysis; http://medivalue.tecnico.ulisboa.pt/; PTDC/EGE-OGE/29699/2017).

References

[1] GLOBOCAN 2018. [Online] Available: https://gco.iarc.fr/ [Accessed: 29-Oct-2020]

[2] Liga Portuguesa Contra o Cancro. Guia: As Mutações BRCA e o Cancro. [Online] Available: https://www.ligacontracancro.pt/ [Accessed: 29-Oct-2020]

[3] Smith, T. J., & Hillner, B. E. (2001). "Ensuring Quality Cancer Care by the Use of Clinical Practice Guidelines and Critical Pathways". *Journal of Clinical Oncology*, 19(11), 2886–2897.

[4] Buchman, S. et al. (2018). "Bridging silos: Delivering integrated care to patients with cancer in Ontario, Canada". *Psycho-Oncology*, 1-4.

[5] IPO-Lisboa: Sobre o Cancro [Online] Available: https://www.ipolisboa.min-saude.pt/ [Accessed: 10-Mar-2020]

[6] Almagooshi, S. (2015). "Simulation Modelling in Healthcare: Challenges and Trends". *Procedia Manufacturing*, 3, 301–307.

[7] Traoré, M. K. et al. (2019). "Modeling and simulation framework for value-based healthcare systems". *SIMULATION*, 95(6), 481-497.

[8] Cai, H., & Jia, J. (2018). "Using Discrete Event Simulation (DES) To Support Performance-Driven Healthcare Design". *HERD: Health Environments Research & Design Journal*, 1-18.

[9] Bana e Costa, C. A. et al. (2011). "MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique)". *Wiley Encyclopedia of Operations Research and Management Science*, 1-6.

[10] Rotter, T. et al. (2008). "A systematic review and meta-analysis of the effects of clinical pathways on length of stay, hospital costs and patient outcomes". *BMC Health Services Research*, 8(265).

[11] Van Egdom, L. S. E. et al. (2019). "Implementation of Value Based Breast Cancer Care". *European Journal of Surg Oncol*, 45, 1163-1170.

[12] Abrahams, E. et al. (2017). "Clinical Pathways: Recommendations for Putting Patients at the Center of Value-Based Care". *Clinical Cancer Research*, 23(16), 4545–4549.

[13] Lorenz, T., & Jost, A. (2006). "Towards an orientation framework in multi-paradigm modelling". In Proceedings of the 24th international conference of the system dynamics society, 23–27 July 2006 (pp. 2134–2151). Nijmegen, The Netherlands.

[14] Jacobson, S. H. et al. (2013). "Discrete-Event Simulation of Health care Systems". *International Series in Operations Research & Management Science*, 273–309.

[15] Barros, T. et al. (2012). "Discrete Event Simulation Combined with Multiple Criteria Decision Analysis as a Decision Support Methodology in Complex Logistics Systems." *Discrete Event Simulations - Development and Applications*, 105-132.

[16] Oliveira, M. D. et al. (2012). "Prioritizing health care interventions: A multicriteria resource allocation model to inform the choice of community care programmes". *International Series in Operations Research & Management Science*, 173, 141–154.

[17] Belton, V., & Stewart, T. (2010). "Problem Structuring and Multiple Criteria Decision Analysis". *Trends in Multiple Criteria Decision Analysis*, 209–239.

[18] Marsh, K. et al. (2016). "Multiple Criteria Decision Analysis for Health Care Decision Making - Emerging Good Practices: Report 2 of the ISPOR MCDA Emerging Good Practices Task Force". *Value in Health*, 19(2), 125–137.

[19] Lourenço, J. C. (2002). "Modelo aditivo hierárquico: exemplos de métodos de ponderação e problemas associados". Working Paper 13-2002, CEG-IST.

[20] Phillips, L. D., & Bana e Costa, C. A. (2007). "Transparent prioritisation, budgeting and resource allocation with multi-criteria decision analysis and decision conferencing". *Annals of Operations Research*, 154(1), 51–68.

[21] Bana e Costa, C. A., & Vansnick, J.-C. (1994). "MACBETH – An interactive path towards the construction of cardinal value functions". *International Transactions in Operational Research*, 1(4), 489-500.

[22] Keeney, R. L. (1992). "Value-Focused Thinking: A Path to Creative Decisionmaking". *Harvard University Press*.

[23] Landercasper, J. et al. (2010). "A Quality Review of the Timeliness of Breast Cancer Diagnosis and Treatment in an Integrated Breast Center". *Journal of the American College of Surgeons*, 210(4), 449-455.

[24] Mukherjee, N., et al. (2018). "Comparison of techniques for eliciting views and judgements in decision-making". *Methods in Ecology and Evolution*, 9(1), 54–63.