Decision Analysis for Thyroid Cancer Treatment

A Proposal for IE 512 Decision Analysis Project

Group 2 - Project Proposal Report

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***Abstract*—Thyroid cancer is a unique condition. A patient's thyroid condition is largely a mystery until it is removed. This proposal outlines a decision analysis project focusing on the complex decision-making process faced by patients with thyroid nodules. They must determine when or whether to undergo thyroidectomy surgery, biopsies, blood tests, and more. Patients may require active monitoring, surgeon and ENT advice, and other services from healthcare professionals. The project applies decision analysis principles to evaluate the uncertainties, objectives, and available options in this critical health decision.**

***Index Terms*—Thyroid cancer, decision analysis, thyroidectomy, healthcare decision-making, ENT.**

I. Introduction

Thyroid nodules are a common medical condition that can develop into thyroid cancer. Five to ten percent of thyroid nodules are malignant [10]. Many nodules are benign, but the possibility of them being cancerous presents patients with a challenging and complex decision.

Thyroid cancer is unique among other types of cancer as treatment rarely involves chemotherapy, and the initial decision to undergo surgery is left largely up to the patient. The patient being the main decision-maker is due to two main factors: The impact the surgery can have on the rest of a patient's life, and the relatively low risks associated with waiting in comparison to other cancers [7]. Papillary thyroid cancer, the most common type of thyroid cancer, is generally slow-growing, and in some cases, it can be safely monitored long term without immediate intervention [7]. Chemotherapy is rarely used to treat thyroid cancers, as it is typically reserved for aggressive forms such as anaplastic thyroid cancer [8]. Additionally, thyroid cancers do not respond to chemotherapy or PET scans in the same way other cancers do, which makes diagnosis and treatment heavily reliant on ultrasound imaging and fine needle aspiration biopsies [9]. The critical decision patients face is whether to have their thyroid gland removed or pursue non-surgical alternatives.

The decision to remove the thyroid, given a thyroid nodule is discovered, is complicated by several factors. Obtaining a definitive cancer diagnosis often requires surgical removal of the thyroid. Thus, patients will not know if the surgery was necessary until after it has been completed. Surgical removal also results in lifelong hormone replacement therapy, which can significantly impact a patient's quality of life. Options such as ongoing monitoring and invasive procedures like Fine Needle Aspiration biopsies come with their own drawbacks. These methods often fail to provide definitive answers, leading to increased uncertainty and anxiety for patients.

Given these challenges, this project seeks to model and analyze the decision-making process using decision analysis techniques. By structuring the problem, identifying key uncertainties, evaluating alternatives, and quantifying trade-offs, this project aims to provide insights that can aid patients in making this critical and deeply personal choice about their health and longevity.

Problem Statement

Thyroid nodules are a common medical condition. Between 50% to 65% of the population is found to have a thyroid nodule [1]. While most nodules are benign, a subset may develop into thyroid cancer. Deciding whether to proceed with thyroid removal surgery presents a significant decision-making challenge. This decision is made more difficult due to the following factors: A definitive cancer diagnosis often requires surgical removal of the thyroid. Surgical removal results in lifelong hormone replacement therapy, which can impact quality of life. Non-surgical options involve ongoing monitoring and invasive diagnostic procedures which are not always helpful, such as the Fine Needle Aspiration Biopsy. These methods can leave patients with even more uncertainty and anxiety. This project explores the decision-making process for patients facing this choice.

Why Not Remove Just the Nodule?

It is important to note that surgery in the thyroid region is generally considered safe. However, the proximity of vital structures such as the laryngeal nerve, carotid artery, and other critical tissues increases the complexity of the procedure. Complications, though rare, can have significant consequences. For this reason, surgeons avoid nodule biopsies and instead perform a thyroidectomy to ensure the safety of the surrounding structures. This information is important to understand.

The fact that a nodule will not be removed without the surrounding thyroid causes the decision weather or not to go into surgery to be more challenging. If a doctor could remove the nodule without removing the surrounding thyroid lobe, unnecessary removal of the thyroid organ could be prevented, and hormone replacement therapy would not be necessary. Doctors will not perform this type of surgery because of the risk to surrounding tissues.

II. Literature Review

This section reviews the key sources and data used to construct the decision model, focusing on thyroid cancer incidence, survival rates, treatment practices, and demographic patterns. The information is directly applied to the creation of decision trees and influence diagrams to guide patient decision-making.

A. *Thyroid Cancer Statistics from SEER*

The SEER (Surveillance, Epidemiology, and End Results) program provides comprehensive population-level statistics on thyroid cancer in the United States.

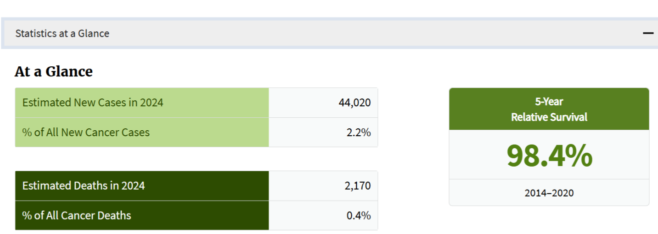


Fig. 1. Statistics Overview. Image retrieved from SEER [15]

In 2024, it is estimated that 44,020 new thyroid cancer cases will be diagnosed, making up 2.2% of all new cancer cases, with 2,170 deaths accounting for 0.4% of cancer mortality [15]. More overall statistics on cancer rates can be seen in Figure 5 below.

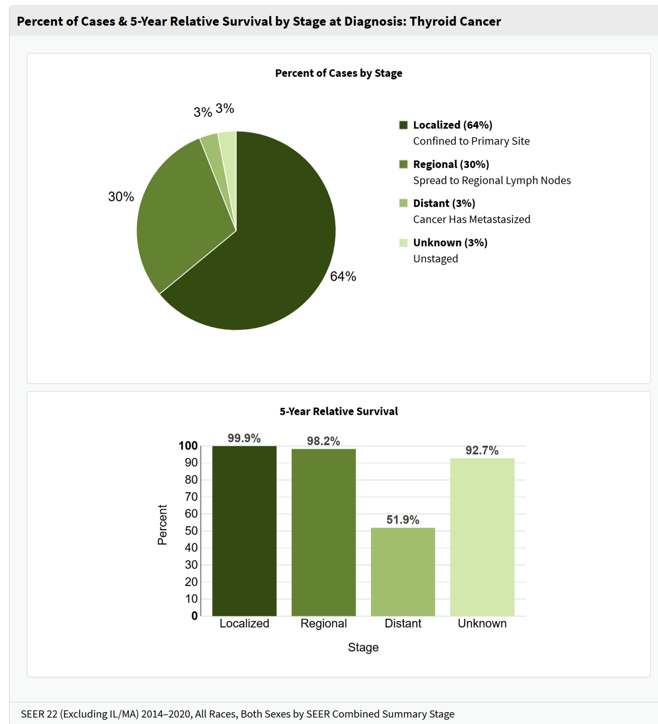


Fig. 2. Population Percentages and Survival Rates. Image retrieved from SEER [15]

In Figure 2 we can see the survival rates for different stages of this disease. This statistic is important for the creation of our decision tree, as the stage and characteristics of the thyroid nodule is a very signifigant factor in choosing to remove the thyroid.

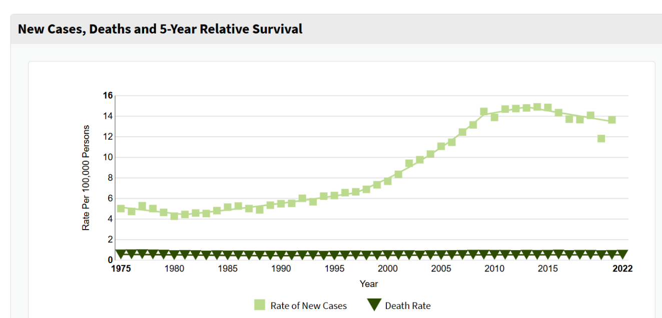


Fig. 3. Mortality and Incidence. Image retrieved from SEER [15]

Something interesting you can observe in Figure 3 above is that the incidence of thyroid cancer increases over the past few years, however the mortality rate seems to remain relatively constant. This could mean several things, but the first two ideas that come to mind in the context of this report are as follows: treatment for this type of cancer may be improving, causing the mortality rate to not increase, or better screening and detection technology has revealed more cases of thyroid cancer that would otherwise have remained undetected. We need to keep an eye out for cases like this in our statistics, and avoid interpreting data in a way that may not be entirely reliable. For example, we should not simply assume that the death rate will remain constant and ignore advances in medical technology or other factors.

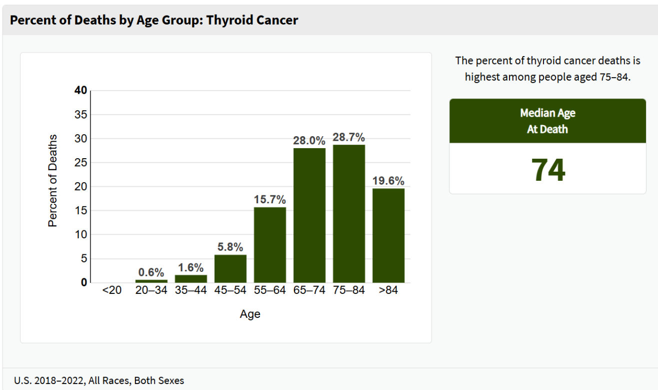


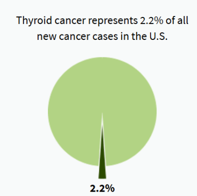
Fig. 4. Mortality and Age. Image retrieved from SEER [15]

This data seen in figure 4 will be important for our assessment. The tree and influence diagram will be created with the knowledge that incidence rates differ over different age rates. To reduce complexity, the decision tree we make may adopt one of these demographics, but another larger tree can be made to cover all ages.

How Common Is This Cancer?

Compared to other cancers, thyroid cancer is relatively rare.

	Common Types of Cancer	Estimated New Cases 2024	Estimated Deaths 2024
1.	Breast Cancer (Female)	310,720	42,250
2.	Prostate Cancer	299,010	35,250
3.	Lung and Bronchus Cancer	234,580	125,070
4.	Colorectal Cancer	152,810	53,010
5.	Melanoma of the Skin	100,640	8,290
6.	Bladder Cancer	83,190	16,840
7.	Kidney and Renal Pelvis Cancer	81,610	14,390
8.	Non-Hodgkin Lymphoma	80,620	20,140
9.	Uterine Cancer	67,880	13,250
10.	Pancreatic Cancer	66,440	51,750
	-	-	-
12.	Thyroid Cancer	44,020	2,170



In 2024, it is estimated that there will be 44,020 new cases of thyroid cancer and an estimated 2,170 people will die of this disease.

Fig. 5. Thyroid Cancer Occurrence. Image retrieved from SEER [15]

The 5-year relative survival rate is 98.4%, with localized cases achieving 99.9% survival, while survival drops to 51.9% for distant metastases. Thyroid cancer is most frequently diagnosed among individuals aged 55–64, with women being three times more likely than men to develop the disease. Additionally, racial disparities exist, with lower incidence rates reported in Black individuals compared to White and Hispanic populations.

The incidence of thyroid cancer has declined by approximately 1% annually since 2012, attributed to more stringent diagnostic criteria. However, the age-adjusted mortality rate has remained stable at 0.5 deaths per 100,000 since 2013 [15].

B. *Key Statistics for Thyroid Cancer from the American Cancer Society*

The American Cancer Society emphasizes the prevalence of thyroid cancer among younger age groups, with a median age of diagnosis at 51 years [14]. Women account for 72% of all new cases, reflecting a significant gender disparity. Incidence rates are notably lower among Black individuals compared to White and Hispanic populations. The organization highlights emerging treatments, such as active surveillance for small, low-risk thyroid cancers and targeted therapies focusing on genetic mutations like BRAF. Trends indicate a decline in thyroid cancer incidence by approximately 2% annually since 2014, linked to stricter diagnostic criteria, while mortality rates have remained stable [14].

C. *Epidemiology of Thyroid Cancer*

The review by Kitahara and Schneider explores the dramatic rise in thyroid cancer incidence over the past four decades, with rates peaking in the mid-2010s before stabilizing. The overall 5-year survival rate remains at 98.6%, with a sharp decrease for distant metastatic disease. Women are disproportionately affected, with an incidence rate of 22.8 per 100,000 compared to 8.0 per 100,000 in men [13]. This difference and how it varies over time can be seen in fitgure 6 below.

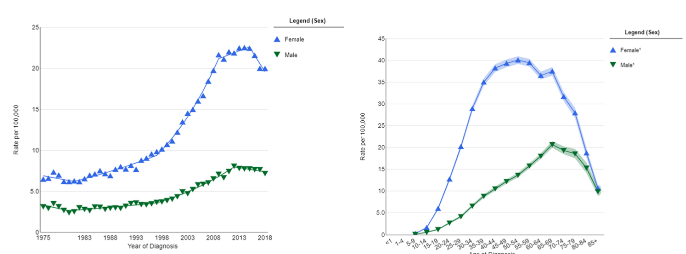


Fig. 6. Incidence Rates per 100,000 and Gender Disparity. Image Retrieved from the National Library of Medicine [13]

Papillary thyroid carcinoma (PTC) accounts for 90% of cases, and key mutations, such as BRAF V600E and TERT promoter mutations, are associated with recurrence and poor outcomes.

The dramatic rise in thyroid cancer incidence has been attributed largely to overdiagnosis due to widespread use of sensitive imaging tools, particularly for small, localized PTCs. Overdiagnosis due to advanced imaging tools has led to the need to re-think modern biopsy and treatment guidelines, leading to a stabilization of incidence rates in recent years [13].

Most thyroid cancers are treated effectively with total or partial thyroidectomy. Radioactive iodine is often used to destroy remaining thyroid tissue after surgery, particularly for advanced cases. Poorly differentiated and anaplastic thyroid cancers are less amenable to treatment and require individualized therapies, including kinase inhibitors [13].

D. Thyroid Cancer Statistics from City of Hope

The City of Hope data aligns with other sources, reporting an estimated 44,020 new thyroid cancer cases in 2024, including 31,520 women and 12,500 men [12]. Lifetime diagnosis probability is approximately 1.2% for adults in the U.S. The 5-year survival rate remains high at 98.4%, reflecting the efficacy of treatments such as thyroidectomy and radioactive iodine therapy for advanced cases. Environmental and genetic factors, such as exposure to radiation, high iodine levels, and mutations in RET and TP53 genes, significantly influence risk. Additionally, trends indicate a 2% annual decline in thyroid cancer incidence since 2014, attributed to improved diagnostic practices [12].

Papillary Thyroid Cancer (PTC) accounts for 80% of cases, is slow-growing, and tends to spread to lymph nodes. Follicular Thyroid Cancer (FTC) accounts for 10%, spreads more readily to other organs than PTC. Oncocytic Thyroid Cancer makes up 3% of cases and is harder to treat and locate. Medullary Thyroid Carcinoma (4%) arises from C cells and spreads to lymph nodes and other organs, while Anaplastic Thyroid Cancer (2%) is highly aggressive. Rare tumors, such as thyroid sarcomas and lymphomas, account for 4% of cases [12].

E. Thyroid Cancer Incidence in the UK

Data from Cancer Research UK highlights a similar pattern, with 4,040 new thyroid cancer cases reported annually between 2017 and 2019, equivalent to 11 new cases daily [11]. Survival rates are high, with 84% of patients surviving 10 or more years. Women face a significantly higher risk, with 2,900 annual cases compared to 1,100 in men. Projections suggest a 74% increase in incidence by 2035, driven by demographic changes and advancements in diagnostic technologies. Mortality rates are expected to rise by 6% by 2040, highlighting the importance of balancing early detection with the risks of overdiagnosis [11].

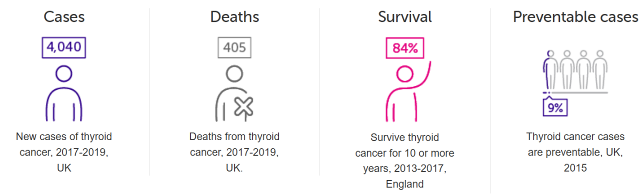


Fig. 7. Thyroid Cancer Statistics Overview in the UK Image Retrieved from Cancer Research UK [11]

This literature provides a robust foundation for modeling thyroid cancer decision-making by integrating demographic, clinical, and treatment data into structured frameworks. The statistics and trends directly inform the probabilities and trade-offs within the decision tree and influence diagram, ensuring they reflect real-world patient scenarios and challenges.

III. Components of Decision Model

By structuring this decision-making process and accounting for the patient's uncertainties and objectives, this project aims to provide a clear framework for patients facing this challenging choice.

A. Decision Maker

The primary decision-maker in this scenario is the patient with a thyroid nodule. While doctors provide critical insights, diagnostic evaluations, and treatment recommendations, the ultimate choice lies with the patient. This decision-making process requires the patient to consider numerous factors, including risks, age, uncertainties, and personal values.

B. Options/Alternatives

Patients diagnosed with thyroid nodules that are suspected to be malignant face two main options:

Surgical Removal (Thyroidectomy): This approach offers a definitive cancer diagnosis, as thyroid cancer is typically confirmed after removing and analyzing the thyroid lobe [2]. However, surgery involves significant trade-offs. It requires lifelong hormone replacement therapy, which can affect the patient's quality of life [3]. Additionally, the invasive nature of thyroidectomy introduces risks, such as potential complications from surgery. In short, surgical removal provides definitive cancer diagnosis but requires lifelong hormone replacement therapy [2], [4].

Active Monitoring: This alternative avoids immediate surgery, focusing instead on regular imaging, blood tests, genetic testing, and Fine Needle Aspiration (FNA) biopsies. While this approach may reduce unnecessary surgical interventions, it is not without challenges. Active monitoring can lead to ongoing uncertainty, as thyroid nodules may worsen over time, and diagnostic methods like FNA biopsies occasionally yield inconclusive results, such as a "non-diagnostic" outcome. This can add to the patient's anxiety and uncertainty during the decision-making process. Active monitoring involves regular imaging, biopsies, and blood tests, offering a less invasive approach but with ongoing uncertainty [3].

C. Uncertainties

The primary uncertainties are as follows:

- Whether the thyroid nodule is cancerous or benign.
- Whether surgery is truly necessary.
- The potential complications arising from surgery.
- How quality of life will change due to lifelong hormone therapy.
- The risk of undiagnosed cancer progressing if surgery is deferred.
- The risk of parathyroid or other more aggressive types of cancer

The biggest uncertainty is whether the thyroid nodule is cancerous or benign. A definitive diagnosis often requires surgical removal of the thyroid lobe with a nodule on it. Surgery inherently carries risks and long-term consequences [1], [3]. This brings the added challenge determining of whether surgery is necessary, particularly given that many thyroid nodules are benign [7], [8]. Surgery poses potential complications, including damage to the laryngeal nerve or other vital structures in the neck, which could result in hoarseness, difficulty swallowing, or other long-term effects [5], [6]. Beyond surgical risks, the lifelong need for hormone replacement therapy following thyroidectomy introduces its own uncertainties, including potential changes to quality of life due to the need for hormone replacement [3], [7]. The risk of undiagnosed cancer progressing if surgery is deferred adds a layer of urgency and anxiety for patients who opt for active monitoring over immediate intervention [7], [9].

D. Objectives

The main objectives are as follows:

- Ensuring a definitive cancer diagnosis if cancer is present.
- Minimizing health risks associated with undiagnosed thyroid cancer.
- Maximizing quality of life by balancing how invasive treatment is with how necessary treatment is.

The primary objective of patients is to obtain a definitive diagnosis to confirm whether cancer is present. It is also important to address and treat more aggressive thyroid cancers, particularly as some forms of thyroid cancer, such as anaplastic carcinoma, can progress rapidly if left untreated [8]. Patients also aim to maximize their quality of life by carefully balancing invasive treatments with their necessity, choosing a path that aligns with their priorities, risk tolerance, and personal values [7], [9].

IV. Decision Tree

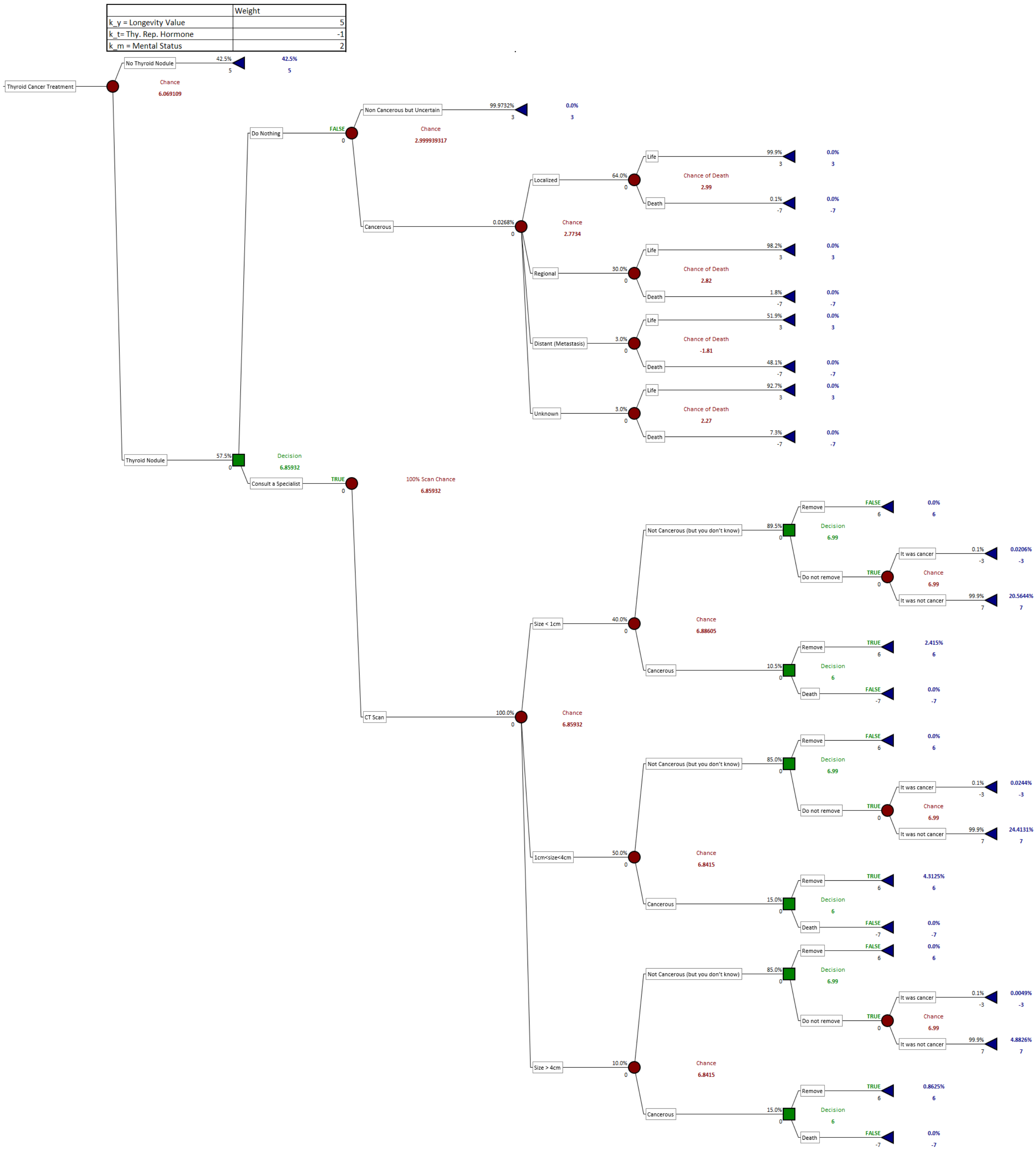


Fig. 8. Decision Tree for Thyroid Cancer Treatment

The decision tree seen above in figure 8 is created to model the decision-making process faced by patients diagnosed with thyroid nodules. It provides a representation of potential actions, outcomes, and uncertainties associated with managing this condition. Below is a thorough explanation of the key components, pathways, probabilities, and rationale underlying the decision tree:

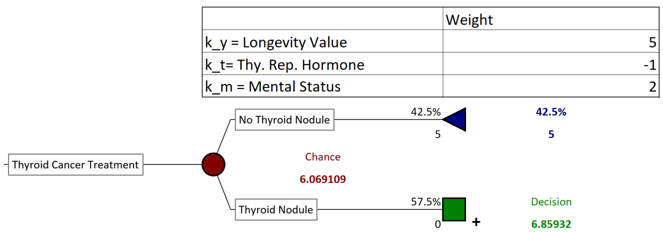


Fig. 9. First Chance Node: Thyroid Nodule Presence

As you can see in Figure 9 below, the decision tree begins with a chance node representing the presence or absence of a thyroid nodule. At this stage, the probabilities are based on population-level data, where 57.5% of individuals are estimated to have a thyroid nodule, while 42.5% do not. For patients without a nodule, the decision-making process ends here, as there is no need for further action. For those with a nodule, the process continues with additional decisions and chance events.

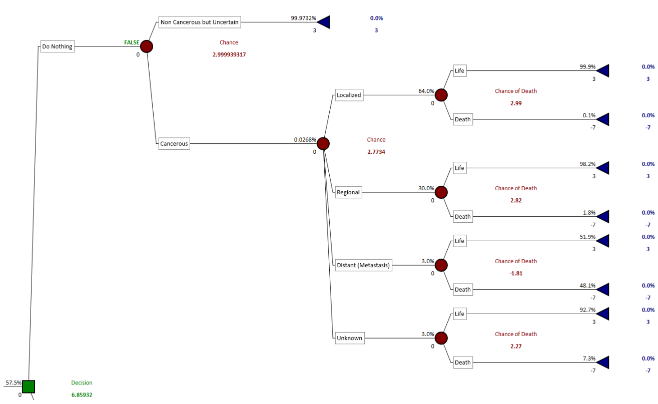


Fig. 10. Tree If the Patient Does Nothing

If the patient chooses to do nothing, the outcomes diverge based on the actual status of the nodule. The tree accounts for the possibility that the nodule may be non-cancerous, cancerous, or malignant but undiagnosed. Refer to Figure 10 for this part of the tree. Each of these branches is associated with distinct probabilities and survival rates, which are factored into the expected utility calculations. This segment highlights the risks of avoiding medical consultation, as undiagnosed malignancies can progress, significantly impacting survival and quality of life.

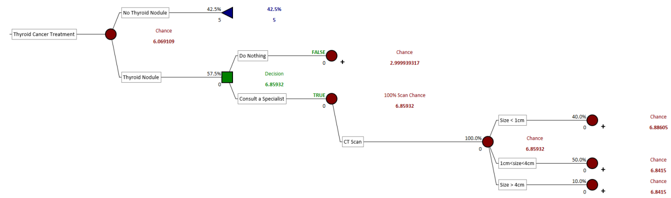


Fig. 11. Consulting A Specialist

Figure 11 represents what happens when you do eventually decide to consult a specialist. This decision tree makes it fairly clear that when a nodule is discovered, you should go see a doctor. Consulting a specialist introduces additional branches for diagnostic testing, such as imaging or biopsy, which refine the probabilities of malignancy and guide subsequent treatment decisions. By consulting a specialist, patients gain access to expert insights and tailored recommendations, reducing uncertainty and improving decision-making clarity.

The tree acknowledges the recursive nature of thyroid nodule management. Patients undergoing monitoring often face repeated diagnostic cycles, requiring continual reassessment of risks and benefits. While making a fully realized model with this level of complexity is beyond the scope of the current model, future expansions may incorporate long-term monitoring pathways and outcomes.

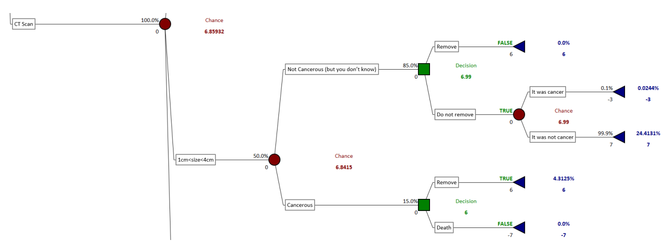


Fig. 12. Results of a CT Scan

The results of a CT Scan can vary. Looking at Figure 12 above, you can see an example of what decisions you are met with once you get results, in this case the nodule size is below 4cm and above 1cm, which is both common for thyroid nodules, and commonly cancer. Based on the size of the nodule, the decision tree branches into different probabilities of malignancy. This section demonstrates how diagnostic imaging results are integrated into the model to inform treatment paths, balancing the risks of unnecessary surgery against the potential consequences of delayed intervention.

V. Influence Diagram

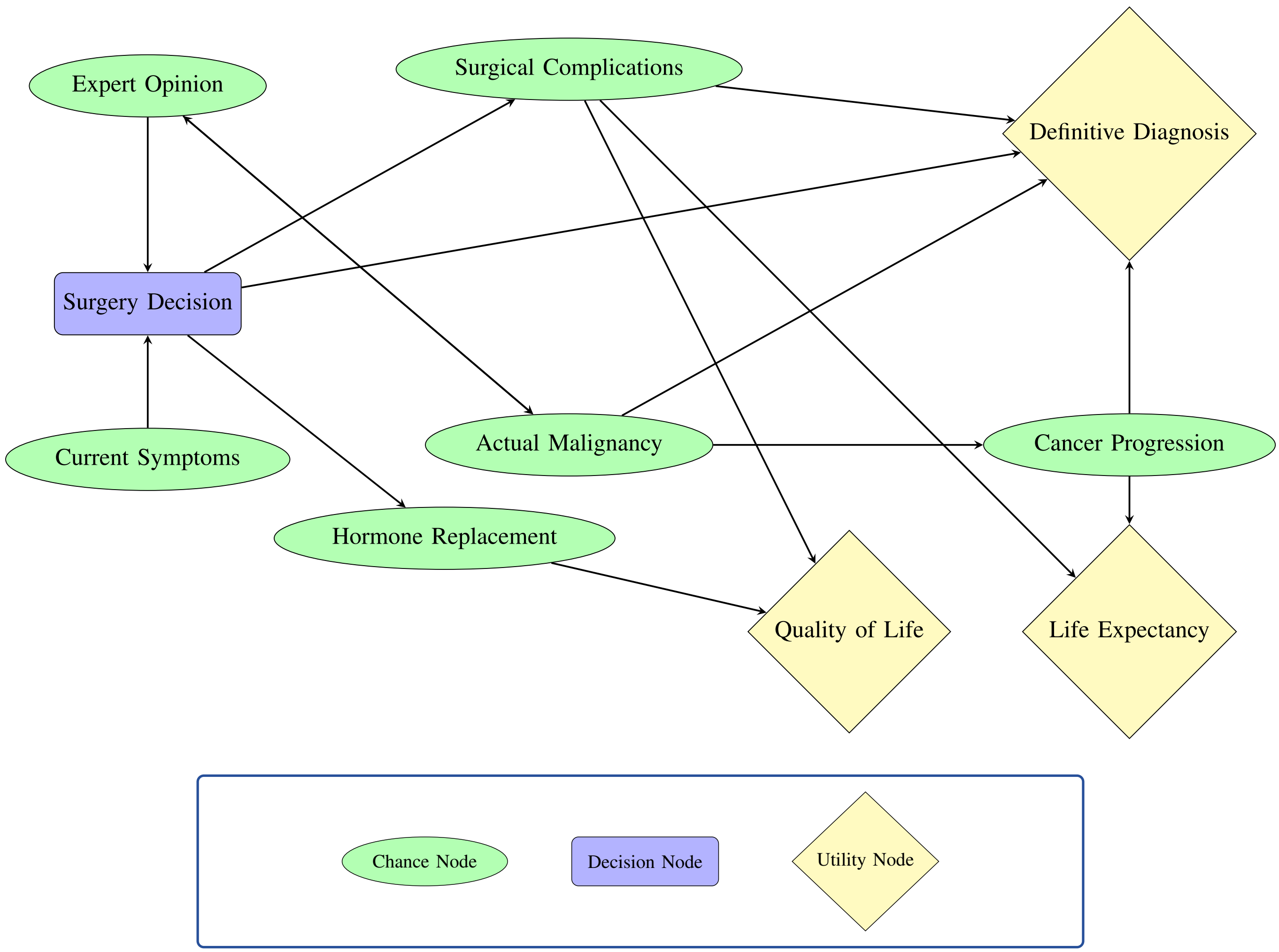


Fig. 13. Enhanced Influence Diagram of Thyroid Cancer Treatment with Expert Opinion and Actual Malignancy Adjusted

This influence diagram looks fairly complicated. Many of the chance and decision nodes effect multiple other nodes. Let's break down each individual influence so that we can better understand what is going on in the diagram above.

Decision Nodes:

- Surgery Decision (Decision Node): This represents the decision to proceed with surgery or not. This node chooses between having a thyroidectomy, or not removing the thyroid.

Chance Nodes:

- Current Symptoms (Chance Node): This represents the patient's present condition and symptoms, which directly influence the Surgery Decision node. An example of a symptom is the nodule affecting a patient's ability to swallow.
- Expert Opinion (Chance Node): This is the medical opinion regarding the likelihood of malignancy. It is bi-directionally linked to Actual Malignancy, indicating uncertainty and feedback. The expert opinion is what drives the decision of the patient weather or not to remove the thyroid. For the patient, the expert opinion serves as a gauge for the actual malignancy.
- Actual Malignancy (Chance Node): This is the true state of malignancy in the patient. The actual malignancy is something unknown until the thyroid is removed. This node influences Cancer Progression, Definitive Diagnosis, and Life Expectancy.
- Surgical Complications (Chance Node): This is the probability of complications arising from surgery. This can include damage to the surrounding tissues

and can even result in an unsuccessful surgery.

- Hormone Replacement (Chance Node): This represents the need for hormone replacement therapy post-surgery. It directly influences Quality of Life, and is required after a full thyroidectomy.
- Cancer Progression (Chance Node): This reflects the likelihood of cancer advancing without intervention. It impacts both Definitive Diagnosis and Life Expectancy. Untreated cancer can signifigantly reduce life expectancy.

Utility Nodes:

- Definitive Diagnosis (Utility Node): This represents achieving a clear understanding of the cancer's stage, and characterizing the cancer type. This diagnosis often requires a thyroidectomy, and the surgery decision often occurs before a diagnosis is formed.
- Quality of Life (Utility Node): Reflects the patient's overall well-being post-treatment. It is influenced by Surgical Complications and Hormone Replacement.
- Life Expectancy (Utility Node): Represents the expected survival outcomes. This node is influenced by Cancer Progression, Surgical Complications, and Surgery Decision. If the wrong decision is made, the cancer progression node can significantly reduce the life expectancy.

Influences:

- Expert Opinion $\rightarrow$ Surgery Decision: The expert's assessment of malignancy impacts the decision-making process for surgery.
- Current Symptoms $\rightarrow$ Surgery Decision: The patient's present symptoms provide key input for determining whether surgery is necessary. Some surgery can be deemed necessary based on symptoms alone, like if the nodule stops a patient from swallowing properly.
- Surgery Decision $\rightarrow$ Definitive Diagnosis: Surgery normally leads to a more conclusive diagnosis.
- Surgery Decision $\rightarrow$ Surgical Complications: Choosing surgery introduces the potential for complications.
- Surgery Decision $\rightarrow$ Hormone Replacement: Surgery often leads to the need for hormone replacement therapy.
- Expert Opinion $\leftrightarrow$ Actual Malignancy: The bidirectional influence reflects the uncertainty between expert assessment and actual malignancy status.
- Actual Malignancy $\rightarrow$ Cancer Progression: The likelihood of cancer progression is directly tied to the true state of malignancy.
- Actual Malignancy $\rightarrow$ Definitive Diagnosis: A definitive diagnosis is influenced by the actual malignancy status.
- Actual Malignancy $\rightarrow$ Life Expectancy: True malignancy status impacts survival outcomes.
- Cancer Progression $\rightarrow$ Definitive Diagnosis: Cancer progression informs the clarity of the diagnosis. If an aggressive cancer grows double its size, a doctor could form a diagnosis of cancer.
- Cancer Progression $\rightarrow$ Life Expectancy: Cancer progression significantly impacts the patient's survival outlook.
- Surgical Complications $\rightarrow$ Quality of Life: Post-surgical complications affect the patient's well-being.
- Surgical Complications $\rightarrow$ Life Expectancy: Severe complications can reduce survival outcomes.
- Surgical Complications $\rightarrow$ Definitive Diagnosis: Complications during surgery can impede obtaining a definitive diagnosis. Unsuccessful surgery may result in no material to run tests on post-operation.
- Hormone Replacement $\rightarrow$ Quality of Life: Hormone therapy affects the patient's long-term quality of life. Hormone replacement therapy involves frequent blood draws, and daily medication.

You may notice that the arrow between the Expert Opinion node and the Actual Malignancy node is bidirectional. The actual malignancy influences the expert opinion because the specialist relies on current and historical statistics to make their predictions. Also, while making a prediction for malignancy will give an indicator for weather a nodule is cancer, the prediction does not affect the malignancy itself. On the other hand, the expert opinion also influences our perception of the likelihood of certain outcomes. A benign prediction increases our belief that there is no rush to go into surgery, and similarly, a prediction of an aggressive cancer increases the likelihood we will opt for surgery. From these two ideas, we can say that the arrow indicating which chance node influences the other is bidirectional.

VI. Description and Summary of Data Used

This section summarizes the key data and statistics extracted from the literature, which form the basis for the decision tree and influence diagram used in this project. The information spans disease prevalence, demographic disparities, survival rates, treatment options, and trends, as well as uncertainties and objectives relevant to the decision model. **Numbers that we used in the Decision Tree or Influence Diagram will appear in bold.** An important assumption in one of our decision trees is that *the value of each outcome is the years a patient survives after diagnosis.* This has a maximum of 5 years, since most studies consider a patient to be in remission or considered cancer-free when there is no incident for 5 years.

A. Disease Prevalence and Incidence

An estimated 44,020 new thyroid cancer cases are expected in 2024, comprising 12,500 males and 31,520 females, accounting for 2.2% of all new cancer cases [12], [14], [15].

From the National Library of Medicine, we get the following information: *"Thyroid cancer incidence is approximately three-fold higher in women (22.8 per 100,000 per year in 2014–2018) than in men (8.0 per 100,000 per year). Currently, one in 55 U.S. women and one in 149 U.S. men are expected to be diagnosed with thyroid cancer during their lifetime (10). Thyroid cancer mortality is very low relative to incidence (approximately 0.5 deaths per 100,000 per year)" [13]*

The statistic we will use in our model is that **22.8 out of 100,000 women and 8.0 out of 100,000 men have thyroid cancer [13].** Incidence trends show a decline of 1% annually (2012–2021) in the U.S., reflecting stricter diagnostic criteria and technological improvements [15].

From the Yale School of Medicine, we know that between 50% to 65% of the population is found to have a thyroid nodule [1]. For our analysis and decision tree, we will be using the average of these two numbers, such that **57.5% of people have thyroid nodules. [1]**

B. Survival Rates and Mortality

The overall 5-year relative survival rate for thyroid cancer is 98.4%. Stage-specific survival rates are as follows: - Localized: 99.9% - Regional: 98.2% - Distant: 51.9% [12], [13], [15]. - The age-adjusted mortality rate has remained stable at 0.5 per 100,000 since 2013 [15].

Recall the mortality rates per age group from the literature review:

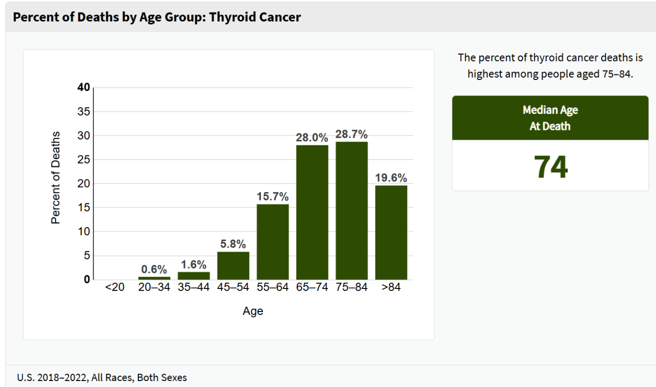


Fig. 14. Mortality and Age. Image retrieved from SEER [15]

From this graph, we can deduce that:

- Age of <20 has effectively 0% mortality.
- Age 20-34 has 0.6% mortality
- Age 35-44 has 1.6% mortality
- Age 45-54 has 5.8% mortality
- Age 55-64 has 15.7% mortality
- Age 65-74 has 28.0% mortality
- Age 75-84 has 28.7% mortality
- Age >84 has 19.6% mortality

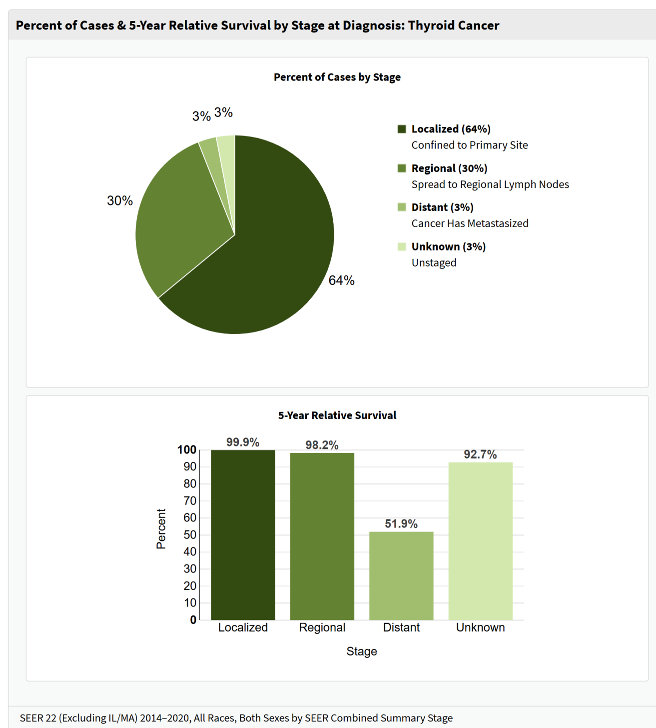


Fig. 15. Population Percentages and Survival Rates. Image retrieved from SEER [15]

From the above figure, we can use the following information:

- **64% of cases are Localized, with a 99.9% 5-year survival rate.**
- **30% of cases are Regional, with a 98.2% 5-year survival rate.**
- **3% of cases are Distant, with a 51.9% 5-year survival rate.**
- **3% of cases are Localized, with a 92.7% 5-year survival rate.**

C. Demographic Patterns

Thyroid cancer is most frequently diagnosed among individuals aged 55–64, with a median diagnosis age of 51 [12], [14], [15]. Lifetime risk of thyroid cancer is 1.1% for men and women in the U.S., while the UK figures are 1 in 200 for females and 1 in 340 for males [11], [12]. Genetic and environmental factors, such as mutations in BRAF and RET genes, high radiation exposure, and BMI, significantly influence risk [12], [13].

From an online source we obtained the cancer risk associated with different nodule sizes. **A nodule larger than 4cm in diameter has a 15% chance of being cancer.** This number was obtained from The American Thyroid Association in this online source. Another source called ”Thyroid Nodule Size and Prediction of Cancer” [18] gives us the following numbers:

- **1.0–1.9 cm: 10.5% of nodules are cancerous**
- **2.0–2.9 cm: 14% of nodules are cancerous**
- **3.0–3.9 cm: 16% of nodules are cancerous**
- **>4 cm: 15% of nodules are cancerous**

A paper named ”Fine needle aspiration biopsy of thyroid nodule smaller than 1.0 cm: accuracy of TIRADS classification system in more than 1000 nodules” gives insight to how the TIRADS system classifies different nodules.

”A practical TIRADS classification to categorize thyroid nodules and stratify their malignancy risk19 was expressed with scores ranging from 1 to 5:

- *TIRADS 1 corresponds to a normal gland*
- *TIRADS 2 to a benign nodule (both with 0% malignancy)*
- *TIRADS 3 to a highly probable benign nodule (<5% malignancy)*
- *TIRADS 4 (5 to 80% malignancy)*
- *TIRADS 5 (>80% malignancy)*

For a suspicious nodule, TIRADS 4A, 4B and 4C corresponds to low, intermediate and moderate suspicion for malignancy respectively. TIRADS 5 corresponds to a high suspicion for malignancy. Risk ranges from 5 to 80% of malignancy. ” [17]

D. Treatment Options and Advances

Common treatments include thyroidectomy and radioactive iodine for advanced cases. Emerging alternatives like microwave and radiofrequency ablation are under exploration for low-risk cancers [12], [14]. New targeted therapies are focusing on genetic markers, such as BRAF and TERT mutations, improving outcomes for aggressive cancer types [13]. Active surveillance is gaining traction for small, low-risk cancers, reducing unnecessary interventions [14].

E. Trends and Uncertainties

Overdiagnosis due to sensitive imaging has been a major contributor to increased incidence rates, leading to reevaluation of biopsy and treatment guidelines [13]. Long-term projections indicate a potential rise in incidence by 74% by 2035, with mortality rates potentially increasing by 6% by 2040 [11]. The decision model incorporates uncertainties around diagnostic practices, treatment advancements, and demographic trends.

One study reports that 56 to 68% of indeterminate thyroid nodules underwent unnecessary surgery. [21]

F. Relevance to Decision Model

The above data is directly incorporated into the influence diagram and decision tree by: Modeling probabilities of disease prevalence and survival outcomes by stage. Assessing demographic influences, such as age, gender, and racial disparities, on risk and treatment decisions. Including uncertainties around future trends, diagnostic practices, and treatment advancements.

This data-driven approach ensures that the decision model accurately reflects the complexities and nuances of thyroid cancer diagnosis and treatment planning.

VII. Model Solution

For this model to be built on real-world statistics, we need some probabilities first:

Given our assumptions we know: 7.2 in 100000 men, and 19.8 in 100000 women have thyroid cancer [13].

$$.0080\% \text{ of men have thyroid cancer}$$

$$.0228\% \text{ of women have thyroid cancer}$$

This means approximately 0.0154% of people have thyroid cancer

$$57.5\% \text{of people have a thyroid nodule [1]}$$

We will use Bayes' theorem to find the conditional probability that you have thyroid cancer given you have a thyroid nodule. $TC = Thyroid\ Cancer$, $TN = Thyroid\ Node$ Note: We assume here if you have thyroid cancer, that means you must have a nodule. $\therefore P(TN|TC) = 1$

$$P(TC|TN) = \frac{P(TN|TC) * P(TC)}{P(TN)}$$

$$= \frac{1 * 0.000154}{.575} = 0.0002678$$

$$\boxed{P(TC|TN) = 0.02678\%}$$

There are many aspects we need to consider here. We have the age of the person and their chance of dying ranging from .6 to 28.7%. We have the size of the nodule greatly impacting the chance to recommend certain treatment.

Since there is the option to do nothing, but that will leave a person with a lump in their neck, and a significant chance of thyroid or other cancers, we have created a double objective analysis. We assess the 5 year survival and the mental anxiety as weights.

	Weight
k_y = years lived	5
k_m = mental anxiety	2

Fig. 16. Double Objective Weights

Each node consequence will be a function of those weights on years lived along with the quality of those years through the anxiety weight. These weights are incorporated into the decision tree model as seen in Figures 16 and 17.

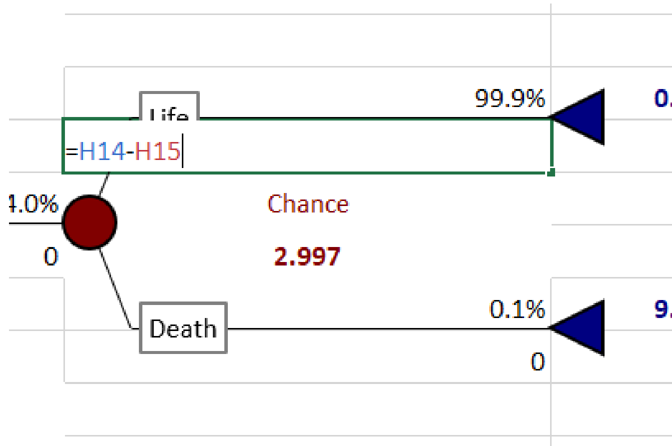


Fig. 17. Double Objective Implementation

A. Evaluating Treatment Options

The first decision point in the tree evaluates whether a patient should do nothing, consult a specialist, or undergo initial diagnostic testing. If the patient does nothing, the model assigns weights to reflect the mental health toll and survival probability associated with leaving a thyroid nodule untreated. Figures 25 and **??** show how these weights interplay, showing how doing nothing is generally not optimal when you have a nodule.

B. Specialist Consultation and CT Scans

Once a specialist is consulted, a CT scan is recommended, with subsequent decisions branching based on the size and malignancy potential of the nodule. For nodules less than 1 cm, active monitoring may be favored due to their low malignancy rates, reflected in a higher mental health utility. Conversely, nodules between 1 cm and 4 cm or greater than 4 cm are more likely to be malignant, with the model prioritizing surgical interventions to maximize life expectancy despite the added weight from hormone replacement therapy.

C. Cancer Staging and Survival Probabilities

For malignant cases, survival probabilities are calculated based on stage: localized, regional, or distant metastasis. As shown in the sensitivity analysis, survival rates dramatically decrease as the cancer progresses. For example, localized cancers yield a 99.9% 5-year survival rate, while distant metastases drop to 51.9%. These probabilities influence the utility calculations, encouraging early and decisive intervention for higher-staged nodules.

D. Sensitivity Analysis

A sensitivity analysis was conducted to explore how different weights—longevity, mental health, and hormone replacement—affect the expected utility. Results indicate that longevity has the greatest impact on decision-making, while mental health influences outcomes more moderately. For example, increasing the weight of longevity emphasizes the benefits of surgery, whereas prioritizing mental health might favor monitoring or less invasive options.

E. Balancing Double Objectives

As demonstrated in the double-objective implementation (Figure **??**), the model balances survival and mental health objectives. By structuring decisions around these weights, we create a flexible framework that adapts to individual patient priorities. For example, a patient with high anxiety about monitoring may lean towards surgery despite the associated lifelong hormone therapy.

F. Model Output

The decision tree assigns utilities to each potential outcome, calculating the expected utility based on survival probabilities and mental health impacts. For most patients, consulting a specialist and following diagnostic recommendations (e.g., CT scans and biopsies) is favored. However, the model highlights cases where active monitoring might be sufficient, particularly for younger patients or those with low-risk nodules.

G. Solution of the Decision Model

The solution of our decision model provides insight into the optimal course of action for managing thyroid nodules and potential thyroid cancer. From examining the decision tree and applying the weights for longevity and mental well-being, we can derive the following solutions for making this decision:

H. Consulting a Specialist is Critical

The decision tree strongly indicates that consulting a specialist is the most favorable first step when a thyroid nodule is detected. This path consistently yields the highest expected utility, as it accounts for the potential to avoid unnecessary surgery while providing a pathway to diagnosis and treatment if malignancy is suspected.

I. CT Scans Provide Valuable Information for Risk Level

The results of a CT scan significantly influence the subsequent decisions. Nodules less than 1 cm in size are associated with lower malignancy probabilities, which makes active monitoring a more viable option. For nodules larger than 1 cm, the model highlights an increased likelihood of malignancy, often leading to surgical recommendations.

J. Surgery is Optimal for Malignant Nodules

For nodules confirmed or highly suspected to be malignant, the decision tree suggests that surgery is the optimal choice. Despite the lifelong requirement of hormone replacement therapy, the significant increase in life expectancy outweighs the negative impact of this tradeoff. This is especially true for localized or regional thyroid cancer, where survival probabilities remain high.

K. Mental Status Considerations

Mental health plays a substantial role in the model's calculations. Patients who experience high anxiety from uncertainty may benefit more from definitive treatments like surgery, even if the nodule's malignancy is uncertain. Conversely, patients less impacted by uncertainty may prefer active monitoring for low-risk nodules, avoiding the potential complications of unnecessary surgery.

L. Double Objective Framework

The double objective framework balances the need for maximizing life expectancy with preserving mental well-being. This approach ensures that the decision-making process aligns with the patient's values and preferences. For instance, patients who prioritize longevity may lean towards more aggressive treatment options, while those focused on mental health might choose monitoring when appropriate.

M. Survival Probabilities by Stage Drive Decisions

The model uses survival probabilities at different stages. Localized cancers have near-perfect survival rates (99.9%), while distant metastases drastically reduce survival (51.9%). This disparity validates the decision to intervene early for high-risk cases.

N. Doing Nothing is Rarely Optimal

The "do nothing" option generally results in the lowest expected utility. Leaving a thyroid nodule untreated carries significant risks, including potential malignancy progression and associated anxiety from the lack of resolution. As such, this path is not recommended unless the patient's circumstances specifically favor it.

O. Final Conclusion

The decision model illustrates that the best course of action depends on a combination of nodule characteristics, survival probabilities, and patient priorities. For most if not all cases, consulting a specialist and following through with diagnostic procedures, including CT scans, is the optimal starting point. Surgery is favored when malignancy is likely, while active monitoring is a valid option for low-risk nodules.

VIII. Sensitivity Analysis

The sensitivity analysis examines the robustness of the decision model by varying key parameters such as longevity, mental health weight, and hormone replacement impacts. By analyzing how changes in these variables affect the expected utility, we provide insights into the relative importance of these factors in guiding treatment decisions.

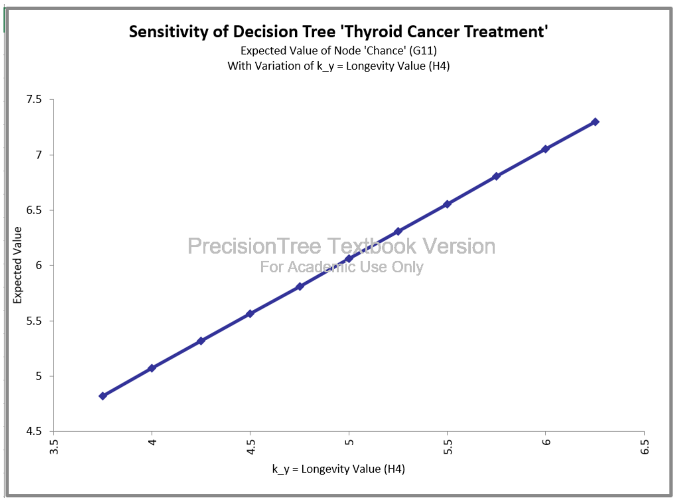


Fig. 18. Sensitivity Analysis w.r.t longevity

A. One Way Sensitivity Analysis

The One Way Sensitivity Analysis explores the impact of individual parameters on the expected utility.

Sensitivity Data				
	Input		Output	
	Value	Change (%)	Value	Change (%)
#1	3.75	-25.00%	4.822766891	-20.42%
#2	4	-20.00%	5.0701072	-16.34%
#3	4.25	-15.00%	5.317521721	-12.25%
#4	4.5	-10.00%	5.565003993	-8.17%
#5	4.75	-5.00%	5.812548443	-4.09%
#6	5	0.00%	6.06015022	0.00%
#7	5.25	5.00%	6.307805076	4.09%
#8	5.5	10.00%	6.555509261	8.17%
#9	5.75	15.00%	6.803259447	12.26%
#10	6	20.00%	7.051052664	16.35%
#11	6.25	25.00%	7.29888625	20.44%

Fig. 19. Sensitivity Analysis Table w.r.t longevity

Longevity weight, the one-way sensitivity analysis of which is seen in Figure 18, has the most significant influence, with changes of over 20% in expected utility when its value is varied. Mental health weight also affects outcomes but to a lesser extent, demonstrating that patients with higher anxiety may prioritize definitive treatments like surgery. Thyroid hormone replacement, while relevant, shows minimal impact, highlighting that survival and mental health considerations dominate the decision-making process.

B. Spider Graph

The Spider Graph illustrates the sensitivity of expected utility to simultaneous variations in multiple parameters. Longevity weight consistently drives the steepest changes in utility, followed by mental health weight and hormone replacement. This visualization underscores the critical role of survival probabilities and mental health in shaping optimal treatment paths. For low-risk cases, the spider graph suggests that active monitoring becomes a viable choice as mental health considerations gain prominence.

The following is a spider graph on how each weight influences our expected value. We want to maximize this value.

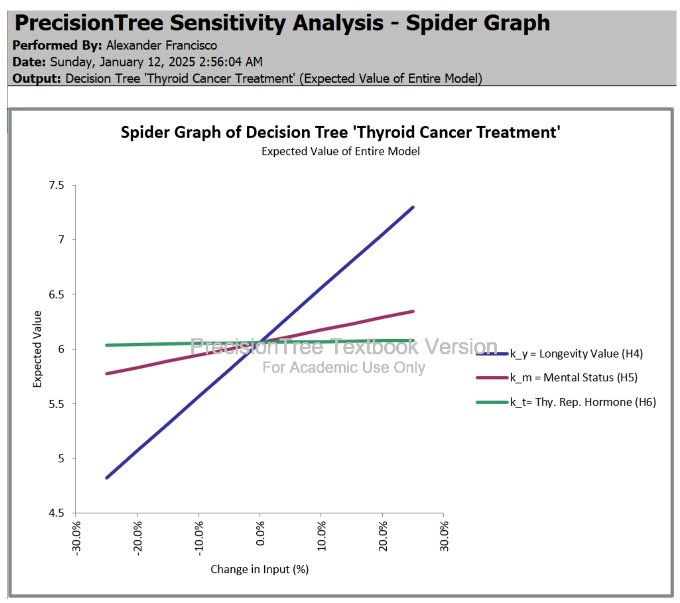


Fig. 20. Spider Graph of Decision Tree

Importantly, you can see how longevity is our primary objective for maximizing the expected value. This makes sense, as the primary objective is getting the patient to survive for the longest time.

Spider Graph Data

Decision Tree 'Thyroid Cancer Treatment' (Expected Value of Entire Model)

			Input Variation			Output Variation		
Input Name	Cell	Step	Value	Change	Change (%)	Value	Change	Change (%)
k_y = Longevity Value (H4)	H4	1	3.75	-1.25	-25.00%	4.822766891	-1.237383329	-20.42%
		2	4	-1	-20.00%	5.0701072	-0.99004302	-16.34%
		3	4.25	-0.75	-15.00%	5.317521721	-0.742628499	-12.25%
		4	4.5	-0.5	-10.00%	5.565003993	-0.495146227	-8.17%
		5	4.75	-0.25	-5.00%	5.812548443	-0.247601778	-4.09%
		6	5	0	0.00%	6.06015022	0	0.00%
		7	5.25	0.25	5.00%	6.307805076	0.247654856	4.09%
		8	5.5	0.5	10.00%	6.555509261	0.495359041	8.17%
		9	5.75	0.75	15.00%	6.803259447	0.743109227	12.26%
		10	6	1	20.00%	7.051052664	0.990902444	16.35%
		11	6.25	1.25	25.00%	7.29888625	1.23873603	20.44%
k_m = Mental Status (H5)	H5	1	1.5	-0.5	-25.00%	5.77265022	-0.2875	-4.74%
		2	1.6	-0.4	-20.00%	5.83015022	-0.23	-3.80%
		3	1.7	-0.3	-15.00%	5.88765022	-0.1725	-2.85%
		4	1.8	-0.2	-10.00%	5.94515022	-0.115	-1.90%
		5	1.9	-0.1	-5.00%	6.00265022	-0.0575	-0.95%
		6	2	0	0.00%	6.06015022	0	0.00%
		7	2.1	0.1	5.00%	6.11765022	0.0575	0.95%
		8	2.2	0.2	10.00%	6.17515022	0.115	1.90%
		9	2.3	0.3	15.00%	6.23265022	0.1725	2.85%
		10	2.4	0.4	20.00%	6.29015022	0.23	3.80%
		11	2.5	0.5	25.00%	6.34765022	0.2875	4.74%
k_t= Thy. Rep. Hormone (H6)	H6	1	-1.397542486	-0.279508497	-25.00%	6.038935525	-0.021214695	-0.35%
		2	-1.341640786	-0.223606798	-20.00%	6.043178464	-0.016971756	-0.28%
		3	-1.285739087	-0.167705098	-15.00%	6.047421403	-0.012728817	-0.21%
		4	-1.229837388	-0.111803399	-10.00%	6.051664342	-0.008485878	-0.14%
		5	-1.173935688	-0.055901699	-5.00%	6.055907281	-0.004242939	-0.07%
		6	-1.118033989	0	0.00%	6.06015022	0	0.00%
		7	-1.062132289	0.055901699	5.00%	6.064393159	0.004242939	0.07%
		8	-1.00623059	0.111803399	10.00%	6.068636098	0.008485878	0.14%
		9	-0.95032889	0.167705098	15.00%	6.072879037	0.012728817	0.21%
		10	-0.894427191	0.223606798	20.00%	6.077121976	0.016971756	0.28%
		11	-0.838525492	0.279508497	25.00%	6.081364915	0.021214695	0.35%

Fig. 21. Spider Graph Table of Decision Tree

C. Tornado Graph

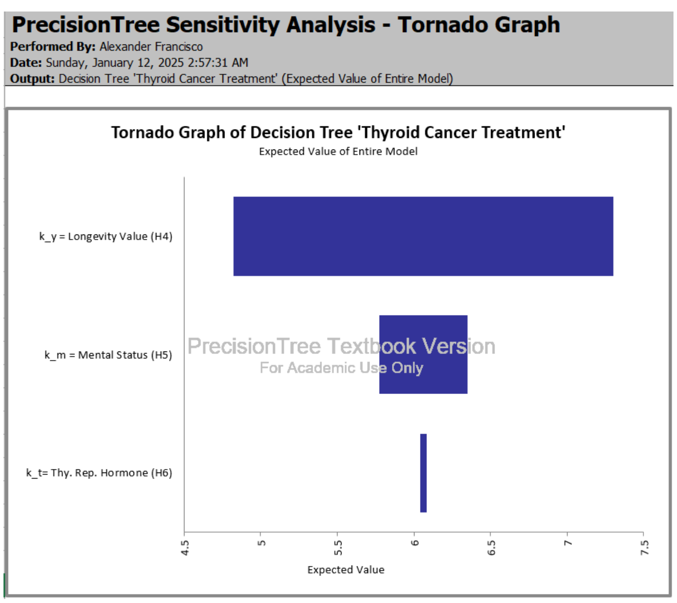


Fig. 22. Tornado Diagram

The Tornado Graph provides a comparative view of the variables' influence on expected utility. Longevity weight again emerges as the dominant factor, with mental health weight exerting a moderate but meaningful effect. Hormone replacement impacts remain comparatively low. The Tornado Graph confirms that decisions prioritizing longevity yield the most favorable outcomes, particularly for high-risk nodules where surgery provides substantial survival benefits.

Tornado Graph Data

Decision Tree 'Thyroid Cancer Treatment' (Expected Value of Entire Model)

			Minimum			Maximum		
			Output		Input	Output		Input
Rank	Input Name	Cell	Value	Change (%)	Value	Value	Change (%)	Value
1	k_y = Longevity Value (H4)	H4	4.822766891	-20.42%	3.75	7.29888625	20.44%	6.25
2	k_m = Mental Status (H5)	H5	5.77265022	-4.74%	1.5	6.34765022	4.74%	2.5
3	k_t= Thy. Rep. Hormone (H6)	H6	6.038935525	-0.35%	-1.397542486	6.081364915	0.35%	-0.838525492

Fig. 23. Tornado Diagram Table

It is worth pointing out that as many patients would agree, their longevity is of the highest priority. This is reflected in this tornado graph. Prioritization of years alive after diagnosis has the largest impact on our expected value.

D. Two Way Sensitivity Analysis

Our two way sensitivity analysis below will demonstrate how our decision tree weight variables influence each other and the expected value. Keep in mind we seek to maximize expected value.

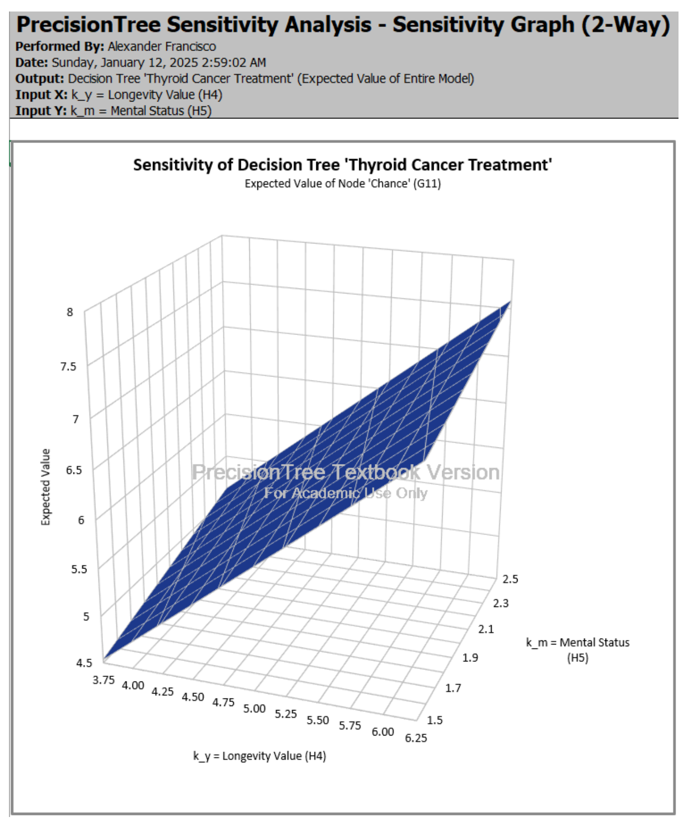


Fig. 24. 2 way sensitivity Analysis

The Two Way Sensitivity Analysis evaluates the interaction between longevity and mental health weights. The corresponding graph demonstrates that these two objectives are complementary rather than competing. Increasing either longevity or mental health weight improves the expected utility, with the highest values achieved when both are prioritized simultaneously. This finding validates the double-objective framework, which balances survival and quality of life in decision-making.

Two-Way Sensitivity Data of Decision Tree 'Thyroid Cancer Treatment' (Expected Value of Entire Model)

With Variation of k_y = Longevity Value (H4) and k_m = Mental Status (H5)

		k_y = Longevity Value (H4)										
		3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50	5.75	6.00	6.25
k_m = Mental Status (H5)	1.5	4.535266891	4.7826072	5.030021721	5.277503993	5.525048443	5.77265022	6.020305076	6.268009261	6.515759447	6.763552664	7.01138625
	1.6	4.592766891	4.8401072	5.087521721	5.335003993	5.582548443	5.83015022	6.077805076	6.325509261	6.573259447	6.821052664	7.06888625
	1.7	4.650266891	4.8976072	5.145021721	5.392503993	5.640048443	5.88765022	6.135305076	6.383009261	6.630759447	6.878552664	7.12638625
	1.8	4.707766891	4.9551072	5.202521721	5.450003993	5.697548443	5.94515022	6.192805076	6.440509261	6.688259447	6.936052664	7.18388625
	1.9	4.765266891	5.0126072	5.260021721	5.507503993	5.755048443	6.00265022	6.250305076	6.498009261	6.745759447	6.993552664	7.24138625
	2.0	4.822766891	5.0701072	5.317521721	5.565003993	5.812548443	6.06015022	6.307805076	6.555509261	6.803259447	7.051052664	7.29888625
	2.1	4.880266891	5.1276072	5.375021721	5.622503993	5.870048443	6.11765022	6.365305076	6.613009261	6.860759447	7.108552664	7.35638625
	2.2	4.937766891	5.1851072	5.432521721	5.680003993	5.927548443	6.17515022	6.422805076	6.670509261	6.918259447	7.166052664	7.41388625
	2.3	4.995266891	5.2426072	5.490021721	5.737503993	5.985048443	6.23265022	6.480305076	6.728009261	6.975759447	7.223552664	7.47138625
	2.4	5.052766891	5.3001072	5.547521721	5.795003993	6.042548443	6.29015022	6.537805076	6.785509261	7.033259447	7.281052664	7.52888625
	2.5	5.110266891	5.3576072	5.605021721	5.852503993	6.100048443	6.34765022	6.595305076	6.843009261	7.090759447	7.338552664	7.58638625

Fig. 25. Two Way Sensitivity Table

We see two important behaviors here. The graph of expected value increases almost linearly with mental status and longevity, with a slight curvature. That curvature is because the thyroid replacement coefficient is a function of both mental state and longevity.

Mental state increasing in priority increases our expected value. However, this increase is not nearly as much as the increase observed from longevity. While longevity should be prioritized, only together can the two parameters maximize expected value.

Lastly we can see our parameters do not compete. This means we do not have to choose between longevity or mental state. While there are some areas where you must choose one in terms of removing the thyroid or remaining uncertain, If there is an option to maximize mental health and longevity, that will have the greatest positive impact on our expected value. This can be seen as the maximum value in the top right corner of our graph.

E. Key Insights from Sensitivity Analysis

The sensitivity analysis, visualized through the One Way Sensitivity Analysis, Spider Graph, Tornado Graph, and Two Way Sensitivity Analysis, reveals several critical insights: - Longevity weight is the most influential factor, favoring surgical intervention for malignant nodules. - Mental health considerations shift preferences toward less invasive treatments like active monitoring for low-risk cases. - Hormone replacement has minimal effect on overall utility, suggesting survival and mental health are prioritized. - A balanced approach integrating longevity and mental health delivers optimal outcomes for most patients.

F. Impact of Longevity Weight

Longevity, representing survival probability, exerts the largest influence on expected utility. Increasing its weight significantly raises the utility of aggressive treatments like surgery, aligning with its primary goal of life extension. The tornado graph shows that variations in longevity account for over 20% of changes in expected utility, confirming its importance in decision-making.

G. Mental Health Weight and Its Role

Mental health, reflecting anxiety and stress, has a moderate impact on outcomes. Higher weights favor less invasive approaches like active monitoring, particularly for low-risk nodules. Patients highly affected by uncertainty may prefer surgery for its definitive diagnosis, while others prioritize mental stability by avoiding unnecessary interventions.

H. Thyroid Hormone Replacement Impacts

Thyroid hormone replacement, required post-surgery, has the least influence on expected utility. While it entails lifelong adjustment, its impact is minor compared to survival and mental health. Patients are generally willing to accept hormone therapy for improved longevity and reduced cancer risks.

I. Interaction Between Longevity and Mental Health

A two-way sensitivity analysis revealed that longevity and mental health are complementary, not competing objectives. Prioritizing both results in higher expected utility, validating the model's double-objective framework. Interventions that maximize survival while minimizing mental stress produce the best outcomes.

J. Summary of Sensitivity Analysis

- Longevity is the dominant factor, favoring surgical treatment for malignancies.
- Mental health considerations promote less invasive options for low-risk cases.
- Hormone replacement, while relevant, is less critical in decision-making.
- A dual focus on survival and mental well-being optimizes patient outcomes.

IX. Conclusion and Discussion

This study provides a comprehensive analysis of the decision-making process for thyroid cancer treatment, utilizing decision trees, influence diagrams, and sensitivity analyses to explore patient options. By integrating robust data and structured models, we offer insights into navigating the complexities of this critical health decision.

A. Importance of Specialist Consultation

The analysis highlights the critical role of consulting a specialist when a thyroid nodule is detected. This step consistently yields the highest expected utility by balancing the risks of malignancy against the potential for unnecessary interventions. Diagnostic tools, such as CT scans, refine malignancy probabilities and guide subsequent decisions, emphasizing the value of early medical engagement.

B. Optimal Treatment Decisions

For patients with confirmed or highly suspected malignancies, surgery emerges as the optimal choice. The significant increase in life expectancy outweighs the negative impacts of lifelong hormone replacement therapy. Conversely, active monitoring is suitable for low-risk nodules, reducing unnecessary surgical interventions while maintaining patient quality of life.

C. Balancing Longevity and Mental Health

The sensitivity analysis demonstrates the complementary relationship between longevity and mental health. Prioritizing both objectives results in the highest expected utility. Patients experiencing significant anxiety about uncertainty may benefit from surgery, while those with lower risk tolerance might prefer monitoring.

Sensitivity Analysis Insights

D. Longevity as a Dominant Factor

Longevity consistently drives the most significant changes in expected utility, validating its prioritization in treatment decisions. Aggressive interventions, such as surgery, are heavily favored for their life-extending benefits, particularly in cases of localized or regional thyroid cancer.

E. Role of Mental Health

Mental health considerations moderately influence decision outcomes. Higher weights for mental well-being favor less invasive approaches, underscoring the importance of personalized treatment plans that align with patient priorities.

F. Minimal Impact of Hormone Replacement

The impact of thyroid hormone replacement on overall utility is comparatively low. While it remains a consideration, patients generally prioritize survival and mental health over the inconveniences of lifelong therapy.

Challenges and Limitations

G. Unaddressed Factors

Some items were excluded to maintain this model being feasible to create in one class session:

- Risks of surgical complications and mortality.
- Variability in outcomes based on patient gender, and genetic predispositions.
- Recursiveness of monitoring pathways, which often involve repeated diagnostic cycles.
- Age plays a huge role in death rate
- There is a significant disparity between men and women. Women get thyroid cancer at nearly 3X the rate of men.
- The biggest issue is that information from the doctor is not perfect. They will not know for sure if you have cancer until they remove the thyroid.
- The decision process for a thyroid patient is recursive. They require frequent monitoring at the end point of our decision tree. This was not included for simplicity

H. Uncertainty in Medical Diagnoses

The inherent uncertainty in expert opinions and diagnostic tools significantly influences patient decisions. This underscores the need for improved diagnostic accuracy and clear communication to empower patients.

Recommendations for Future Work

I. Enhancing Model Precision

Future iterations should incorporate:

- Detailed age and demographic-specific survival probabilities.
- Comprehensive modeling of recursive monitoring pathways.
- Integration of emerging diagnostic tools, such as TIRADS and molecular testing.

J. Expanding Patient-Centered Analysis

Incorporating patient-specific factors, such as personal risk tolerance and psychological profiles, can refine treatment recommendations. Tailored decision frameworks would better address individual needs, improving both clinical outcomes and patient satisfaction.

K. Addressing Overdiagnosis and Overtreatment

Given the risks of overdiagnosis, future models should evaluate the thresholds for intervention, balancing early detection with the potential for unnecessary treatments.

L. Final Thoughts

This project underscores the complexity of thyroid cancer treatment decisions. By prioritizing longevity and mental health within a structured decision framework, patients and healthcare providers can navigate these challenges more effectively. The findings highlight the importance of early specialist consultation, informed by data-driven tools, to achieve optimal outcomes tailored to individual patient needs.

X. Roles of Group Members

In this project, each team member contributed their unique skills and expertise to ensure a well-rounded and comprehensive approach to decision analysis for thyroid cancer treatment. As identical twins living in the same house, Alexander and Marcus Francisco share similar schedules, creating an environment that grants seamless communication and collaboration. We divided responsibilities as follows:

Marcus Francisco: Marcus led the literature review, analyzing and summarizing key data points from various research sources. His work provided a strong foundational understanding of thyroid cancer prevalence, survival rates, and the impact of different treatment approaches. Additionally, Marcus designed the influence diagram, visually representing the complex relationships between uncertainties, decisions, and outcomes. This diagram played a crucial role in conceptualizing the decision-making process and informed the development of the decision tree. An interesting addition to Marcus' responsibilities in this project has been consulting with a thyroid specialist. This was for the purpose of treating his own condition, but the answers and advice given by the thyroid surgeon helped significantly to further our understanding of this topic.

Alexander Francisco: Alexander Francisco created the decision tree, established the project plan and timeline, and also researched data values specifically for the decision tree. Alex focused on constructing the decision tree, which served as the backbone of the project's analysis. He developed a structured model to evaluate potential treatment options, incorporating probabilities, outcomes, and utilities to guide decision-making. Alex also performed the sensitivity analysis, exploring how variations in key variables, such as longevity and mental status, impacted the overall expected value. He created visual representations of these analyses, making the results accessible and actionable.

Together, both members collaborated closely to align their work and ensure that the final model addressed the complexities of thyroid cancer treatment. By leveraging their individual strengths, Marcus and Alex produced a robust and nuanced decision framework that balances longevity, quality of life, and diagnostic clarity for patients facing this critical choice.

XI. Presentation

The accompanying presentation serves as a visual and narrative complement to this report, summarizing our findings and decision analysis for thyroid cancer treatment. The presentation gives you a closer look at the decision tree, influence diagram, and analysis to illustrate how patients can navigate the critical choice between surgery and alternative treatments. The presentation can be accessed via the following link: Link to Panopto.

This presentation also discusses the psychological aspects of decision-making, highlighting the balance between longevity and mental well-being as key objectives. Through visuals and explanations, it provides an overview of the decision model created in this report.

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