ISE 562: Final Report

Heart Attack Treatment Options

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ISE 562 Value and Decision Theory
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1 Description

The CDC reports that someone in the United States suffers from a myocardial infarction every 40 seconds [1]. Given the relative ubiquity of this condition, the choice of treatment plan following a heart attack is, or will inexorably be, a common decision problem confronted by most Americans at some point in their lifetime.

The treatment options for a heart attack are typically either a coronary artery bypass graft (an open-heart surgery) or a percutaneous coronary intervention (also known as angioplasty or heart stent). A percutaneous coronary intervention is a less invasive procedure than a coronary artery bypass graft, and involves the insertion of a wire-mesh tubular support into the artery for the purpose of relieving obstruction and restoring blood flow to the heart [2]. A third alternative treatment often used by physicians is to employ a pharmaceutical therapy regimen to alleviate the strain on the heart and restore relative function. Although this may be a mitigating tactic, it can be an independently successful treatment depending on the severity of the arterial obstruction.

While the advancement of modern medicine has led to significant risk reductions in treatment implementations, each approach to alleviating a heart attack still presents its own set of distinctive costs and longer-term risks to a patient's well-being that must be taken into account in order to identify the best choice treatment alternative. Therefore, this decision analysis attempts to model the treatment decision confronted by an "average" heart attack victim in the US and identify the optimum treatment plan. This is followed by a sensitivity analysis of the treatment probabilities and cost of death with a discussion of the key factors which would affect a change in the optimum solution to this decision problem. This analysis will conclude with a discussion of the final recommendation for the patient along with salient considerations identified within the sensitivity analysis.

2 Analysis Framework

2.1 Decision Makers and Stakeholders

The primary decision maker and key stakeholder in this decision problem will be the heart attack victim. For modeling reasons, it was chosen to represent the "average" patient as an elderly man of age 60 that maintains a regularly active lifestyle with no pre-existing health conditions. In addition, it was assumed that the patient has standard health insurance and has just suffered a heart attack of moderate severity (less severe narrowing or blockage) within the last hour.

2.2 Alternatives

As discussed in the introduction, the three primary treatment options will be coronary artery bypass graft, percutaneous coronary intervention, or pharmaceutical treatments.

2.2.1 Coronary Artery Bypass Graft

Coronary artery bypass graft (CABG) is an open-heart surgical procedure in which unobstructed blood vessels from another part of the body are grafted onto the aorta and the obstructed artery to restore blood flow and restore cardiopulmonary function [3]. As a form of open-heart surgery, the trauma to the patients' body is naturally greater than less invasive alternatives and carries a bevy of different potential surgical and post-operative complications such as pleural effusion, arrhythmia/atrial fibrillation, and sepsis among many others [3]. However, advances in medical technology have drastically minimized these risks and current data estimate that the CABG procedure has an overall success rate of approximately 96.4% [4].

2.2.2 Percutaneous Coronary Intervention

Percutaneous coronary intervention (PCI) is also called a balloon angioplasty or stenting. This treatment is a minimally invasive non-surgical procedure in which a permanent wire-mesh tube is inserted and inflated within the obstructed vessel using a catheter and guidewire [2]. As compared to a bypass, this treatment method is a lower risk option. However, there remains potential for operational complications related to embolization and arterial bleeding resulting from over-inflation of the stent or the presence of calcified tissue in the target artery [2]. Nevertheless, the assembled data indicates that the risk of these procedure complications is comparatively lower than CABG with an overall success rate of roughly 99.25% [4].

Despite the high probability of a successful surgery there is a following likelihood that the procedure fails in adequately restoring myocardial function thereby necessitating a subsequent bypass procedure. Based on the observed rates of reinfarction following a stent procedure, the probability of needing a CABG within 30 days and 2-12 months of the PCI treatment is 1.8% and 4.0%, respectively [5]. Consequently, by complementation, the rate of full success stenting with no bypass needed is 94.2%.

2.2.3 Pharmaceutical Treatment

While typically used as a stopgap measure, pharmaceutical treatment of myocardial infarction can sometimes be an effective standalone alternative. This “medical management” or optimal medical therapy (OMT) is especially helpful when the arterial obstruction is less serious, the myocardial tissue damage is less serious, and the patients’ medical history or personal wishes make mechanical revascularization measures more undesirable or risky (i.e. higher failure rate for CABG and stent). Therefore, using an exclusively pharmacological treatment for a heart attack constitutes a third distinct alternative for patients not wishing to pursue mechanical revascularization procedures. As the name suggests, this treatment is a drug regimen consisting of anticoagulants, beta-blockers, ACE inhibitors, nitrates, antiplatelets, statins and other medications typically used for coronary disease patients [6].

Since this treatment only involves chemical arterial intervention, there is no associated surgical procedure risk. Although, based on mortality and cardiac event rate data on patients who had received pharmacological therapy exclusively, the probability of needing a CABG within 30 days and within 2-12 months is 37.5% and 44.0%, respectively [7,8]. Accordingly, by complementation the probability of success of pharmaceutical treatments alone is 18.5%.

2.3 Objectives

Five primary objectives were considered for this decision problem: out of pocket costs for the chosen treatment alternative, longevity of life as a consequence of the treatment, likelihood of survival for each treatment, and the post-treatment quality of life and level of pain that the patient experiences. The decision maker seeks the best treatment plan that would provide minimized costs and pain while maximizing longevity and quality of life.

3 Data and Expert Judgements

3.1 Consequence Table

The consequence table compares each of the three primary treatment alternatives and the four objective attributes, excluding likelihood of treatment survival since it is considered in the formation of the decision tree probabilities for surgery success. The completed consequence table is shown in Table 1.

3.1.1 Alternatives Data

The out of pocket costs are the reported expenses associated with each treatment plan after insurance. For the sake of this decision problem, the average deductible in the US was used to represent out of pocket costs for both surgery options since the patient is assumed to have health insurance [9,10,11].

Five-year survival rates were collected through reported medical statistics on the proportion of patients under each respective treatment that were still surviving after five-years according to each treatments' Kaplan-Meier survival curve [12,13,14,15]. The longevity of life scores are reported as lower bounds on life expectancy which were obtained by multiplying each of the five-year survival rates by five years.

$$Longevity\ of\ Life\ [yr.] = 5\ year\ survival\ rate\ [\%] \times 5\ [yr.] \tag{1}$$

The quality of life for each treatment was scored on a scale of 1 to 5, where 1 equals a severe difference in the patient's quality of life, 3 equals a slight change in their quality of life, and 5 equals a normal quality of life not much different from before the heart attack. A range of 1 to 5 was chosen since the quality of life between each treatment does not change drastically based on personal testimonies and research [16].

Based on Mark A. Hlatky's, MD, a professor of health research and policy and professor of medicine at Stanford University, statement that bypass surgery "is longer lasting, more durable, and gives more angina relief", this treatment was given a 5 out of 5 for quality of life following full recovery [3,12]. Stenting in comparison requires some change in the patient's quality of life such as following a healthy diet, being more physically active, and reducing stress, which is why it was designated a 4 out of 5 [2]. Pharmaceutical treatment has the highest effect on the patient's quality of life since no relief is given to the heart, therefore it has the lowest value of 2 out of 5.

Similarly, the pain level for each treatment was scored on a scale of 1 to 10, where 1 equals severe pain in the chest after treatment recovery, 5 equals medium pain in the chest after treatment recovery, and 10 equals no pain in the chest after treatment recovery. A range of 1 to 10 was chosen since the levels of pain the patient will feel in their chest following the recovery of each treatment greatly differs between treatment options, so it was necessary to have a wider range to represent this difference. No matter the treatment option chosen there will be some chest pain after the patient is fully recovered. Therefore, based on patients' and doctors' testimonies CABG was given a 7 out of 10, whereas stenting was given a 5 out of 10 because "there is not as much chest pain [angina] relief" [12]. Since pharmaceutical treatment only masks the side effects and provides little to no chest pain relief it was given a 3 out of 10.

3.1.2 Alternatives with Secondary Bypass Treatment Data

In addition, to the three primary treatments, two additional treatment plans were ranked since "it is very likely [that the patient] will need a second procedure within six months" of a stent or pharmaceutical treatment. These two treatment paths are: stenting followed by a bypass surgery and pharmaceutical treatment followed by a bypass surgery. In both of these two latter cases, the same five-year survival rate as the baseline bypass surgery, and therefore similar longevity of life, was assumed to be the same. The main difference in these cases is quality of life and pain level changes associated with the additional physiological strain of undergoing two treatments instead of one. For stenting followed by a bypass, 1 point was subtracted from the quality of life and pain level of stenting due to the dual procedures and the increased level of stress on the patient's body. Since pharmaceutical treatment already accounts for a drastic change in quality of life and increased pain levels the values were kept the same.

Table 1: Consequence table comparing alternatives and objectives.

	5 Yr. Survival Rate *[%]*	Longevity of Life *[years]*	Quality of Life *[scale: 5-normal, 3-slight change, 1-severe difference]*	Pain Level *[scale:10-none, 5-medium, 1-severe]*
Coronary Bypass Graft	90%	4.5	5	7
Stenting (PCI)	89%	4.45	4	5
Pharmaceutical Treatments	35%	1.75	2	3

Stenting + Bypass	90%	4.5	3	4
Pharm. Treatments + Bypass	90%	4.5	2	3

3.2 Decision Tree Data

This decision problem has several treatment options with various outcomes based on the initial decision, thus a decision tree was created in order to determine the best recommendation.

3.2.1 Quality Adjusted Life Expectancy

In order to translate the objectives in the consequence table (Table 1) to values in the decision tree a quality adjusted life expectancy was calculated for each treatment outcome. Based on collected data estimates of the average value of a statistical life year (VSLY) it was found that one life year is approximately weighted at $100,000 [17,18]. Although, there is considerable theoretical indeterminacy in the estimation of VSLY dependent on the choice of wage model, confronted labor market, and risk attitudes. This ambiguity in life valuation is further confounded by the fact that this decision problem involves life valuations from the perspective of the heart attack sufferer as opposed to the viewpoint of regulatory agencies (as is commonly done in VSLY model estimations) [17,19,20]. Despite this, it was determined that a slight variation in the number would not affect the final analysis of this project as long as there is consistency, which was based on consultation with a professor whose expertise is in decision theory. Therefore, for the sake of this decision problem, a weighting of $100,000 per life year was used for the longevity of life objective.

This value allows for a dollar equivalent scale in order to estimate the gain in life years by choosing one treatment over another. Since quality of life and pain level affect the value of a life year, they were each weighted based on the $100,000 per life year. The quality of life following the chosen treatment is important for the patient's future years of living, so it was weighted by 40% of one life year which is equal to $40,000. Finally, given the fact that living with some chest pain is possible it was only weighted by 10% of one life year which is equal to $10,000. Table 2 shows the corresponding equivalent life years for each objective. Quality adjusted life expectancy (Q) was then calculated using a linear combination of each attribute value with the corresponding attribute weight

$$Q = (Longevity\ of\ life \times \$100{,}000) + (Quality\ of\ life \times \$40{,}000) + (Pain\ level \times \$10{,}000) \quad (2)$$

Lastly, based on the research utilized in the analysis, a failure in surgery represents the patient's death. Therefore, it was necessary to evaluate the cost of the patient's life. Since no patient will choose to lose their life, a large value of -$10,000,000 was used for the cost of death. Based on these values, the final dollar equivalent utility is shown in Table 2.

Table 2: Quality adjusted life expectancy calculation for each treatment outcome using Equations (1) & (2).

	Longevity of Life *[years]*	**Quality of Life** *[scale: 5-normal, 3-slight change, 1-severe difference]*	**Pain Level** *[scale:10-none, 5-medium, 1-severe]*	**Quality Adjusted Life Expectancy**
Coronary Bypass Graft	4.5	5	7	$720,000
Stenting (PCI)	4.45	4	5	$655,000
Pharmaceutical Treatments	1.75	2	3	$285,000
Stenting + Bypass	4.5	3	4	$610,000
Pharm. Treatments + Bypass	4.5	2	3	$560,000
Cost of Failed Surgery (Death)	-	-	-	- $10,000,000
Equivalent Life Years	$100,000	$40,000	$10,000	-

3.2.2 Decision Tree Costs and Probabilities

The last cost necessary to account for in the decision tree is out of pocket costs. This combined with the quality adjusted life expectancy, shown in Table 3, complete all of the costs in the decision tree.

Table 3: Cost inputs for the decision tree.

	Out of Pocket Costs	Quality Adjusted Life Expectancy
Coronary Bypass Graft	- $4,400	$720,000
Stenting (PCI)	- $4,400	$655,000
Pharmaceutical Treatments	- $625	$285,000
Stenting + Bypass	- $8,800	$610,000
Pharm. Treatments + Bypass	- $5,025	$560,000
Cost of Failed Surgery (Death)	-	- $10,000,000

The final necessary calculation for the decision tree is the probability of having a secondary treatment. Based on medical practitioner data it was assumed that having a secondary surgery will decrease the probability of the success of that surgery due to the stress on the human body and lack of recovery time, especially when that surgery is performed quickly after the initial trauma [21]. Due to HIPAA restrictions, there is a dearth of data on situations of this granularity, so this compromising risk was represented by penalizing the surgery success rate and assigning lower secondary surgery success rates, shown in Table 4.

The reasoning behind looking at the difference between having the secondary treatment after 30 days compared to 2-12 months is that the failure of the initial treatment implies an additional period of myocardial stress. Here, the degree of strain is inversely related to the delay until the secondary bypass since a 30 day necessity implies a more serious underlying problem than a patient who is able to go without a bypass for several months. Accordingly, for stents, the success rate of bypass is 90% of the baseline success rate of 96.4% if needed within 30 days and 95% of the baseline success rate if the patient is able to wait 2-12 months. Similarly, following the pharmaceutical treatment, the success rate is 92% of the baseline 96.4% if needed within 30 days and 99% of the baseline rate if needed within 2-12 months. The percentages are larger for pharmaceutical treatments since it does not require two procedures, which means the body will be under less stress. All the necessary probabilities for the decision are shown in Table 4.

Table 4: Surgery success and failure probabilities.

			Successful Surgery	Failed Surgery (Death)
Coronary Bypass Graft			96.4%	3.6%
Stenting (PCI)			99.25%	0.75%
Stenting	+	**Bypass within 30 Days**	90% × 96.4% = 86.8%	13.2%
Stenting	+	**Bypass within 2-12 Months**	95% × 96.4% = 91.6%	8.4%
Pharm. Treatments	+	**Bypass within 30 Days**	92% × 96.4% = 88.7%	11.3%
Pharm. Treatments	+	**Bypass within 2-12 Months**	99% × 96.4% = 95.4%	4.6%

3.3 Decision Tree

Given all of the previously calculated values in Table 3 and 4, the final decision tree is shown in Figure 1.

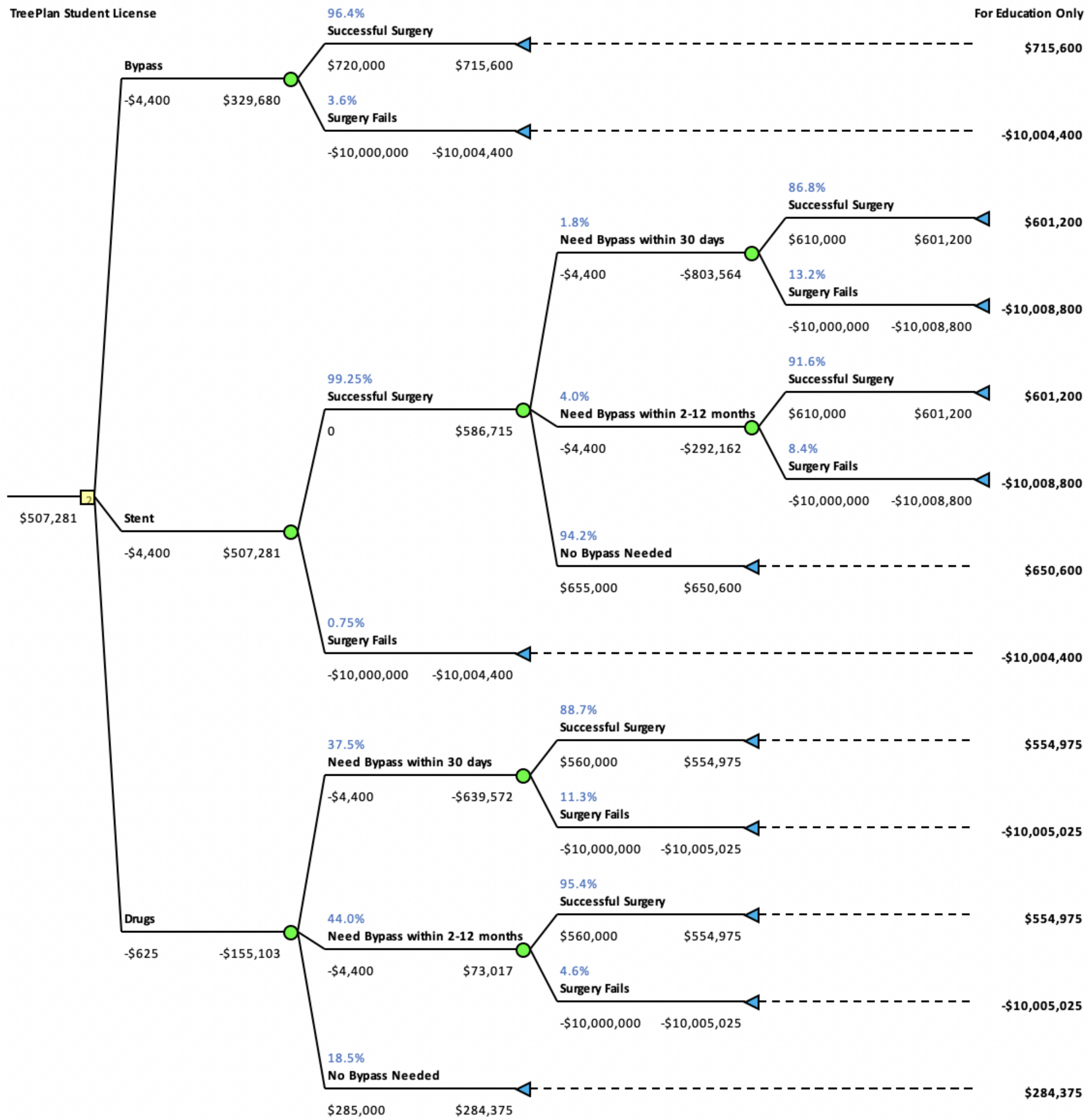

Figure 1: Decision tree for heart attack treatment options.

4 Analysis and Evaluation

4.1 Sensitivity Analysis

For a conclusive recommendation it is imperative to conduct a sensitivity analysis of the values which are influential to the final decision. Two sensitivity analyses were conducted: (1) no bypass needed after stenting and (2) the cost of failed surgery.

4.1.1 No Bypass Needed After Stenting Sensitivity Analysis

After evaluating the decision tree, it is evident that a prominent probability for the final decision of choosing stenting is the need for a bypass within 30 days versus within 2-12 months. As a result, different values for the probability of "No Bypass Needed" after stenting were adjusted to determine the switching point for the final decision to be bypass instead of stenting, shown in Figure 2. A ratio of 1:2 between need bypass within 30 days and need bypass within 2-12 months remained consistent as the value for no bypass needed was varied, all other values remained constant.

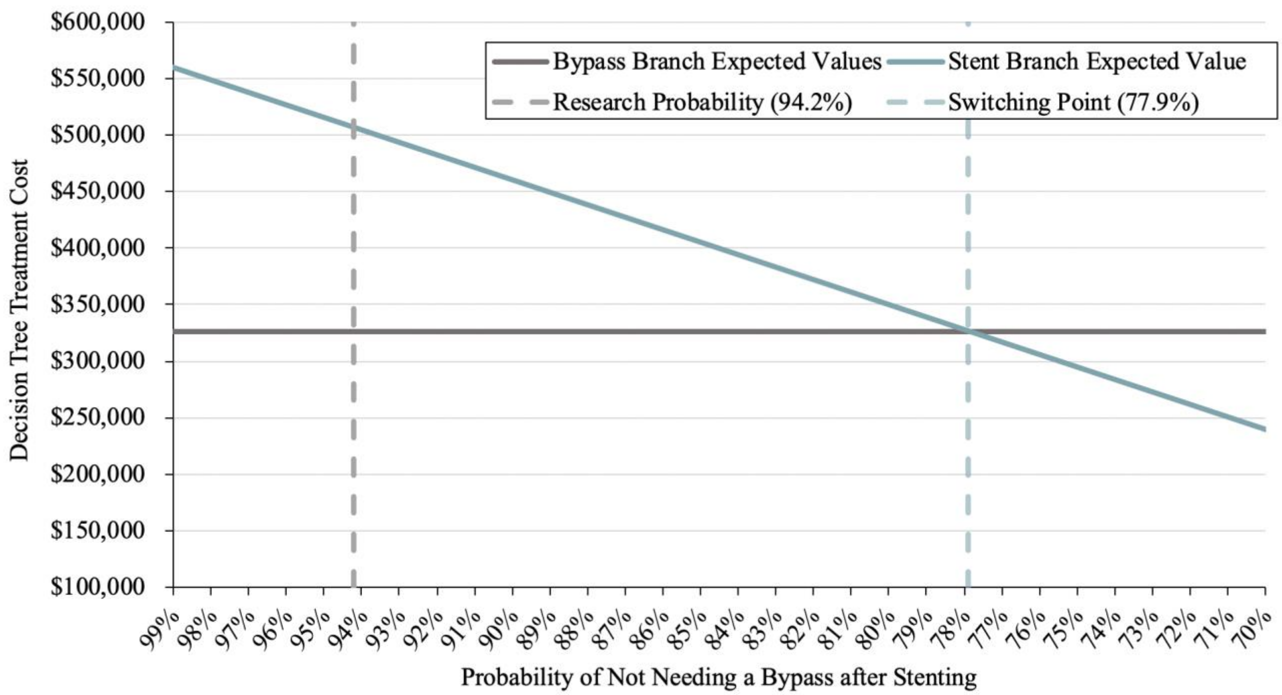

Figure 2: Sensitivity analysis of no need for bypass after stenting, assuming a 1:2 ratio between bypass needed within 30 days and 2-12 months.

As shown in Figure 2, the switching point where the patient should choose a bypass over stenting is when the probability of not needing a bypass after stenting is equal to 77.92%, which means that the probability of needing a bypass within 30 days would be 7.36% and within 2-12 months would be 14.72%.

4.1.2 Failed Surgery Cost Sensitivity Analysis

Another attribute that may affect the final recommendation is the cost of death which is represented as failed surgery in the decision tree. Therefore, the cost of death was varied until a switching point where the patient should choose bypass over stenting was achieved. This analysis is shown in Figure 3.

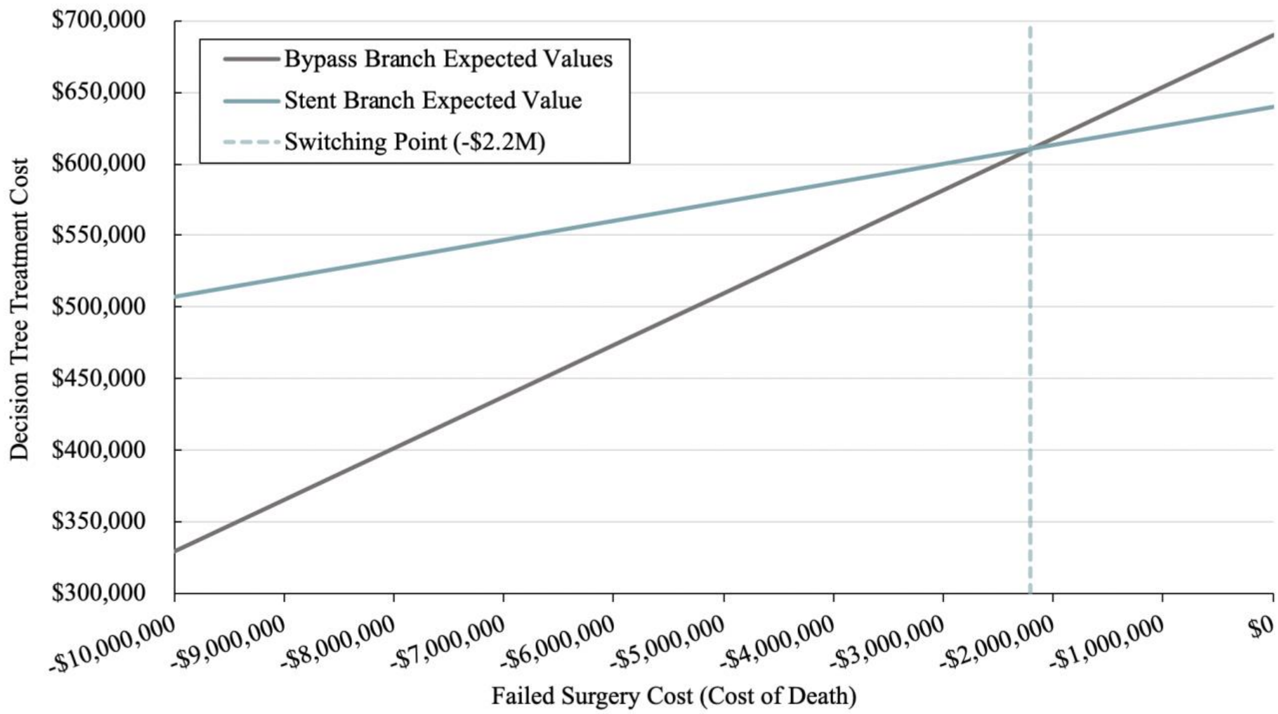

Figure 3: Sensitivity analysis of the cost of a failed surgery, or in other words, the cost of the death of the patient.

As shown in Figure 3, the switching point where the patient should choose bypass instead of stenting is -$2.2 M, which is 22% of the original evaluated cost of death of -$10 M.

5 Conclusion and Recommendation

Based on the outcome of the decision tree in Figure 1, the treatment with the best dollar equivalent life expectancy is stenting at $507,281, as shown in Table 5. The second best treatment based on the estimated dollar equivalency is coronary bypass graft with $329,680. The last option, which should not be chosen given the negative dollar equivalent life expectancy of -$155,103, is pharmaceutical treatment.

Table 5: Final decision tree results for each treatment outcome.

	Decision Tree Results
Coronary Bypass Graft	$329,680
Stenting (PCI)	**$507,281**
Pharmaceutical Treatments	-$155,103

The variance in these concluding values demonstrate that for the described patient, their choice of treatment plan has a meaningful effect on their post-treatment experience of life.

This conclusion was further validated through the sensitivity analyses. As shown in Figure 2, the switching point for the probability of not needing a bypass after stenting where the patient should choose bypass over stenting was 77.9.%, whereas the researched probability was 94.2%. Although the required decrease of this probability by 16.3% is possible, based on the research it is very unlikely. Thus, this analysis again justifies the decision tree outcome that stenting should be the most preferred treatment option for the described patient.

Finally, as shown in Figure 3, the switching point for the patient to choose bypass treatment over stenting based on the cost of death was -$2.2 M. This inflection point represents a low valuation of life that is a relatively improbable reflection of the modeled patient's desire to avoid death at all costs. Therefore, based on the decision tree outcome shown in Table 5 and both sensitivity analyses, it is evident that the preferred recommendation for the patient who has just suffered a heart attack is a percutaneous coronary intervention (stenting).

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