A DECISION MODEL FOR WELL WORKOVER: CASE STUDIES FOR ONSHORE OILFIELD IN THAILAND

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แบบจำลองการตัดสินใจสำหรับการซ่อมบำรุงหลุมผลิต: กรณีศึกษาสำหรับแหล่งน้ำมันบนบกในประเทศไทย

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วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต

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แหล่งปิโตรเลียมบนบกในประเทศไทย ได้รับการพัฒนามาตั้งแต่สามทศวรรษ หลุมผลิตในบางหลุมมีการไหลที่ลดลงตามเวลา งานที่ช่วยในการซ่อมแก้ไขและรักษากำลังการผลิตปิโตรเลียม คืองานซ่อมบำรุงหลุมผลิตซึ่งมีความซับซ้อนของอุปกรณ์การผลิต รวมถึงวิธีการซ่อมหลุม การใช้เทคโนโลยีซ่อมหลุม การวางแผนงานซ่อม ค่าใช้จ่ายด้านการซ่อมหลุม ความไม่แน่นอนและความเสี่ยงจากการเลือกวิธีการซ่อมหลุม ซึ่งส่งผลโดยตรงต่อค่าใช้จ่ายในงานซ่อมบำรุงหลุมผลิต

ดังนั้นเพื่อให้การตัดสินใจอย่างเป็นระบบโดยคำนึงถึงผลจากความไม่แน่นอนของงานซ่อมหลุมผลิต งานวิจัยนี้จึงนำเสนอแบบจำลองการตัดสินใจภายใต้ความเสี่ยงดังกล่าว โดยใช้ข้อมูลทางสถิติจากตัวอย่างของความน่าจะเป็นของข้อมูลในอดีต นำมาสร้างแบบจำลองต้นไม้การตัดสินใจของงานซ่อมบำรุงหลุมผลิตของแหล่งน้ำมันบนบกในประเทศไทยโดยการสร้างต้นไม้การตัดสินใจในรูปแบบแผ่นตาราง และระบุวิธีการได้มาของต้นทุนที่คาดหวังของแต่ทางเลือก รวมถึงความเป็นไปได้ของแต่ละเหตุการณ์ที่ไม่แน่นอนที่อาจเกิดขึ้นของแต่ละทางเลือก

ผลการศึกษาพบว่าแบบจำลองต้นไม้การตัดสินใจ ช่วยให้ได้ผลตัดสินใจที่เป็นระบบจากทางเลือกที่ให้ค่าใช้จ่ายในงานซ่อมบำรุงหลุมผลิตที่ต่ำที่สุด

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Onshore petroleum reserves in Thailand have been developing since last three decades. Some production wells have been declined. Workover is part of well interventions, which are necessary to maintain production. However, the risk and uncertainty of the retrieving existing completion procedure, recovering technology and fishing planning create the complication of well workover operation, which directly affected its cost.

To make the systematic decision concerning the uncertainty of the well workover cost evaluation, this study aims to present a decision model under risk using the probability approach from the operational historical data. In order to construct decision tree models using the spreadsheet from the case studies for onshore well workover operations, in Thailand. In addition, the outcomes of each decision alternatives and their probability assessments are also provided to evaluate the expected cost of the choices.

The findings of the studies are provided the systematic decision approached from the lowest expected cost of workover.

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List of Abbreviations

API	American Petroleum Institute (viscosity unit)
BHP	Bottom hole pressure
°C	Degree Celsius
F or °F	Degree Fahrenheit
psia	Pound per square inch absolute
ppm	Part per million
EMV	Expected monetary value
EV	Expected value
AFE	Authority-for-expenditure
PBR	Polished bore receptacle
ID	Internal diameter
RIH	Run in hole
BHA	Bottom hole assembly
PKR	Packer
M/U	Make up (to tighten the tread of connection)
R/U	Rigging up
R/D	Rigging down
POOH	Pull out of hole
CAPEX	Capital expenditure
PDF	Probability distribution functions
ROR	Rate of return
AFE	Authority-for-expenditure
P/I	Profit to investment ratio
DPI	Profit to investment ratio
OOIP	Original oil in place
SSD	Sliding side door
SPM	Side pocket mandrels
WEG	Wireline entry guide.
ESP	Electrical submersible pump

Nomenclatures

P_i	probability of outcome, I (fraction unit)
i	value of outcome, I (currency unit)
SP	straight pulling
C1	to cut one cutting above packer or seal
C2	to cut two cutting above packer or seal
C3	to cut three cutting above packer or seal
C4	to cut four cutting above packer or seal
Model 1A	one retrievable packer - PHL/HS packer type
Model 1B	one retrievable packer - RH/FH packer type
Model 2A	two retrievable packers - PHL/HS packer type
Model 2B	two Retrievable packers - RH/FH packer type
Model 3A	three retrievable packers - PHL/HS packer type
Model 3B	three retrievable packers - RH/FH packer type
Model 3C	two retrievable packers - RH packer type and one permanent packer
Model 4A	four Retrievable packers - PHL/HS packer type
Model 4B	three Retrievable packers-RH/FH packer types and one permanent packer
Model 5	electrical submersible pump (ESP) completion
Model 6	rod pumping completion

CHAPTER I

INTRODUCTION

1.1General

Today, oil and gas industry is complex. Accounting for the world's trend petroleum price is increasing. A low point was reached in 1999, then increasing rapidly, in 2000 to $35, after that it decreased until the end of 2001. It was slightly uptrend increasing as World's demand from 2004 till present [1]. Simultaneously, most of companies have been increasing their capability to supply petroleum product to world markets.

From the increasing of demand and supply, many brown fields have been being encountered the depleted pressure. However, they need to maintain the well for consistent flowing. Workover operation refers to the remedial operations which performed on the well to improve flowing efficiency, to maintain, to repair or to reinstall production casing, tubing and finally, to improve overall productivity that need for maintain production wells.

Commonly, workover operations include replacing damaged tubing, recompleting to zone, recompleting with water shut off, completing well with water shut off by cement techniques, cleaning sand in case hole, acidizing near-wellbore damage, plugging and abandoning a zone. Generally, one workover job is consisted of several sequential activities. Hence the probability of success in one workover job depends on many factors such as the well conditions, the type of its activities.

For onshore well workover operations, in Thailand, since, most wells have been being produced for long period. Reservoir pressure has been depleted in some concession area, so the workover operations are necessary to maintain production. Generally, most of asset and management team evaluate workover economic by using only conventional deterministic method such as net present value (NPV), profitability index (P/I) and internal rate of return (IRR) which is suitable for estimation of capital investment, production rates, and expenditures. In the case of, the economic evaluation is passed, and then the well will be passed through operation team to execute without taking account of the uncertainties. In addition, after starting operation, the problems have been encountered; it has not been studying probabilistic to do operation successfully within the budget as illustrated flowchart in Figure 1.1.

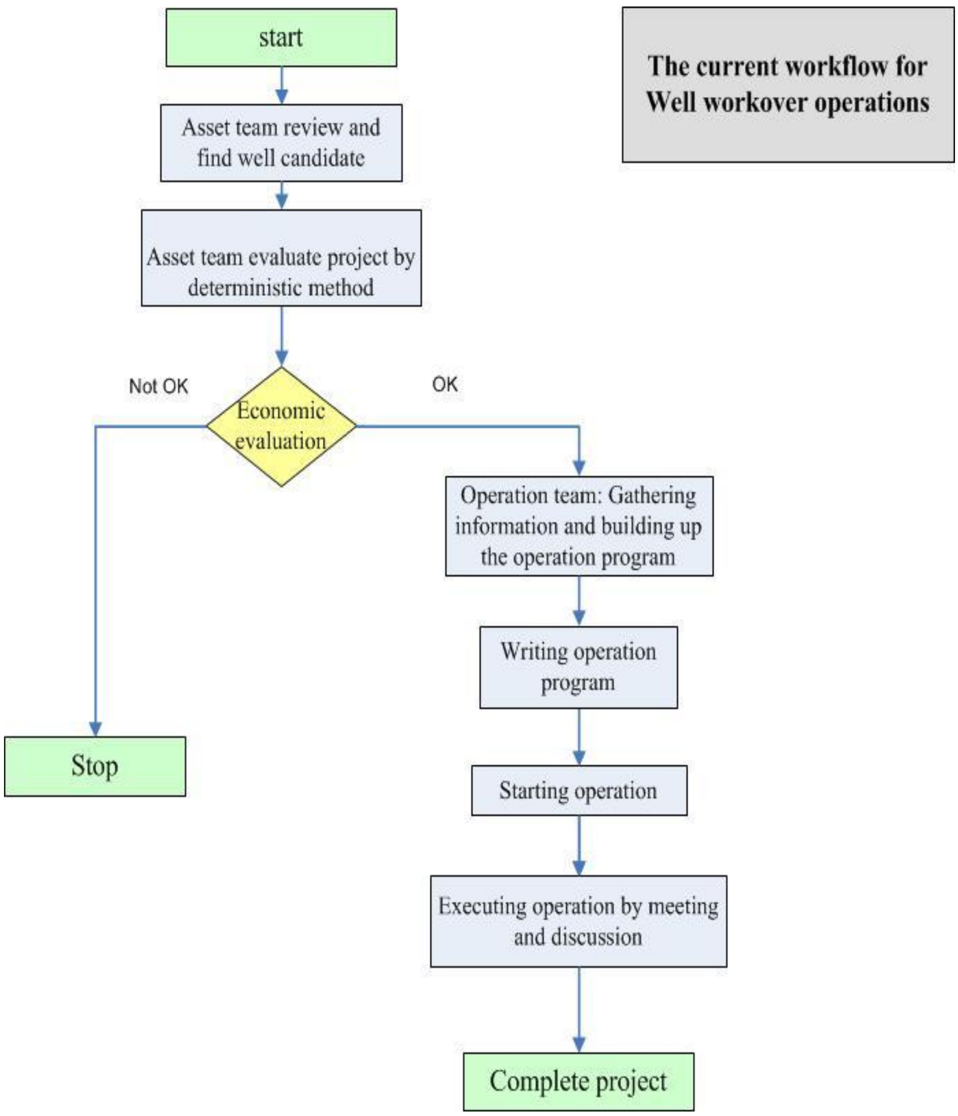

Figure 1.1 The current workflow for executing workover operations.

Since workover operations involve the risk and uncertainty circumstance. The operations were being identified with huge scenario. So, the frequency and probability should be used in the part of executing job to success both technical and economic.

Hence, the probability-weighted average (expected value) is become too important for decision making process and it would help to provide optimum decision.

To seek the probabilistic tool for helping workover project, one of probabilistic tools is decision tree which can accommodate more complexly scenarios than spread sheet calculation table (payoff table). Decision trees are more flexible than the other tool for allowing decision makers update the problems in real time situation. It also can be extended current scenarios to future scenarios, while the payoff table is suitable for simple decision models.

Hence, the objective of this study is to develop and to approach the probabilistic decisions supported by using the decisions tree analysis technique in the workover evaluation. This methodology can assist engineers in their decision making process. It will help evaluate risk, select and provide the lowest expected cost for onshore well workover operations, in Thailand. Decision makers can use this model to predict budget from any circumstance, contingency plan, probabilities which obtain from the pure deterministic model.

Moreover, this methodology can help operation management during job planning and job execution in day to day operation and evaluation phase. It can be seen in Figure 1.2.

From Figure 1.2, the orange shaded blocks are the proposed step of study, composed of the construction of decision tree, evaluation of expected cost and checking constraint such as equipment used is not available on time or exceeds budget , so it would be required evaluating again. In case of the equipment is available, the operational program can be written from selected decision alternative. When operation start up, the result of decision shall be evaluated again compare with selected decision alternative. This result shall be updated and combined with existing data base in order to provide accurate probability for the future circumstance.

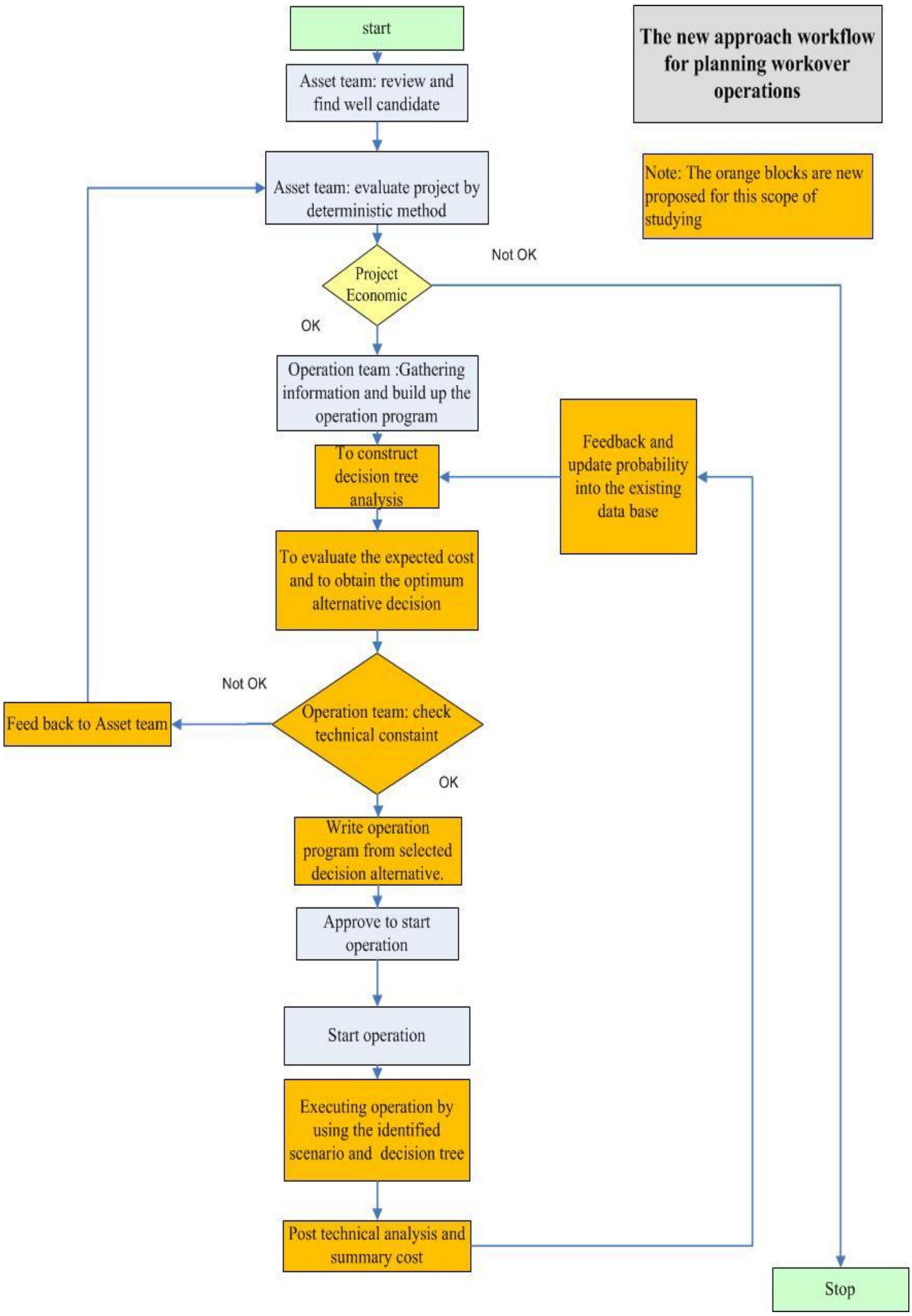

Figure 1.2 The new approach workflow for executing workover operations

1.2 Objectives of thesis

The main objectives of this studying are;

1. To propose a decision model base on probabilistic approach for onshore oilfield well workover operations, in Thailand.
2. To construct case studies by using decision tree models for onshore well workover operations, in Thailand.

1.3 Outline of methodology

This paper aims to study probabilistic model for onshore workover. The thesis uses decision tree analysis model to explain the probabilities or operation success and convert to investing value. Engineers can use this diagram to predict budget from any circumstance, contingency plan, probabilities and expected value which compare with their deterministic model. This evaluation can help to optimizing workover cost more realistically than pure deterministic method and within authority-for-expenditure (AFE).

In addition, when operations start up, engineers can use this decision tree analysis to tracking operations and updating any new circumstances. Moreover, when operations obstruct or deviate from identified planning, they can predict additional operation time and expected cost to make decision whether project should continue or stop.

Finally, the developments of decision tree analysis can make benefit to engineers to apply for any future workover operation projects or the other petroleum projects. The step as described above can be classified as below;

1. To review realistic state of problem.
2. To identify and review state of problem.
3. To review several involved papers, researches for the purpose that creating solution and method of the study.
4. To gather and verify all required data for decision model. It is consisted of three major steps as following.

4.1 Structuring phase. It needs to define and understand the problem components and develop alternatives decision. The outline of root causes is addressed.

- To identify opportunities
- To define the problem
- To identify alternatives

4.2 Modeling and evaluation phase. It needs to identify chance events, sequences, outcomes, probability of chance events and then developing a decision tree model. Finally, the expected cost is calculated.

- To develop decision model
- To quantify uncertainty
- To develop valuation model
- To calculative outcomes
- To recalculate

4.3 Executing phase. After evaluation, it may need to variance analysis by decision makers.

- Implement
- Post-analysis

5. To summarize the optimum production strategy compares results from each model, then inputting the obtained result to the database.

1.4 Thesis outline

The thesis comprises of outline as the following:

Chapter II of the thesis is literature review of the study. It summarizes all of previous related research works, traditional decision analysis tools. The previous methods are described.

Chapter III describes decision analysis process and relevant theories. The details and technical for obtaining outcomes and probability of case studies are illustrated.

Chapter IV describes results of decision in each well model which uses decision tree to provide the best alternatives.

Chapter V summarizes and concludes the decision in each model, including recommendation for further study.

CHAPTER II

LITERATURE REVIEW

This chapter discusses some related works on risk analysis and workover operations.

2.1 Decision Analysis

In the past, there are several papers described and proposed decision model and risk analysis in petroleum projects and there are also many papers introduced model for workover, nevertheless they have not been proposing the probabilistic model for onshore workover, in Thailand. Therefore, this paper would implement the risk analysis for workover operations and develop a model to help decision maker in their decision process.

The early study of simple economic was performed by Jame L.Rike [2], "Workover Economics-Complete but simple" in 1972. He proposed by using a series of tables consist of profit to investment (P/I) ratio and rate of return (ROR). His method used the risk in term of time value of money and production life cycle and investment requirements for workover.

Michael L et al. [3] implemented PC's and Monte Carlo Simulation to evaluation risk in workover in 1994. They proposed four variables (production, product prices, operating costs and workover costs) to taking in account of uncertain. The model used for calculation net present value (NPV), profit/investment ratio (DPI) and rate of return (ROR), then giving authority for expenditure (AFE) in the final.

R.M.Patteson and S.F. Grittner [4] proposed 5 steps for decision making which consisted of preparation of a decision statement, identification of objectives for decision, definition of alternatives, and definition of consequence for each alternatives and evaluation of alternatives. They used the tree software to calculate. An important idea is the project need working team to support decision.

J.R.Gilman et al. [5] demonstrated, in year 1994, how Monte Carlo simulation use to estimate production profile distribution, then calculating the economic value by using parameters such as economic oil rate, downtime, initial oil rate, decline factor, initial gas oil ratio, average gas oil ratio, hyperbolic constant, well life, well failure probability, workover reserve, workover average gas oil ratio, workover incremental rate, recomplete expense and workover failure probability. They used normal distribution for downtime model and used failure probability varied from 25%-75% which depending on failure types while J.C.S Cunha [6] proposed in the same year, a decision-making method based on previous field operation that provided accurate decision for daily basis. He stated an important conclusion that the probability density function for each particular case should be updated when got the new operation.

Alexander and Lohr [7] proposed in year 1998, regarding, good risk analysis process which always supported by well-prepared guidelines, evaluation software, good clearly of dependency between variables and result. They also proposed seven important elements for a successful risk analysis project. They provided suggestion that even though risk analysis cannot replace professional judgment, but it can improve the evaluation and help to reach the right decision.

Lev Virine and Lisa Rapley [8] proposed a practical how to use risk analysis toolsets including proper selection criteria in economic evaluation applications for the oil and gas industry. They illustrated how sensitivity analysis and Monte Carlo simulation tools can be used and described the integration of decision and risk analysis tools with economic engineering application.

Derrick Lewis et al. [9] developed a financial cost analysis in spreadsheet including new present value in order to make simple for management team in 2004.

Cunha, J. C et al. [10] continually proposed in 2005, quantitative risk analysis for uncertainty quantification on drilling operations. They presented the distribution of possible costs for the well and used Monte Carlo simulation to determine a distribution for expected well cost. They described important of decision method with risk analysis that required reliable database and careful analysis of possible outcomes.

D.O. Agiddi [11] approached a decision analysis for hydraulic fracture optimization in the W31S Stevens oil zone, Elk Hills field, California in year 2005. He introduced a quantitative fracturing treatment option model as a useful tool for selecting the treatment with the best chance of economic success. He constructed the decision tree by placing variable required for treatment. He suggested that the chance of success can be improved with real time diagnostic data that would give cost saving or saving designed achieve the target.

J.W.V. Prada et al. [12] proposed uncertainty assessment using experimental design and risk analysis techniques, which applied for offshore heavy oil recovery. They explained probabilistic analysis has an advantage than deterministic analysis. Their proposal used experimental designed techniques to determine the parameters which significant contribute to net present value (NPV) of the prospect, and then an uncertainty analysis was calculated. They constructed the decision tree to map all possible outcomes, and then give the expected monetary value (EMV).

Cunha J. C [13] continually approached in year 2007, regarding, risk analysis and application in petroleum. He gave many examples to use risk analysis application such as stem assisted gravity drainage (SAGD) with simple result. He defined a cumulative distribution of cost should determine from associate percentile-P10, percentile-P50 and percentile-P90 in the well cost estimation. In final, he encouraged decision maker to use risk that would help decision maker understand in their analysis.

Eliana L et al. [14] presented the comparison of the performance of different risk analysis; they gave example of studying such as to use Monte Carlo simulation for offshore petroleum deep reservoirs. In final, they concluded that Monte Carlo and derivative tree techniques can be used similar performance.

Mohammad Akbari et al. [15] proposed the model to generate AFE estimate with risk take into account, their model utilized risk analysis incorporate with Mote Carlo simulation to simulate seven parameters which consist of well depth, free rig time, rig repair time, fishing time, sidetrack time, washout time and waiting time. They kept moving time in constant at 7 days. In conclusion, model was completed by using a commercial spreadsheet, simulation was run 1,000 iterations.

D. Arcos et al. [16] developed a methodology in year 2008, to help decision process for a multilateral well. They presented the process consists of technical, economic and risk analysis with various alternatives in each well completion types. Finally, they proposed a deterministic decision tree to represent in geological uncertainty, drilling, reservoir model and including production. Net present value (NPV) was simple generated from base economic spreadsheet while expected monetary value (EMV) was calculated from decision tree. Later on in year 2011, C.Repetto et al. [17] presented their new approach which take into account both risk and necessary opportunity in order to choose the most appropriate solution. The different scenarios were introduced and compared with technologies for challenging multilateral deep water wells. They divided their risk model into two parts which are deterministic analysis and probabilistic model. The deterministic model presented four operational scenarios. They considered reservoir, well design, production and economics in the parameter of deterministic case.

J. H. Schulze et al. [18] proposed to improve decision quality by integrated between Monte Carlo simulation and decision tree analysis. The decision tree was proposed to provide a visually clear number while Monte Carlo simulation used to simulate a large number of uncertainties such as original oil in place (OOIP).

2.2 Economics and risk analysis for fishing operation

Uncertainty is one of significant with petroleum engineering processes. To construct decision analysis is the way to improve the decision maker in order to visualize the possible actions that can be happen in face of a problem. By this practice, the decision maker can be able to quantify the consequences of each of the possible outcomes including many procedures, methods, and tools for identifying, clearly representing, and formally assessing the important aspects of a project. Cunha J. C [13].

In 1982, Harrison [23] introduced concept to economic fishing time which consider the costs and probability of success as following;

Expected cost of fishing= Daily cost of fishing. Time in days+ (1-p).Total cost to abandon the fish and sidetrack well

Then, Cunha [6] approached the economic fishing time (days) that successful will have cost the same that an operation to abandon fish and sidetrack well,

$$\text{economic fishing time (days)} = \frac{\text{Total cost to abandon the fish and sidetrack well}}{\text{Daily cost of fishing}}$$

He also approached the decision point when operation is ongoing whether operator will decide to continue operations or not. He proposed the total cost to abandon the fish and sidetrack well is equaled to expected cost of fishing as below equation and picture flow chart;

Total cost to abandon the fish and sidetrack well = Daily cost of fishing. Time in days+ (1-p).Total cost to abandon the fish and sidetrack well

In case of operation got interrupted, His method also can be applied day to day operation. In conclusion, He gave comments that an auxiliary tool in decision making process can be used but it also depends on the previous experience of operator also.

In recent years later, there are many papers which are studied uncertainty in the majority of oil industry projects, such as petroleum engineering processes, reserve quantification, reservoir characterization, recovery factor, an expected production, operational schedule, project's timetable, budget estimation, corrosion assessment for pipeline integrity. In case of, there are uncertainties involved, so we should rely in the results that will consequently carry some degree of uncertainty. The fact is very common to see resistance towards risk analysis applications. Many oil and gas operators prefer to apply with one deterministic result, even if it is wrong, more than probabilistic result. Another reason that causes many to be skeptical with risk analysis applications is the somewhat unjustified belief that such applications are complicated and very difficult implementation.

However, after studying all relevant papers regarding economic and risk evaluation, it impact to financial result, so, it strongly recommend applying probabilistic model approach in decision making process.

Decision tree analysis is especially suitable for everyday circumstance that needs to make decision at those times John Schuyle [19]. Decision tree can be applied for more complicated problems. The example of some advantages are such as it can make enable for decision maker to clear thinking, and also it has ability to break the complex decision problem into series of each element. Once the prior part is solved, then it can reassembly to complex. In case of a detailed in tree ready, it can be implement at any node or in case of, conditions change, the remaining alternatives can be revised strategy. It was proposed by Mian M.A [20]. In the application for drilling and well construction, decision tree is used for decision making to repair the well, abandonment the well or drilling a new well as existing wellbore has uncertainties to maintain production. It was proposed by P. D. Pattillo [21].

From example of papers above, they have not been proposing the probabilistic model for onshore workover, in Thailand by using historical to build probability of outcome. Therefore, this paper intends to develop a methodology to help decision maker in their decision process by studying technical, economic and risk analysis of onshore well workover, in Thailand. The decision tree will be used to provide lowest investment and cost analysis. The existing probability information is used to find probability of each outcome in each models, finally the result is showed in spreadsheet and provides lowest practical expected cost for decision makers or engineers.

CHAPTER III

METHODOLOGY

This chapter presents the methodology. To efficiently construct a decision tree model for onshore well workover, first of all, it needs to study all existing well completion types, then classifying the well into major types. Each well model illustrates recovering methods and presents with its cost. Several alternatives can be identified and selected in order to seek lowest practical investment cost. Moreover, risk or uncertainty is also introduced in the chapter.

To properly study, analyze and evaluate a project, it is imperative to study the technical features first, then following by the economic and risk analysis. Prior to find lowest expected cost, the alternative of retrieving each completion types is needed to identify and then, evaluating the expected costs which are obtained from outcomes and its probability.

The existing field data is included in this study, so there are only some assumptions such as rig cost, fishing tool rental cost were made in order to help illustrating of the evaluation of workover operations cost. However, in case there are new technologies or new associated costs, the cost model can be updated by decision maker.

In the analysis part, this paper presents summary of decision alternative in each models which can assist decision makers or engineers in decision their making process by using illustrated models to evaluate whether a retrieving method for workover well is the most efficient alternative to be chosen for a project or not. All details of methodology can be described into three parts: general overview for well completion, categorized of well completion configuration, and concept of decision analysis.

3.1 General overview for well completion

After the production casing is installed and pressure test against casing shoe has done. The final stage of well construction is to complete a well with production tubing string. The hydrocarbon production is drained from reservoir to surface production facilities via completion string. Typical the well completion is consisted of includes such as installing a system of tubular, packers, and other accessory tools. Normally, reservoir engineer will propose the completion schematic as they obtain from logging result and map with sub surface reservoir model. To use of any types of completion depends on the characteristics and location of the hydrocarbon formation to be mined. The suitable artificial lift method is considered, so this completion tubing design may also be consisted of with rod pumping systems, gas lift system, electrical submersible pumping, as for more efficient extraction reservoir to surface, however it may consider covering on the characteristics of the intake portion of the well in the targeted hydrocarbon formation, for example open hole completion, conventional perforated completion, sand control completion, permanent completion or multiple zone completion.

In order to maximize well producing, the selection type of completions are become too challenge for oil and gas company. The basic requirement, such as practical to install, to select the right equipment, to create minimum pressure loss due to restriction diameter, to ensure comply with well integrity, to has effective flow control device and to allow make workover easier, need to consider .Typical well completion components in completion string are production packer, sliding sleeve, side pocket mandrel, landing nipple and subsurface safety valve as following details below;

a. Production packers

Production packers are used to separate of each produced zones, subsurface safety control and casing protections. The main components of packer are consisted of steel slips to grip internal of casing which is pushed by a cone ramp. There is seal which provide isolation between above and below zone of a packer.

In this paper, it divided into two basic types of production packers which classified by the method of retrievable as described in Figure 3.1.

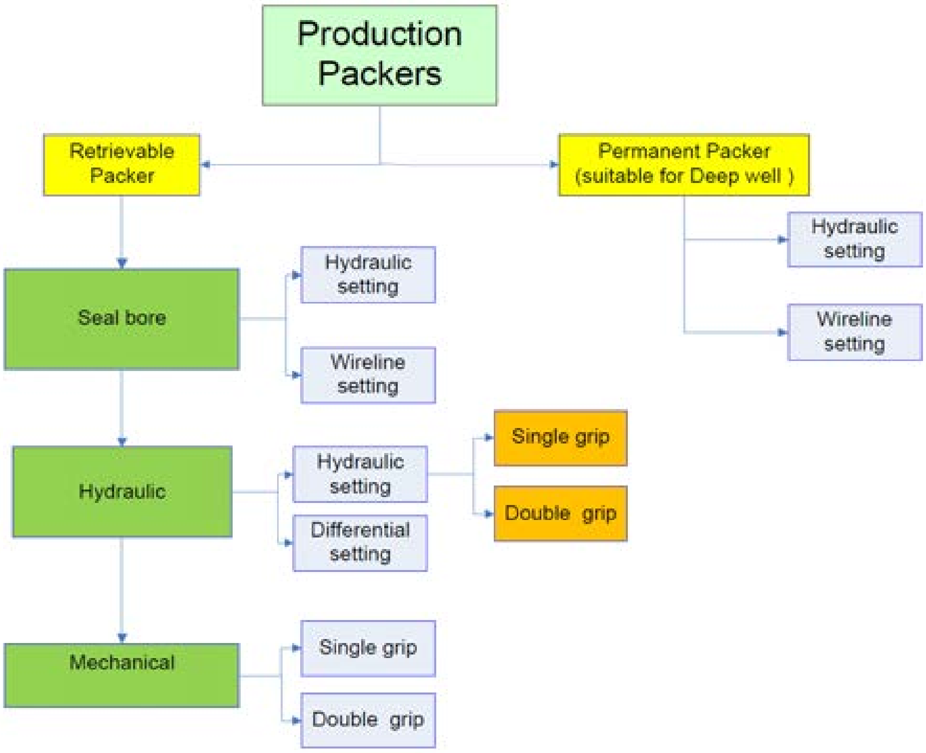

Figure 3.1 Typical of packer type [24]

<u>Hydraulic set retrievable packer</u>

The retrievable packers are installed in the part of completion string. Typically, the setting of hydraulic-set packer requires fluid pressure which is translated to a piston force inside the packer to shear setting pin and set slips. When the packer is set, it remains slips by using mechanical lock to grip internal of casing. For retrieving procedure, most of hydraulic set packers are released by straight pulling. The PHL/HS retrievable packer model is illustrated in Figure 3.2. However there are some types require rotation of string and some types has double grip with “hold down button” that required pumping to activate “hold down button” before retrieving such as RH/FH type. The RH/FH retrievable packer model is illustrated in Figure 3.3.

In table 3.1, it shows comparing between retrievable packer PHL/HS packer type and RH/FH packer type”.

Table 3.1 Summary for comparing between retrievable packer PHL/HS packer type and RH/FH packer type”

Item	**Major technical point**	**PHL/HS Packer type**	**RH/FH Packer type**
1	Slip	Double slips **without** hydraulic “hold down buttons” for differential pressure below packer. (Slips above and below the elements)	Double slips **with** or with hydraulic “hold down buttons” for differential pressure below packer. (Slips above and below the elements)
2	Special locking	Use only top and bottom slips	The button slips use tungsten carbide teeth to ensure good casing bite.
3	Compression/tension environment	Can be landed in tension, compression or neutral	Can be landed in tension, compression or neutral
4	Element pack off system	Triple element pack off system	Triple element pack off system
5	Pressure rating	Available up to 10,000 psi	Available up to 10,000 psi
6	Retrieving method	By upward pulling above shear values	By upward pulling above shear values
7	Price	Awarded price as lowest bidders	Awarded price as lowest bidders

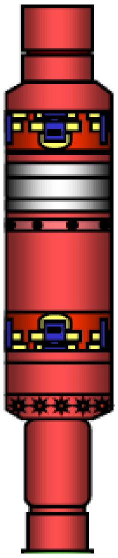

Figure 3.2 Typical hydraulic set retrievable packer without hold down buttons which represent PHL/HS type

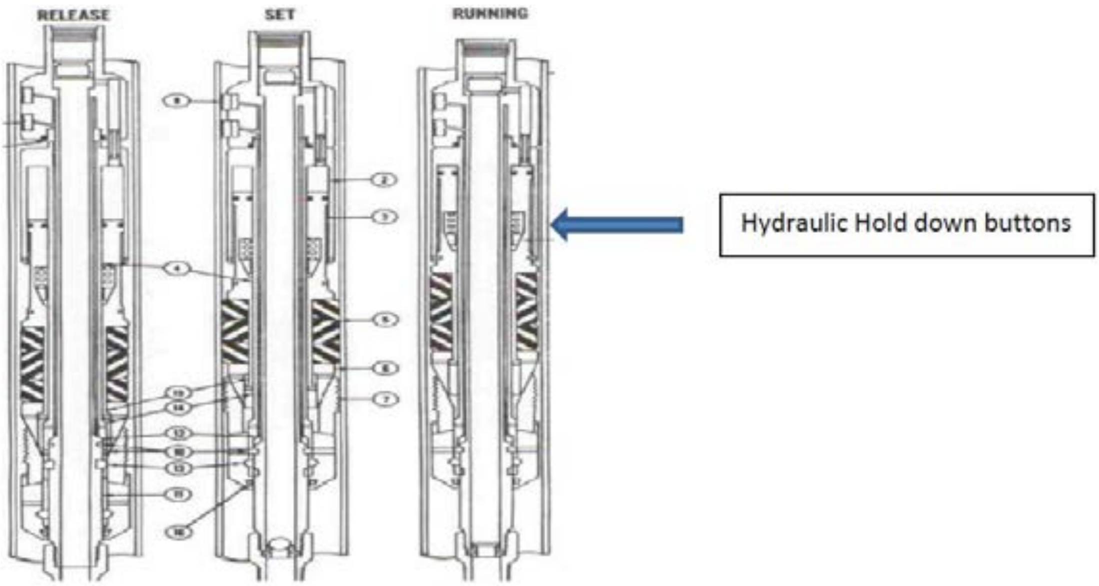

Figure 3.3 Typical hydraulic set retrievable packer-RH type

<u>Permanent Packer</u>

It can be run and set on deployment carrier such as electrical line, drill string. Opposed slips are positioned above and below the packing element. After setting, packer will hold on compression and lock movement position. Typically, one set of permanent packer assembly is consisted of permanent packer, mill out extension, perforated pup joint, landing nipple and wireline entry guide. Figure 3.4 shows typical of permanent packer and Figure 3.5 shows one set of permanent packer assembly in the well bore. The typical setting and retrieving method are explained following;

- Setting, by electrical line setting. The packer is made up with adapter kit and pressure setting assembly via on electrical line. Once, the packer is on position, an electrical current ignites a powder charge within the setting tool. After that, gas pressure transmits a setting force to the packer and shearing a release stud frees the setting assembly from packer. Finally, the electrical line is freed and then, it can be moved to surface.
- Setting, by drill string setting, it can be set by hydraulically with upward pull assist or by combination of sequential rotation and upward pulling.
- Retrieving, typically the permanent packer cannot be released; it is required drilling or milling out.

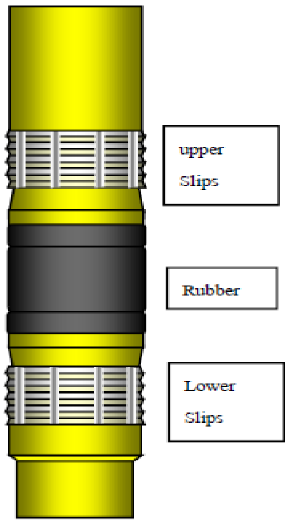

Figure 3.4 Typical permanent packer

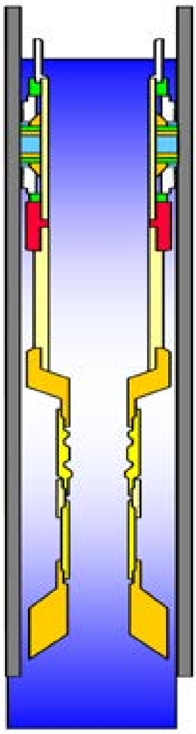

Figure 3.5 One set of permanent packer assembly in the well

b. Sliding sleeve

It provides communication between the tubing and annulus. Normally, it uses for to control flowing from reservoir zones or to regulate pressure between zones. In multiple zone wells, it can be used to select the zones that need produced.

c. Side pocket mandrel

The side pocket mandrels are designed for artificial lift such as gas lift, nitrogen lift. It is equipped with a dummy during running new completion phase and it is replaced to gas lift valve 1” or 1½" diameter when the well need artificial lift .

d. Landing nipples

Landing nipples are one type of flow-control devices which allow installing wireline tool to control the well such as plugs and chokes. During to complete the well, commonly the string needs to install plug at landing nipples in order to do pressure testing. Typically, it can be categorized into three commonly types: no-go nipples, selective-landing nipples and ported or safety-valve nipples.

e. Subsurface safety valve

The function of subsurface safety valve is to protect uncontrolled release of hydrocarbons from the well. Physically, it is a cylindrical valve with either ball closing mechanism type or flapper closing mechanism type.

Typically, it is installed in the production tubing string. The function is "failure to close" mechanism or in another word, normally, it is kept in the open position that required high-pressure from surface contain unit to overcome spring force. The valve will close in case of there is high pressure in line is cut or the wellhead or tree is accidently destroyed.

3.2 Categorized of well completion configuration

The existing well models have many types, after study, it would be categorized into six main configurations or classified into 11 types. It can be seen in Figure 3.6.

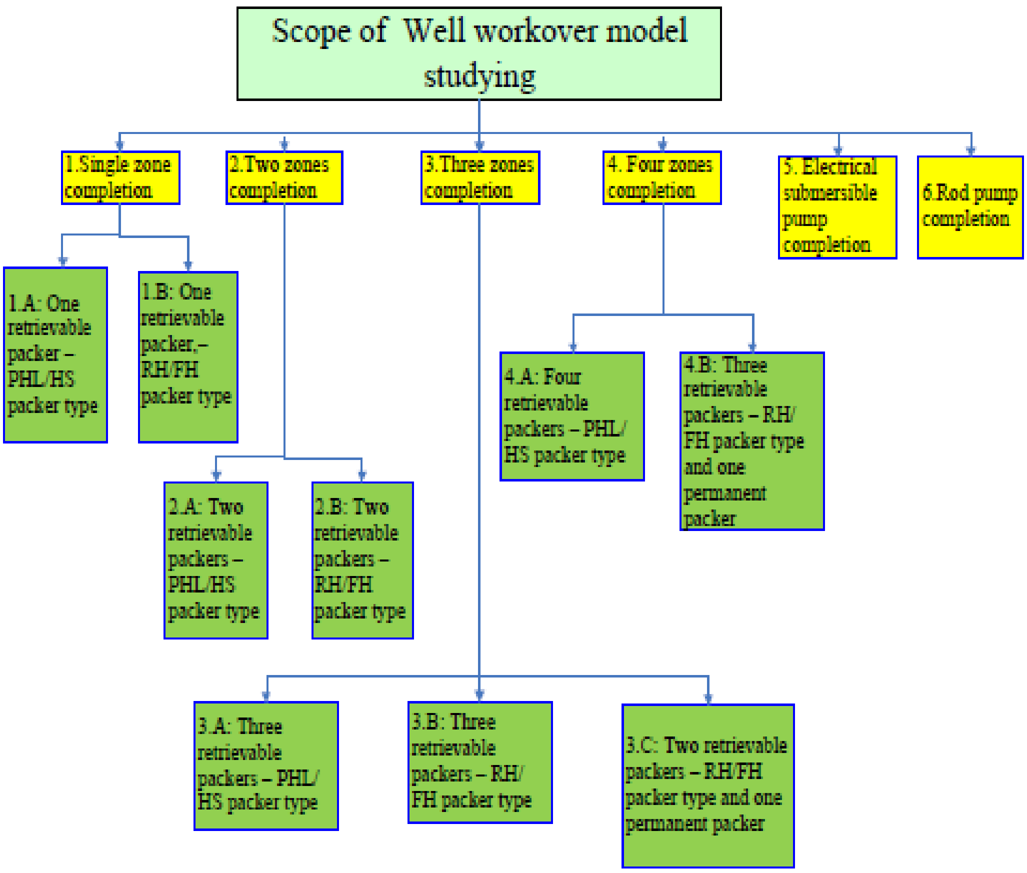

Figure 3.6 Scope of studying well wokover model

3.2.1Single zone completion

In this type, the well is designed to flow from one zone that it is very commonly for onshore oilfield, in Thailand. A packer is installed to protect casing, one landing nipple is installed for flow control device installation. Artificial gas lift is fed into tubing through gas lift valve installed in mandrel, then, hydrostatic head is lowered and the, this gas will be assisted hydrocarbon flowing to surface. Figure 3.7 illustrates single string, single zone completion schematic (one retrievable packer). Single zone can be classified into two minor types which separated by the type of packers as following details.

- Model 1A: one retrievable packer - PHL/HS packer type
- Model 1B: one retrievable packer - RH/FH packer type

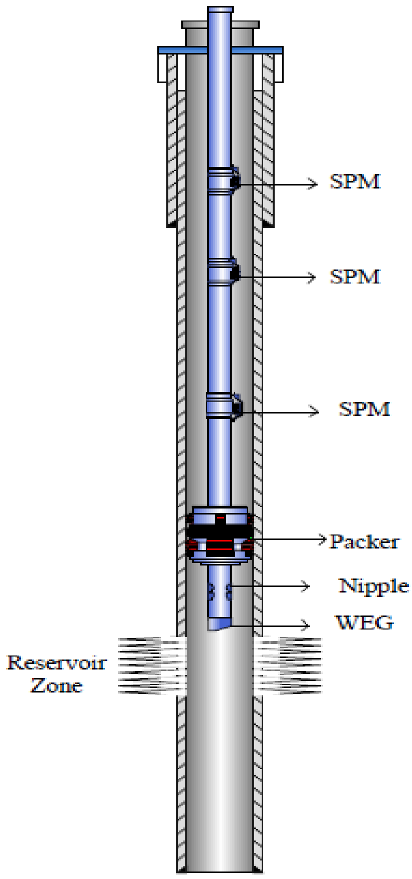

Figure 3.7 Single string, single zone completion

3.2.2 Two zones completion

In case of, reservoir has two zones. It requires more equipment such as packer to separate each zone. The well is designed to flow with artificial gas lift through gas lift valve which installed in side pocket mandrels. One sliding sleeve is designed to install in order to allow hydrocarbon flowing into completion string. Figure 3.8 shows single string, two zones completion schematic (two retrievable packers). Two zones can be classified into two minor types which separated by the type of packers as following details.

- Model 2A: two retrievable packers - PHL/HS packer type
- Model 2B: two Retrievable packers - RH/FH packer type

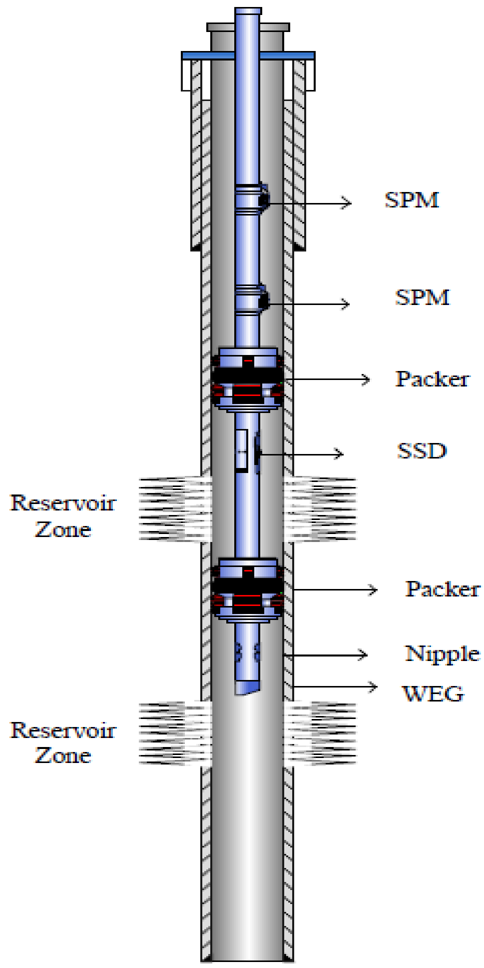

Figure 3.8 Single string, two zones completion (two retrievable packers)

3.2.3 Three zones completion

In case of, the reservoir can be classified into three zones. So, it requires packer to separate in each reservoir. Three packers are designed to separate each zones. Two sliding sleeves are designed to install between each isolation zone in order to allow hydrocarbon flow into completion string. The well is also designed to flow with gas lift through gas lift valve which installed in mandrel. Figure 3.9 illustrates single string, three zones completion schematic (three retrievable packers). In case of, the wells have high pressure differential between above and below zone, permanent packer is suitable to install in these wells. The schematic illustrated single string, three zones completion schematic (two retrievable packers and one permanent packer) as Figure 3.10. In conclusion, three zone models can be classified into three minor types which separated by the type of packers as following details.

- Model 3A: three retrievable packers - PHL/HS packer type
- Model 3B: three retrievable packers - RH/FH packer type
- Model 3C: two retrievable packers - RH packer type and one permanent packer

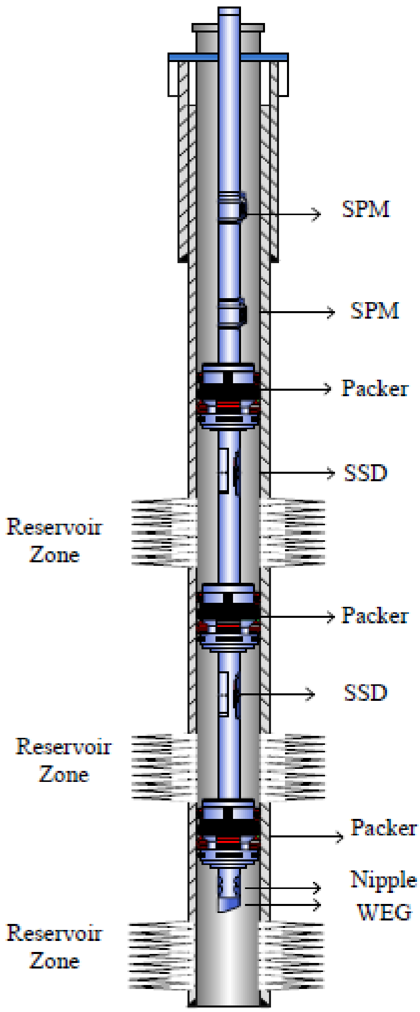

Figure 3.9 Single string, three zones completion (three retrievable packers)

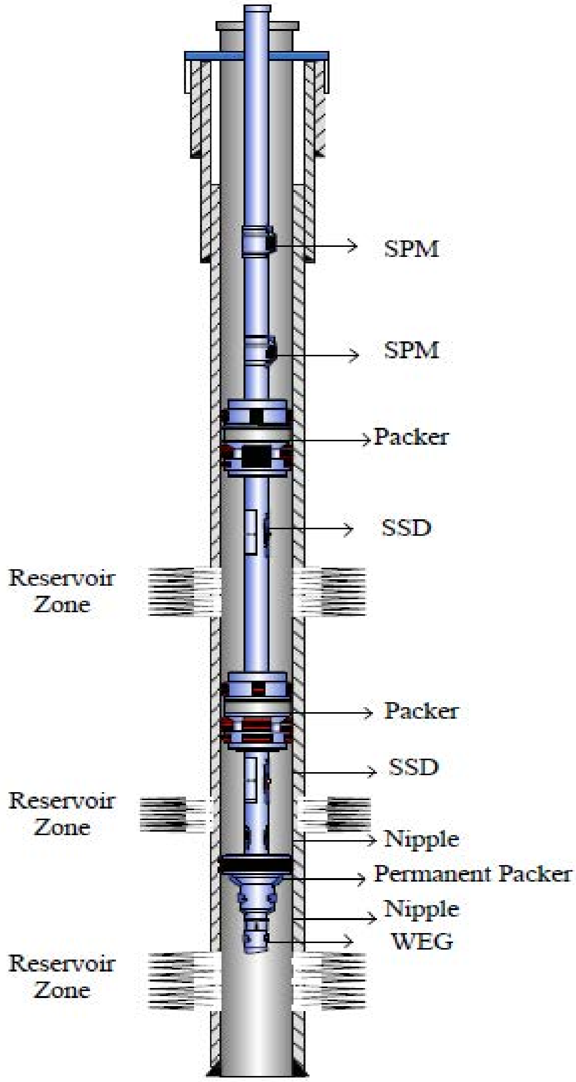

Figure 3.10 Single string, three zones completion (two retrievable packers and one permanent packer)

3.2.4Four zones completion

Four packers are designed to separate each zones. Three sliding sleeves are designed to install between each isolation zone in order to allow hydrocarbon flow into completion string. The well is also designed to flow with gas lift through gas lift valve which installed in mandrel.

Figure 3.11 illustrates single string, four zones completion schematic (four retrievable packers). In case of, there are wells which have high pressure differential between above and below zone, permanent packer is suitable to install in these wells. It can be found in early stage of field development which reservoir has high pressure and multi zones. The schematic illustrated single string, four zones completion schematic (three retrievable packers and one permanent packer) as Figure 3.12. In conclusion, four zone models can be classified into two minor types as following below;

- Model 4A: four Retrievable packers - PHL/HS packer type
- Model 4B: three Retrievable packers-RH/FH packer types and one permanent packer.

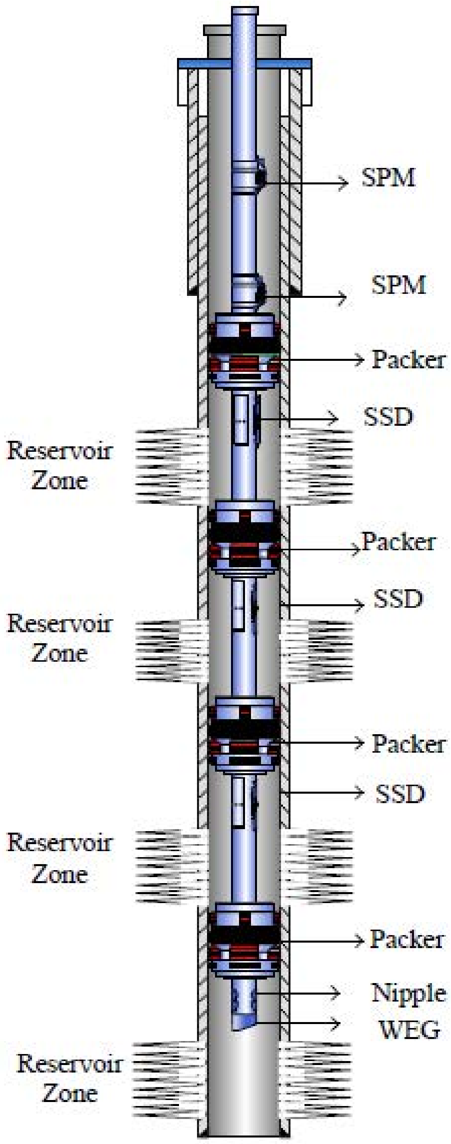

Figure 3.11 Single string, four zones completion (four retrievable packers)

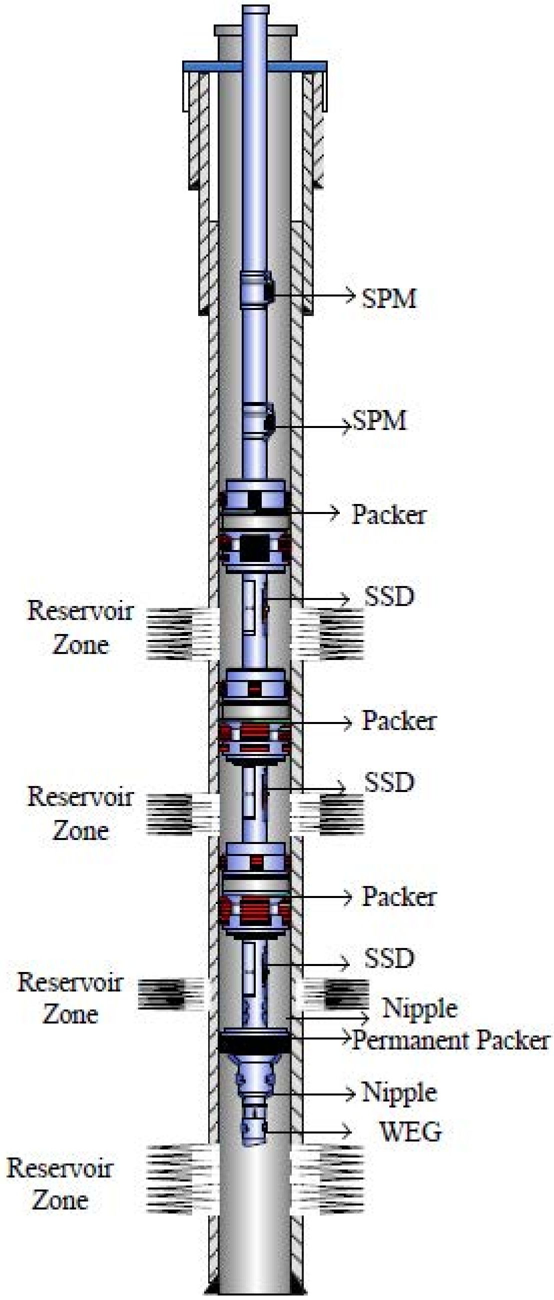

Figure 3.12 Single string, four zones completion (three retrievable packers and one permanent packer)

3.2.5 Electrical submersible pump (ESP) completion

In case of production well has declined, one of artificial lift type is electrical submersible pump (ESP) completion which assist to maximize production. Typical of ESP completion consists of pump assembly, sliding side door (SSD) as illustrated in Figure 3.13.

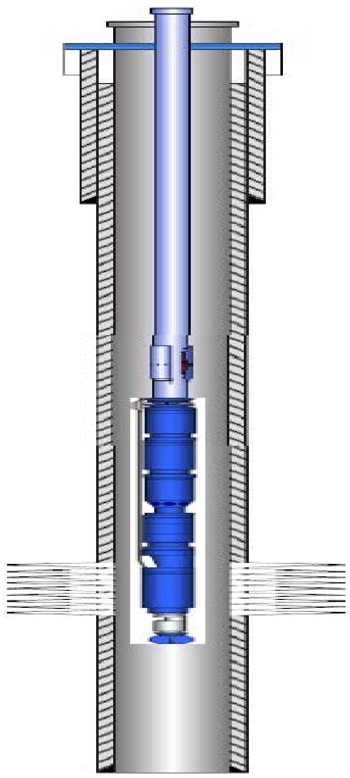

Figure 3.13 Electrical submersible pump completion (model 5)

3.2.6 Rod pumping completion

Rod pumps are found in large numbers on depleted oil fields or low reservoir pressure fields. Rod pump mechanisms are relative simple device. Typical of rod pumping completion consists of pump assembly, nipple, and anti-rotation assembly as illustrated in Figure 3.14.

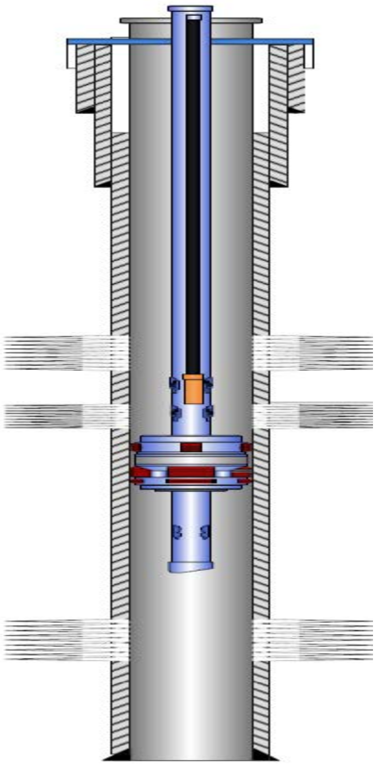

Figure 3.14 Rod pumping completion (model 6)

3.3 Concept of decision analysis

3.3.1 Risk and probability theory

Decision analysis is a term used to describe a decision-making process that combines the methods of statistical decision theory, imaginative creativity, system analysis, and operation research. The objective of decision analysis is to break complex logically decision into element for helping process of decision maker. Typically, the term of technical, economic, environmental, political, legal is affected the process of decision analysis. The procedure deals with uncertainties consist of;

a. Basic development phase
b. Deterministic phase
c. Probabilistic phase
d. Information phase
e. Implement and re looping if required

The basic development phase consists of the basic structuring of the decision problem and then using this structure to identify the crucial variables. In the basic development, the task is mainly used to identify the real decision including the scope and method of approach, requirements and objectives of the analysis [22].

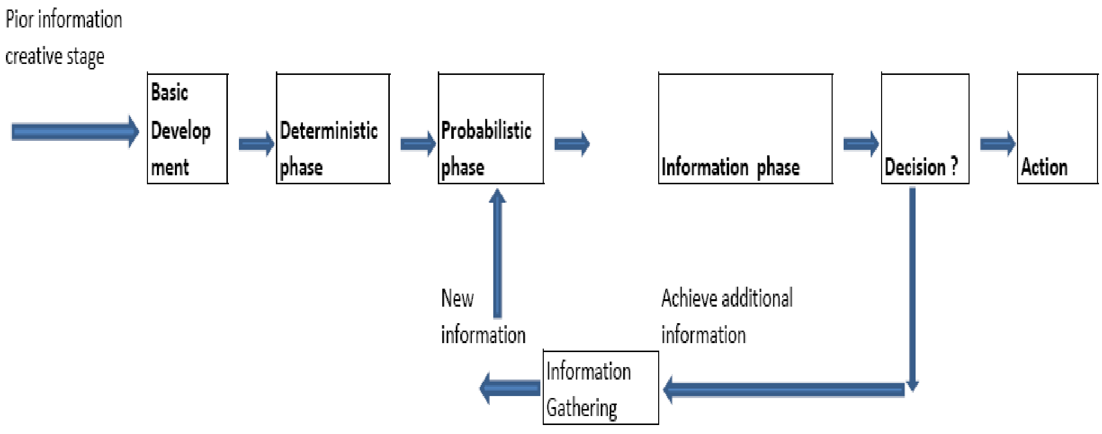

Figure 3.15 The decision analysis cycle modified from after Howard, R.A [22]

3.3.2 Decision analysis cycle and process

Decision analysis is process to help decision makers choose the worst decision along with uncertainty. The estimation can be developed from reasonable process. The logical sequence analysis for decision making consists of structuring phase, evaluation and modeling phase, and executing phase [19].

Finally, in this application, it can be applied the decision process and construct the logic outline as illustrated in Table 3.2.

Table 3.2 Details of decision analysis cycle and process

Structuring phase	Identify opportunities	To seek and develop probabilistic model for workover well.
	Define the problem	Current operation, the problems have encountered, it has not been studying probabilistic to do operation successfully within identified budget. Moreover, need to classify all well into category in order to seek alternatives.
	Identify alternatives	In the exiting model, the decision have made on experience of engineer in charge. So, to gather all possible alternatives into system is very important.
Modeling and evaluation	Develop decision model	To construct the outline of a decision tree model base on alternatives.
	Quantify uncertainty	There are two variables. To obtain the outcomes, it is required to gather all of cost, all of operation times which are affected to the operation cost, probability, chance of success in each decision alternatives.
	Develop valuation model	Develop decision model by using decision tree in each steps and separate in category well models. Create value data for every possible scenario.
	Calculative outcomes	Calculate the expected value from each alternative in decision tree. Then, the best alternatives or best strategy can be identified. The second or contingency plan can be determined for decision maker.
	Re-calculate	Check the state of problem whether the best alternative can provide the right solution.
Executing	Implement	Implement the selected alternatives.
	Post-analyze	Review the decision, whether it can confirm the right decision or it may has new information for improving in the decision.

3.3.3 Expected value and decision tree analysis

Typically, it is mathematic term that combines the pay offs and probabilities of possible chance or outcomes for a decision alternative. Commonly, the most of specifying the quantity probabilistic of uncertainty in decision making is in term of expected value relative to decision methods that ignore uncertainly. It introduces the notion of the expected value of including uncertainty, as a measure of the effect of considering uncertainty in the context of specific decision problem.

The decision elements are normally explained in two terms when dealing with situations involving alternatives and their outcomes. The value might be measured in monetary term or any other dimensions. The second is likelihood of occurrence of this value associated with its respective outcome.

There are several ways to calculate the EV of a probability distribution. If we have the distribution expressed as a mathematical formula, one might be able to solve the EV that is the sum of outcome values times their probabilities.

$$EMV\{C1\} = \Sigma^{N}_{\imath=1}\, pi\,(NPV_i)$$

Where Xi are the outcome values, P(Xi) are the probabilities of these outcomes. We can use the excel function to calculate payoff tables.

Commonly, there are two methods that use for calculation desirable properties when are forecasting a cost or value. First, if we add an amount “X” to all outcomes, then the EV increases by X. Second, in case of, we multiply all outcomes by a factor Y, therefore the EV will consequence change as factor.

The probabilities decisions tree technique is used to map all possible outcomes and then, to estimate the expected monetary value. Scope of approach will present the most likely workover scenario and analysis in decision tree analysis, Final; summarize the EMV in each possible outcome. The direct benefit of approaching, engineers can use this diagram to evaluate budget from any circumstances which may happen, contingent plans, probabilities, while comparing with their deterministic model.

Decision tree analysis is diagram represent of expected value (EV). This tree is consisted of decision, chance, and terminal nodes connecting by branched. The commonly instruction for constructing the decision tree can explain as following details;

Decision node represented by squares (□): It represents actions that the decision maker controls. The most practical optimal alternative between courses of action is to be selected. The option with given the highest EMV shall be chosen.

Chance node represented by circles (O): it represents a chance branch that is one of the possible outcomes emanating from a chance branch. Commonly, there is two or more chance branches are lines drawn to the right from chance node. Typically, there are different possible outcomes at this node. Probability or chance in the tree, it refers to the likelihood of possible outcomes. In case of, decision maker has experience, knowledge or including lesson learned can be used to objectively evaluate the chance of each outcome to occur.

Terminal or end mode or payoff node represented by triangles (optional): represented the endpoints in a decision tree diagram after connected all branches together, where outcome values are presented. In the term of deterministic financial outcome, a decision is based on any type of economic indicator although usually NPV at take account discount rate. In summary of each branches, the expected monetary value (EMV) at the node is calculated together by using probability, pi is for the event while is a chance node. [19]

3.3.4 Decision tree model for well workover operations

When applying the instruction for constructing the decision tree and this study, it can be illustrated as procedure following below; [19]

1) Identify decision, and alternatives available for each decision tree models.

After study and classify each well configuration from the most commonly on onshore, Thailand during year 2010-2012, there are total 219 sampling wells. It consists of 175 conventional completion wells, 29 electrical submersible pumping wells, and 15 rod pumping wells. It can be classified namely decision alternative as following results below;

Model 1A: single zone completion, one retrievable packer -PHL/HS packer type.

- Decision alternative SP: unsetting retrievable packer by straight pulling.
- Decision alternative C1: cutting 1 cut, above PKR #1, then, pulling above part and running BHA: overshot to unset PKR#1.

Model 1B: single zone completion, one retrievable packer- RH/FH packer type.

- Decision alternative SP: unsetting retrievable packer by straight pulling.
- Decision alternative C1: cutting 1 cut, above PKR #1, then, pulling above part and running BHA: overshot to unset PKR#1.

Model 2A: two zones completion, two retrievable packers- PHL/HS packer type.

- Decision alternative SP: unsetting all retrievable packers (PKR#2, 1) by straight pulling.
- Decision alternative C1: cutting 1 cut, above PKR #1, and unsetting retrievable packer (PKR#2) by straight pulling. After that, running BHA: overshot to unset PKR#1.
- Decision alternative C2: cutting 2 cut, above PKR #1, 2, then pulling above part and running BHA: overshot to unset each PKR # 2, 1, respectively.

Model 2B: two zones completion, two retrievable packers-RH/FH packer type.

- Decision alternative SP: unsetting all retrievable packers (PKR#2, 1) by straight pulling.
- Decision alternative C1: cutting 1 cut, above PKR #1, and unsetting retrievable packer (PKR#2) by straight pulling. After that, running BHA: overshot to unset PKR#1.
- Decision alternative C2: cutting 2 cut, above PKR #1, 2 then pulling above part and running BHA: overshot to unset PKR # 2, 1, respectively.

Model 3A: three zones completion, three retrievable packers-PHL/HS packer type.

- Decision alternative SP: unsetting all retrievable packers (PKR#3, 2, 1) by straight pulling.

- Decision alternative C1: cutting 1 cut, above PKR#1, and unsetting retrievable packer (PKR#3, 2) by straight pulling. After that, running BHA: overshot to unset PKR#1.
- Decision alternative C2: cutting 2 cut, above PKR#1, 2 and unsetting retrievable packer (PKR#3) by straight pulling. After that, running BHA: overshot to unset PKR#2, 1, respectively.
- Decision alternative C3: cutting 3 cut, above PKR#1, 2, 3 and pulling above part. After that, running BHA: O-shot to unset PKR # 3, 2, 1, respectively.

Model 3B: three zones completion, three retrievable packers -RH/FH packer type.

- Decision alternative SP: unsetting all retrievable packers (PKR#3, 2, 1) by straight pulling.
- Decision alternative C1: cutting 1 cut, above PKR#1, and unsetting retrievable packer (PKR#3, 2) by straight pulling. After that, running BHA: overshot to unset PKR#1.
- Decision alternative C2: cutting 2 cut, above PKR#1, 2 and unsetting retrievable packer (PKR#3) by straight pulling. After that, running BHA: overshot to unset PKR#2, 1, respectively.
- Decision alternative C3: cutting 3 cut, above PKR#1, 2, 3 and pulling above part. After that, running BHA: O-shot to unset PKR # 3, 2, 1, respectively.

Model 3C: three zones completion, two retrievable packers-RH/FH packer type and one permanent packer.

- Decision alternative SP: unsetting all retrievable packers (PKR#2, 1) and seal by straight pulling.
- Decision alternative C1: cutting 1 cut, above seal and unsetting retrievable packers (PKR #2, 1) by straight pulling. After that, running BHA: overshot to retrieve seal.
- Decision alternative C2: cutting 2 cut, above seal, PKR#1, and unsetting retrievable packer (PKR#2) by straight pulling. After that running BHA: overshot to unset PKR#1 and to retrieve seal, respectively.

- Decision alternative C3: cutting 3 cut, above seal, PKR#1,2 and then pulling above part. After that, running BHA: O-shot to unset PKR # 2, 1 and seal respectively.

Model 4A: four zones completion, four retrievable packers -PHL/HS packer type.

- Decision alternative SP: unsetting retrievable packers PKR#4, 3, 2, 1 by straight pulling.
- Decision alternative C1: cutting 1 cut, above PKR#1 and then unsetting retrievable packers (PKR#4, 3, 2) by straight pulling. After that, running BHA: overshot to unset PKR#1.
- Decision alternative C2: cutting 2 cut, above PKR#1, 2 and then unsetting retrievable packers (PKR#4, 3) by straight pulling. After that, running BHA: overshot to unset PKR#2, 1, respectively.
- Decision alternative C3: cutting 3 cut, above PKR#1, 2, 3 and unsetting retrievable packer (PKR#4) by straight pulling. After that running BHA: overshot to unset PKR#3, 2, 1, respectively.
- Decision alternative C4: cutting 4 cut, above PKR#1, 2, 3, 4 and then pulling above part After that running BHA: O-shot to unset PKR#4, 3, 2, 1, respectively.

Model 4B: four zones completion, three retrievable packers- RH/FH packer type and one permanent packer.

- Decision alternative SP: unsetting retrievable packers (PKR#3, 2, 1) and seal by straight pulling.
- Decision alternative C1: cutting 1 cut, above seal and unsetting retrievable packers (PKR #3, 2, 1) by straight pulling. After that, running BHA: overshot to retrieve seal.
- Decision alternative C2: cutting 2 cut, above seal, PKR#1, and unsetting retrievable packer (PKR#3, 2) by straight pulling. After that running BHA: overshot to unset PKR#1 and to retrieve seal, respectively.
- Decision alternative C3: cutting 3 cut, above seal, PKR#1, 2 and unsetting retrievable packer (PKR#3) by straight pulling. After that,

running BHA: overshot to unset PKR#2, 1 and to retrieve seal, respectively.

- Decision alternative C4: cutting 4 cut, above seal, PKR#1, 2, 3 and then pulling above part and RIH O-shot to retrieve each PKRs.

Model 5: ESP completion (combine zone without packer)

- Decision alternative SP: pulling ESP completion on rig.

Model 6: Rod pumping completion (combine zone without packer)

- Decision alternative SP: pulling Rod pumping completion on rig.

2) Identify chance variables. Each branch will has two or more possible outcomes.

This example model can be started from decision maker need to make a decision between alternative “SP”: unsetting retrievable packer by straight pulling and alternative C1: cutting 1 cut, above PKR #1, then pulling above part and running BHA: overshot to unset PKR#1. There are two chance nodes “successful and failure”.

Figure 3.16 illustrates how to build a root decision node, then shows how to add branch of decision tree.

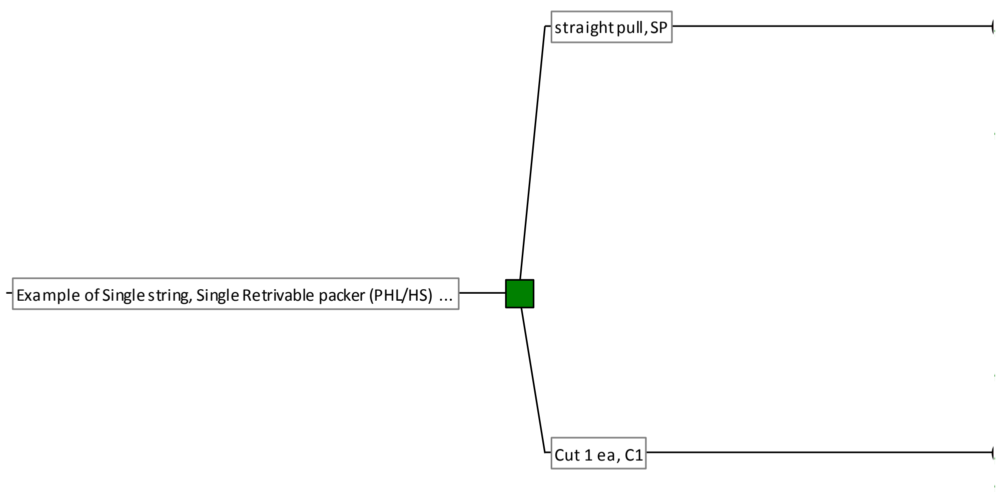

Figure 3.16 To build a root sub trees of decision tree

3) Determine the sequence of decision, chance of events and draw the tree to represent all possible scenarios into the tree.

To build the skeleton of the decision tree, the outcomes of various success and failure paths are converted to present values in investment money. Outcomes are varied depending on the configuration of well model, decision alternatives, and operation scenarios for example, fishing cost is additional cost which will happen when do unsuccessful retrieving packer, so that it has uncertainty. The decision alternatives are set up with code reference following;

- SP refers to straight pulling.
- C1 refers to perform 1 cutting above packer or seal.
- C2 refers to perform 2 cutting above packer or seal.
- C3 refers to perform 3 cutting above packer or seal.
- C4 refers to perform 4 cutting above packer or seal.

For example; SP-F-S is mean, the well is performed by straight pulling failure and then it need to cutting 1 cut, above packer, then running BHA: overshot to unset packer successful. Figure 3.17 illustrates how to build a skeleton of decision tree.

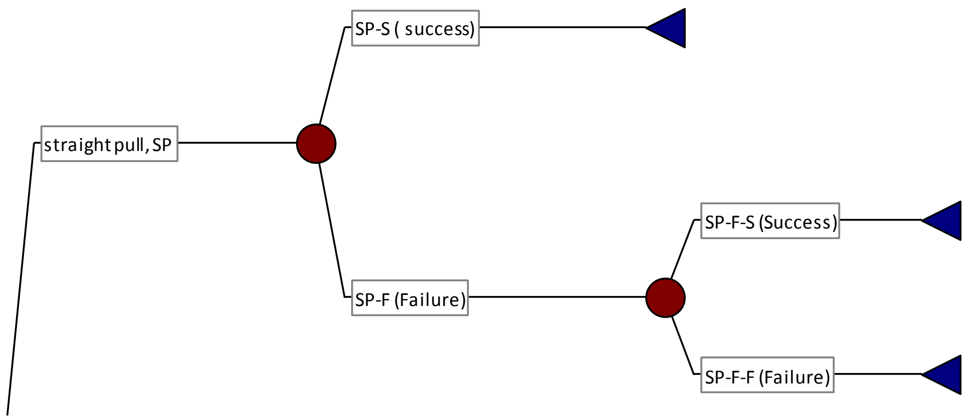

Figure 3.17 To build a skeleton of decision tree

4) Assess the chance event branch probability.

After gathering information, the possible outcome has directly influence for making decision. Each completion models have different possible outcomes and different possibilities. It can be summarized as following below table 3.3.

Table 3.3 Summary data of alternative and its probability in each decision tree models

No	Zone	Type	Decision alternatives	Sampling data	(% Probability of success)	(1-% of Probability of success)
1	Single zone completion	Model 1A	SP	88	86.4%	5.9%
			C1	102	81.4%	18.6%
		Model 1B	SP	30	66.7%	33.3%
			C1	24	75.0%	25.0%
2	Two zone completion	Model 2A	SP	16	81.3%	18.8%
			C1	88	86.4%	5.9%
			C2	102	81.4%	18.6%
		Model 2B	SP	13	46.2%	53.8%
			C1	30	66.7%	33.3%
			C2	24	75.0%	25.0%
3	Three zone completion	Model 3A	SP	6	16.7%	83.3%
			C1	16	81.3%	18.8%
			C2	88	86.4%	5.9%
			C3	102	81.4%	18.6%
		Model 3B	SP	3	0.0%	100.0%
			C1	2	100.0%	0.0%
			C2	30	66.7%	33.3%
			C3	24	75.0%	25.0%
		Model 3C	SP	4	0.0%	100.0%
			C1	1	25.0%	75.0%
			C2	30	66.7%	33.3%
			C3	24	75.0%	25.0%
4	Forth zone completion	Model 4A	SP	3	66.7%	33.3%
			C1	2	50.0%	50.0%
			C2	2	50.0%	50.0%
			C3	88	86.4%	5.9%
			C4	102	81.4%	18.6%
		Model 4B	SP	6	0.0%	100.0%
			C1	1	0.0%	100.0%
			C2	1	50.0%	50.0%
			C3	30	66.7%	33.3%
			C4	24	75.0%	25.0%

No	Zone	Type	Decision Alternatives	Sampling data	(% Probability of success)	(1-% of Probability of success)
5	ESP completion	Model 5	SP	29	100.0%	0.0%
6	Rod pumping completion	Model 6	SP	15	100.0%	0.0%

Table 3.4 Summary probability of BHA: overshot in each packer type

No	Type	Sampling data	(% Probability of success)	(1-% of Probability of success)
1	To retrieve a PHL/HS packer by BHA: Overshot	102	81.4%	18.6%
2	To retrieve a RH/FH packer by BHA: Overshot	24	75.0%	25.0%

5) Determine the outcome value for every path thought the tree.

To calculate outcomes for onshore workover, it is consisted of two variable parameters (sum of operational time and operational cost).

a) Summary of operational time (days)

All of workover operational times are directly affected to rig rental cost, to select only one sampling case may not represent all data. Thus, to build a model, it necessarily constructs a cumulative probability distribution of each operational time from sampling data by preparing sampling data in group of data for analysis. Generally, the group can be rearranged in continuous model or discrete model. In the continuous model, it can be done from sampling data as procedure illustrated below; [20]

- To define range of data set that need to analyze
- To collect data in term of frequency in defined range.
- To calculate relative frequency which represent the proportion or percentage of data ranges.
- To calculate mid-point of range.
- To calculate all data.

After collecting all sampling data to construct histogram represent cumulative distribution function. It can illustrate in the summary of operational time. There are 14 different operational times; it can be seen in Table 3.5. These times are used in the part of outcomes calculation. For histogram illustrated time's distribution can be seen in appendix B.

Table 3.5 Summary of historical operation time (days)

No	Time Category	Time (days)
1	Rigging up time	0.25
2	Pulling time (conventional completion)	0.33
3	Cutting time	0.13
4	Attempt to unset time	0.04
5	BHA: washover operational time	0.50
6	BHA: overshot operational time	0.54
7	BHA: spear operational time	0.50
8	BHA: milling operational time	0.56
9	Completion time (conventional completion)	0.50
10	Rigging down time	0.17
11	Pulling time (ESP completion)	0.74
12	Completion time (ESP completion)	0.87
13	Pulling time (rod pumping completion)	0.49
14	Completion time (rod pumping completion)	0.5

b) Operational cost

For typical onshore workover operation, It is consist of rig cost in day rate, fix cost, fishing tool cost and cutting cost. In this study, would propose basic of calculation as following below;

Total operation cost = rig day rate x (sum of operation time) + fix cost +fishing tool cost + cutting cost.

Table 3.6 illustrates typical workover rig cost with pulling capacity 300,000-340,000 pounds for onshore in Thailand in 2010-2012, with round up.

Table 3.6 Outline of cost assumption parameter for all decision tree calculation

Type	Item	Base
Per day	Rig day rate (per day)	$9,000
	Rig consume per day	$800
	Tariff charge per day	$2,000
	Total rig related payment per day	$11,800
	Fishing tool: stand by cost (per day)	$800
Per run	Pipe cutting (per run)	$15,000
	Fishing tool rental cost (per run)	
	- Overshot (per run)	$2,000
	- Milling shoe (per run)	$3,000
	- Spear (per run)	$2,500
Fix cost	Rig related support cost (Fix cost / well)	$10,000
	Rig moving cost	$15,000
	Completion cost	$20,000
	Total rig payment fix cost (per well)	$45,000

After verified all variable parameters, the next step is to calculate outcome. It can be demonstrated in an example: Model 1.A with decision alternative “SP”: unsetting retrievable packer on rig and failure. Then, it needs to perform cutting 1 cut above packer, after that, running BHA: overshot to retrieve packer.

Total Cost can be demonstrated as following details;

- Operation time cost = (0.29 + 0.10+0.15+0.42+0.66+0.56+0.24) day x $9,000 USD/day = $28,444.
- Rig payment fix cost = $45,000.
- Fishing cost= BHA: overshot $2,000.
- Cutting cost = $15,000.
- Total cost = $28,444+$45,000+$2,000+$15,000 = $90,444.

It can be seen in summary Table 3.7. Then, it needs to determine outcomes to all possible pathways.

Table 3.7 Summary of an example calculation

Workover day		
	Rig up time	0.29
	then attempt to unset PKR#1	0.10
	cutting above PKR#1,	0.15
	Pulling time	0.42
	RIH BHA: Overshot to unset PKR#1	0.66
	RIH completion time	0.56
	Rig down time	0.24
Fishing cost		
	Overshot 1 ea	$2,000
Cutting cost	Cutting 1 ea	$15,000
Summary Cost		
	Total rig related payment per day	$28,444
	Total rig payment fix cost (per well)	$45,000
	Total fishing cost	$2,000
	Total cutting cost	$15,000
Total cost		$90,444

6) Back calculate to determine the expected cost each alternatives (right to left).

Next step, the decision tree completes with terminal nodes and outcomes which are present value costs. According, the root node is decision alternatives. In the chance event node, it shows chance-event outcomes and its probability. Commonly, calculating a decision tree is a simple back calculation process which is started from the terminal nodes at the right, moving to the left and calculating the value in each node and labels its expected cost. To calculate expected cost of each alternatives as show in sequence as following;

Expected cost of alternative "SP" =0.864 (63,861) + 0.136 {0.814 (90,444) + 0.186 (105,199)} = $67,860.

Expected cost of alternative "C1" = 0.814 ($85,488) +0.186 ($102,044) = $88,572.

After calculation all of pathways, it can be seen in Figure 3.18 which illustrates the expected value each alternatives in decision tree.

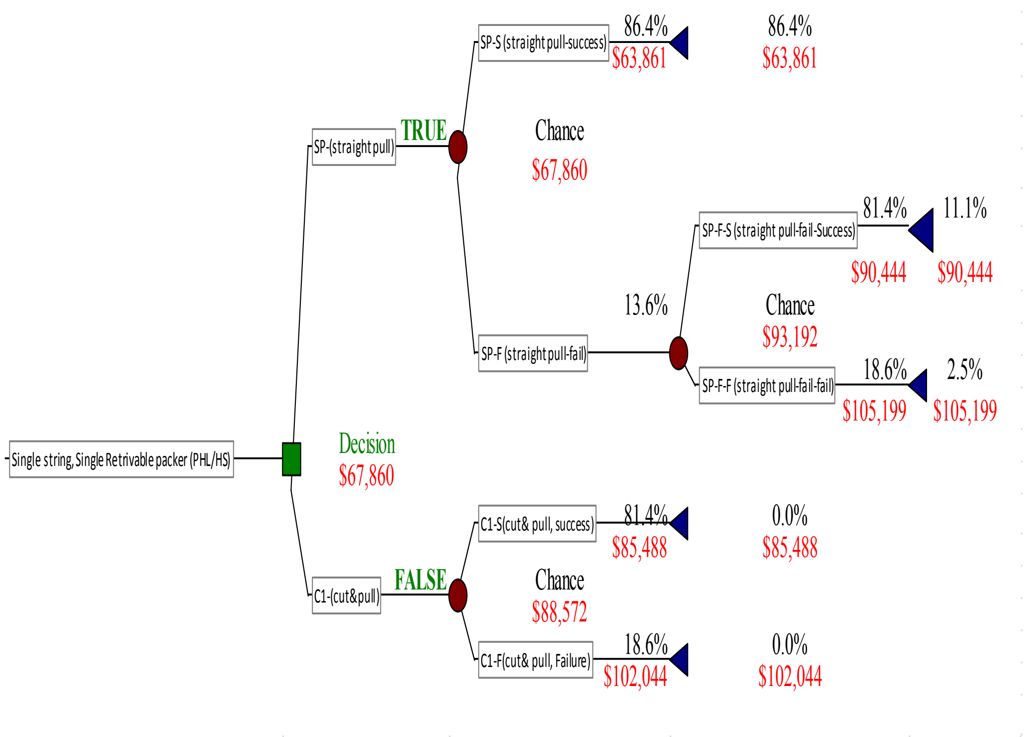

Figure 3.18 To enter probabilities and values a skeleton of decision tree

7) Choose the greatest minimum expected cost

To examine the optimal strategy, it needs to find minimum cost by applying the expected value decision rule:

Expected cost of decision = Minimum {EV (SP), EV (C1)} = Minimum {67,860, - 88,572} = 64,860 USD

Thus, the optimal strategy is obtained from decision tree which is decision alternative "SP": unsetting retrievable packer by straight pulling. It will provide the best expected cost as illustrated in Figure 3.19.

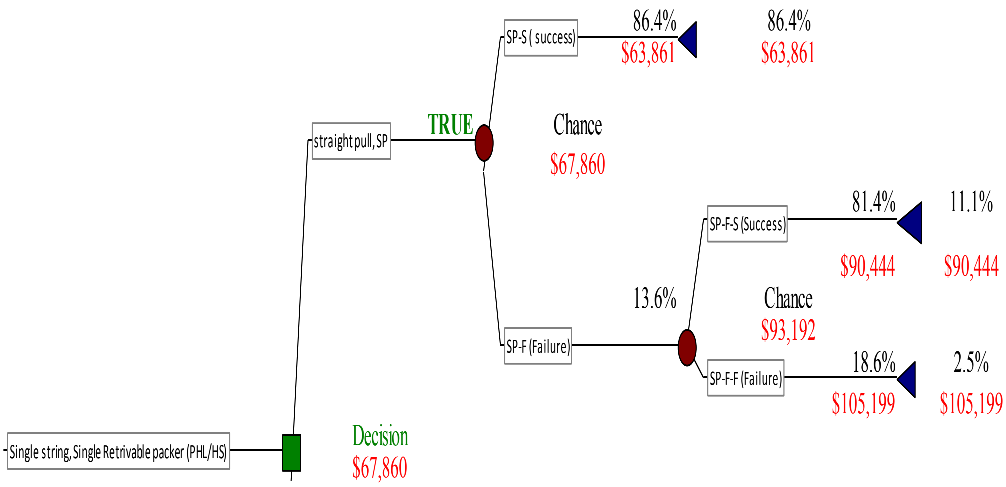

Figure 3.19 To obtain the optimal strategy

CHAPTER IV

RESULTS OF DECISION MODEL

4.1 Result of decision tree analysis single zone completion

4.1.1 Result of decision tree analysis model 1A

To construct a decision tree, it is used to find optimum operation cost for workover single zone completion, one retrievable packer - PHL/HS packer type, represent by decision node (square). The decision tree has decision node for making decision, represented by square. It has two decision alternatives (SP and C1), where alternative "SP", represents method: straight pulling "unsetting retrievable packer by straight pulling", while alternative "C1", represents method "perform 1 cutting above packer. It is referred "perform cutting above PKR #1 one cutting, then pulling above part and run BHA: overshot to retrieve PKR#1 as illustrated in Figure 4.1.

The probabilities associated with each of the chance node outcomes are collected from history data. Alternative node "SP" has probability of success 86.4 %, where alternative node "C1" has probability of success 81.4 %.

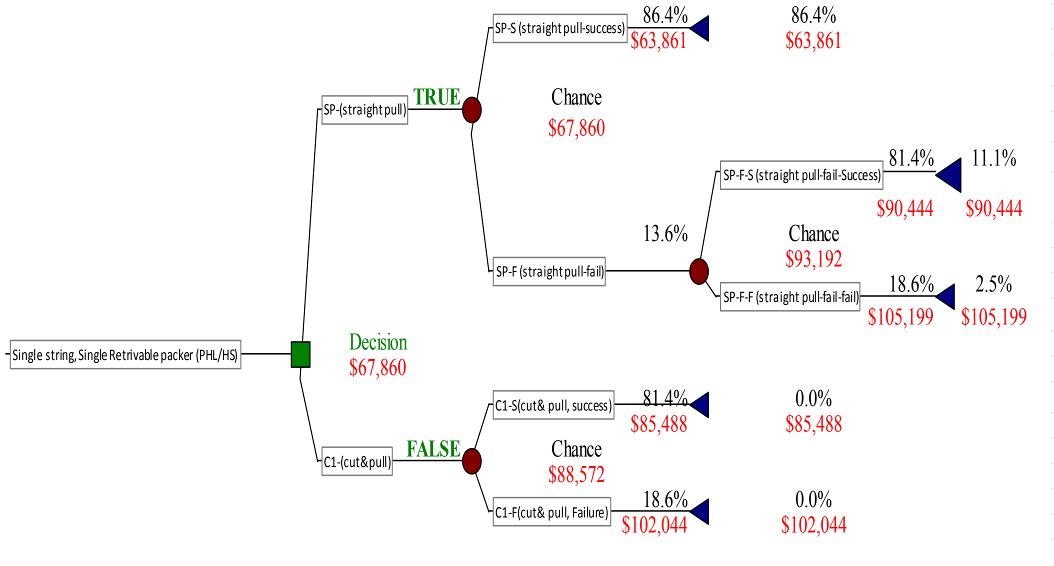

Figure 4.1 Decision tree for "model 1A"

The risk profile is a distribution function. It shows in a discrete density distribution which described the chance associated with all of possible outcome. It also demonstrates the uncertainty of decision using a frequency or cumulative frequency graph.

Figure 4.2 shows the probability chart, the height of the alternative node “SP line at $105,199 is 2.5%, which is equal to the probability that the expected cost of alternative node “SP is $105,199.

Figure 4.3 shows the cumulative chart, the probability that the alternative node “SP” a value less than or equal to $63,861 is 100%.

Table 4.1 also illustrated the statistical summary of the risk profile, which provides a statistical summary report of the decision analysis.

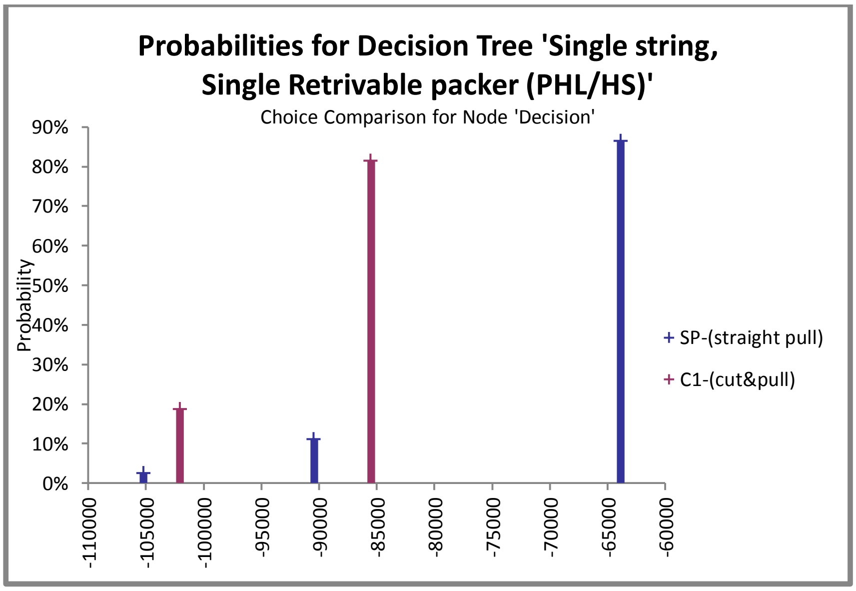

Figure 4.2 Probability decision for decision tree “model 1A”

Table 4.1 Summary data of probability decision for decision tree “model 1A”

Expected cost	Alternative SP-(straight pull)		Alternative C1-(cut & pull)	
	Value	Probability	Value	Probability
#1	$105,199	2.50%	$102,044	18.60%
#2	$90,444	11.10%	$85,488	81.40%
#3	$63,861	86.40%		

Result of constructing risk profile, alternative “SP” has three outcomes, represented by SP-S, SP-F-S and SP-F-F, with expected cost \$105,199, \$90,444, \$63,861 and with probability 2.5 %, 11.1 % and 86.4 % respectively. Alternative “C1” has two outcomes represented by C1-S and C1-F, with expected cost \$85,488 and \$102,044 and with probability 81.4 % and 18.6 % respectively as shown in Table 4.1.

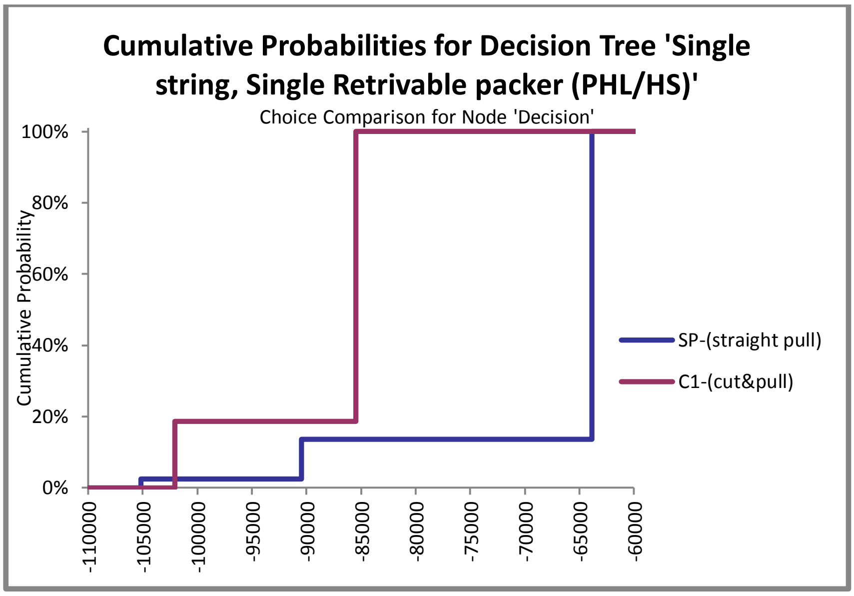

Figure 4.3 Cumulative probabilities for decision tree “model 1A”

Refer decision tree Figure 4.1, at alternative “SP”, the expected cost of unsetting retrievable packer by straight pulling on rig is \$67,860. where alternative “C1”, the expected cost of alternative “C1”: cutting 1 cut above PKR #1, then pulling above part and running BHA: overshot to unset PKR#1, is \$88,572.

The expected cost of alternative “SP” is saving operation cost more than alternative “C1”. Therefore, choosing “unsetting retrievable packer by straight pulling” is most appropriate. It can provide benefit \$20,712 over alternative “C1” as shows in Figure 4.4, illustrated policy suggestion. It presents only the optimum part of decision tree. It shows option was chosen alternative node by illustrating a reduced version of decision tree, with the optimum path highlighted and the expected cost.

The probabilities of each path are also displayed. The summary of statistical can be seen in Table 4.2.

Table 4.2 Statistical summary for decision tree "model 1A"

Statistics	Alternative SP-(straight pull)	Alternative C1-(cut & pull)
Mean	$67,860	$88,572
Minimum	$105,199	$102,044
Maximum	$63,861	$85,488
Mode	$63,861	$85,488
Std. Deviation	10,286.96	6,445.64
Skewness	-2.34	-1.61
Kurtosis	7.01	3.6

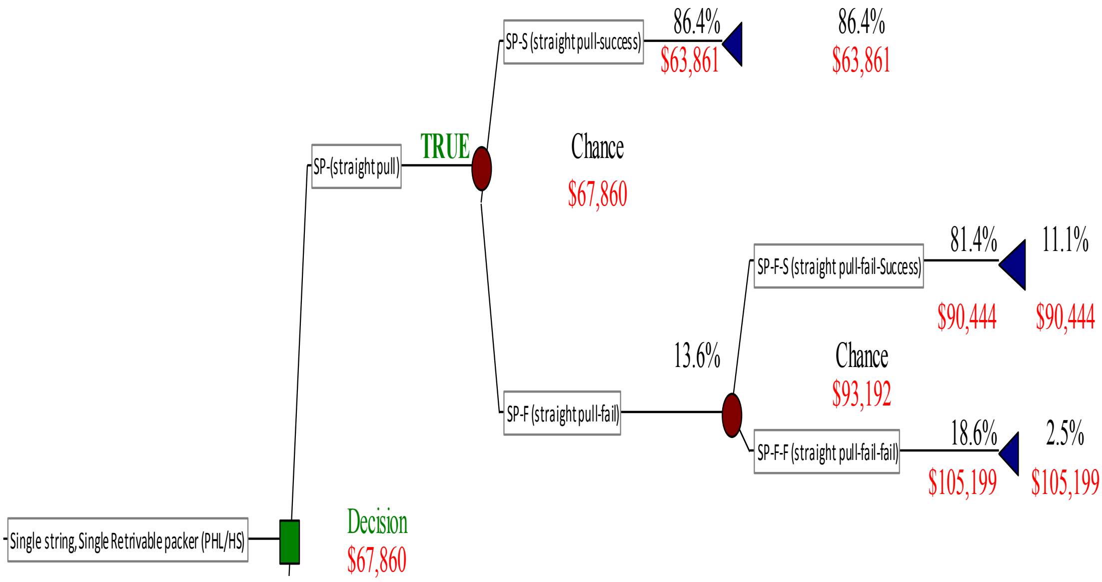

Figure 4.4 Optimum decisions tree suggestion "model 1A"

4.1.2 Result of decision tree analysis model 1B

To construct a decision tree, it is used to find optimum operation cost for workover single zone completion, one retrievable packer - RH/FH packer type, represent by decision node (square). The decision tree has decision node for making decision, represented by square. It has two decision alternatives (SP and C1), where alternative "SP", represents method: straight pulling "unsetting retrievable packer by straight pulling", while alternative "C1", represents method "perform 1 cutting above packer. It is referred "perform cutting above PKR #1 one cutting, then pulling above part and run BHA: overshot to retrieve PKR#1 as illustrated in Figure 4.5**.**

The probabilities associated with each of the chance node outcomes are collected from history data. Alternative "SP" has probability of success 66.7 %, while alternative "C1" has probability of success 75.0 %.

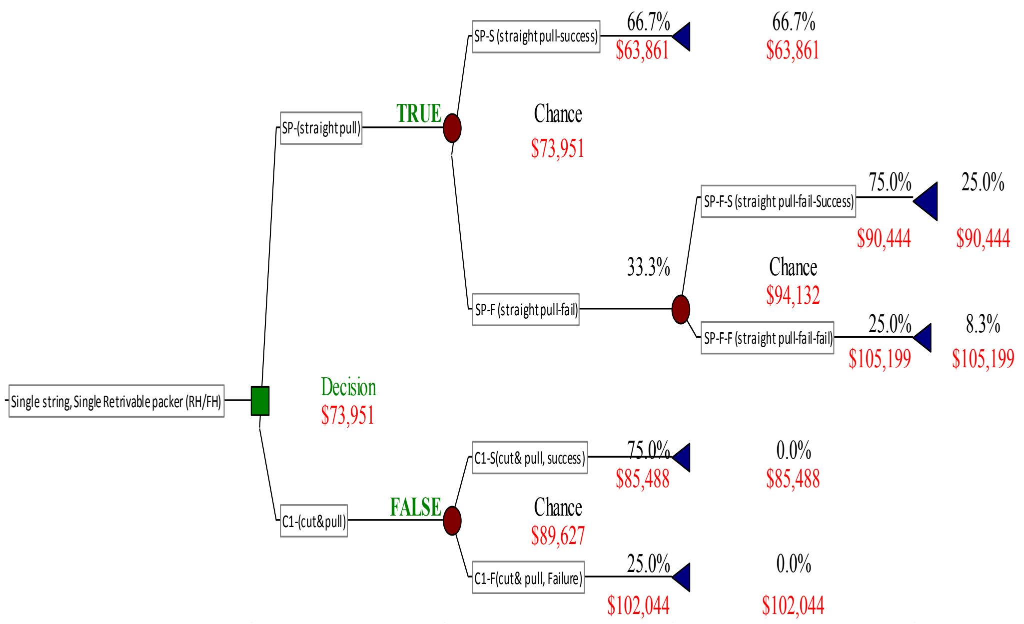

Figure 4.5 Decision tree for "model 1B"

The risk profile is a distribution function. It shows in a discrete density distribution which described the chance associated with all of possible outcome. It also demonstrates the uncertainty of decision using a frequency or cumulative frequency graph.

Figure 4.6 illustrates the probability chart; the height of the alternative node "SP" line at $105,199 is 8.3%, which is equal to the probability that the expected cost of alternative node "SP" is $105,199.

Figure 4.7 illustrates the cumulative chart, the probability that the alternative node "SP" a value less than or equal to $63,861is 100%.

Table 4.3 also illustrated the statistical summary of the risk profile, which provides a statistical summary report of the decision analysis.

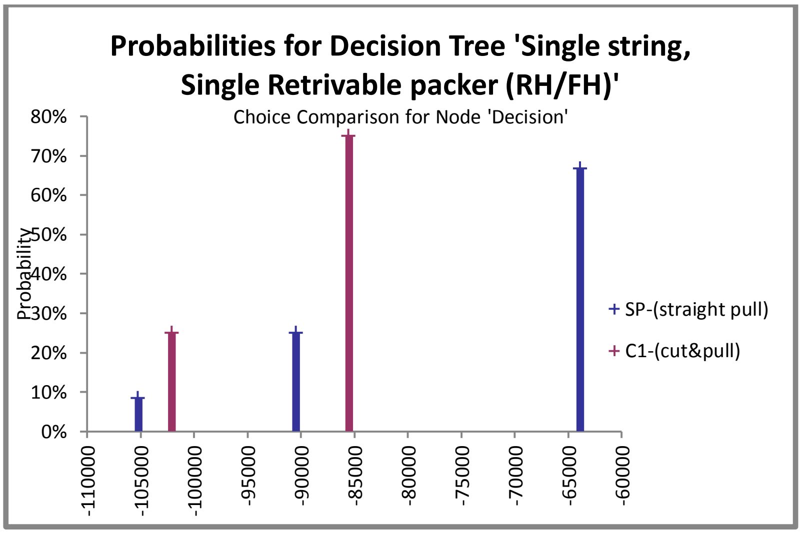

Figure 4.6 Probability decision for decision tree "model 1B"

Table 4.3 Summary data of probability decision for decision tree "model 1B"

Expected cost	Alternative SP-(straight pull)		Alternative C1-(cut & pull)	
	Value	Probability	Value	Probability
#1	$105,199	8.30%	$102,044	25.00%
#2	$90,444	25.00%	$85,488	75.00%
#3	$63,861	66.70%		

Result of constructing risk profile, alternative "SP" has three outcomes, represented by SP-S, SP-F-S and SP-F-F, with expected cost $105,199, $90,444, $63,861 and with probability 8.3 %, 25.0 % and 66.7 % respectively. Alternative

"C1" has two outcomes, represented by C1-S and C1-F, with expected cost $ 85,488 and $102,044 and with probability 81.4 % and 18.6 % respectively as shown in Table 4.3.

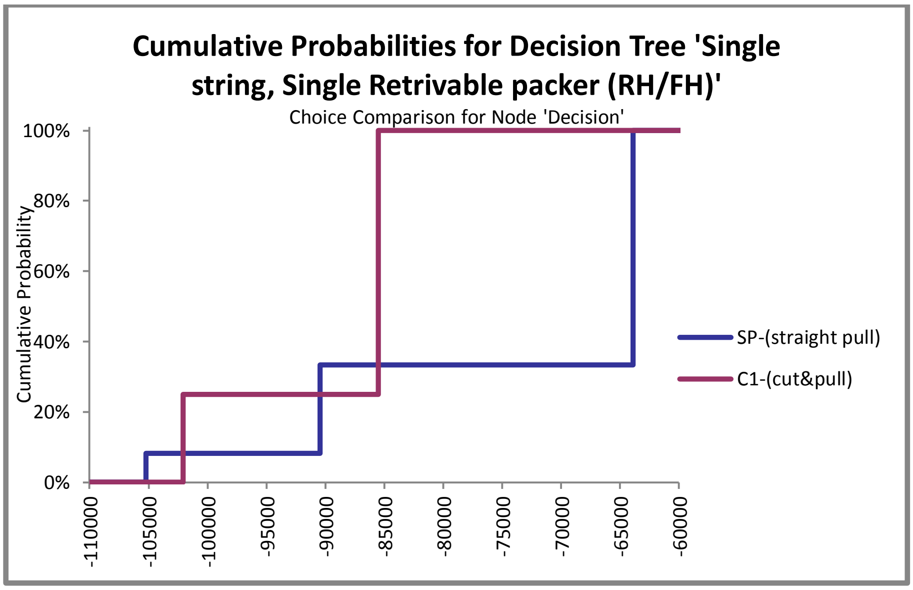

Figure 4.7 Cumulative probabilities for decision tree "model 1B"

Refer decision tree Figure 4.5, at alternative "SP", the expected cost of unsetting retrievable packer by straight pulling on rig is $73,591. where alternative "C1", the expected cost of alternative "C1": cutting 1 cut, above PKR #1, then, pulling above part and running BHA: overshot to unset PKR#1, is $89,627.

The expected cost of alternative "SP" is saving operation cost more than alternative "C1". Therefore, choosing "unsetting retrievable packer by straight pulling" is most appropriate. It can provide benefit $15,676 over alternative "C1" as shows in Figure 4.8, illustrated policy suggestion. It presents only the optimum part of decision tree. It shows option was chosen alternative node by illustrating a reduced version of decision tree, with the optimum path highlighted and the expected cost. The probability of each path displayed. The summary of statistical can be seen in Table 4.4.

Table 4.4 Statistical summary for decision tree "model 1B"

Statistics	Alternative SP-(straight pull)	Alternative C1-(cut & pull)
Mean	$73,951	$89,627
Minimum	$105,199	$102,044
Maximum	$63,861	$85,488
Mode	$63,861	$85,488
Std. Deviation	14739.39	7168.88
Skewness	-0.93	-1.15
Kurtosis	2.22	2.33

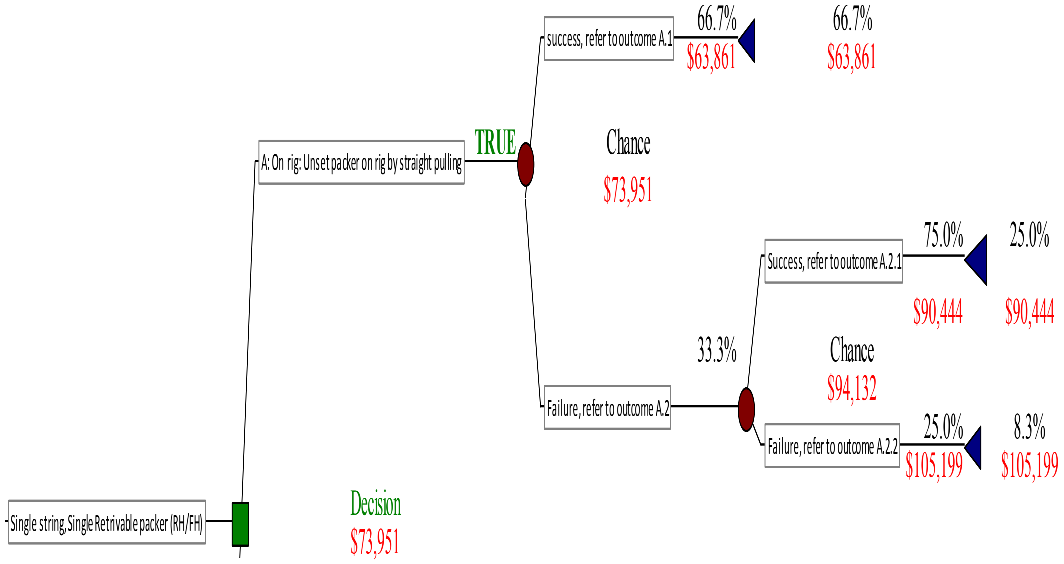

Figure 4.8 Optimum decisions tree suggestion "model 1B"

4.2 Result of decision tree analysis two zones completion

4.2.1 Result of decision tree analysis model 2A

To construct a decision tree, it is used to find optimum operation cost for workover single zone completion, two zones completion, two retrievable packers – PHL/HS packer type, represent by decision node (square). The decision tree has decision node for making decision, represented by square. There are three decision alternatives (SP, C1 and C2) as illustrated in Figure 4.9a, 4.9b which consists of;

- Alternative SP: unsetting all retrievable packers (PKR#2, 1) by straight pulling.
- Alternative C1: cutting 1 cut, above PKR #1, and unsetting retrievable packer (PKR#2) by straight pulling. After that, running BHA: overshot to unset PKR#1.
- Alternative C2: cutting 2 cut, above PKR #1, 2, then pulling above part and running BHA: overshot to unset each PKR # 2, 1, respectively.

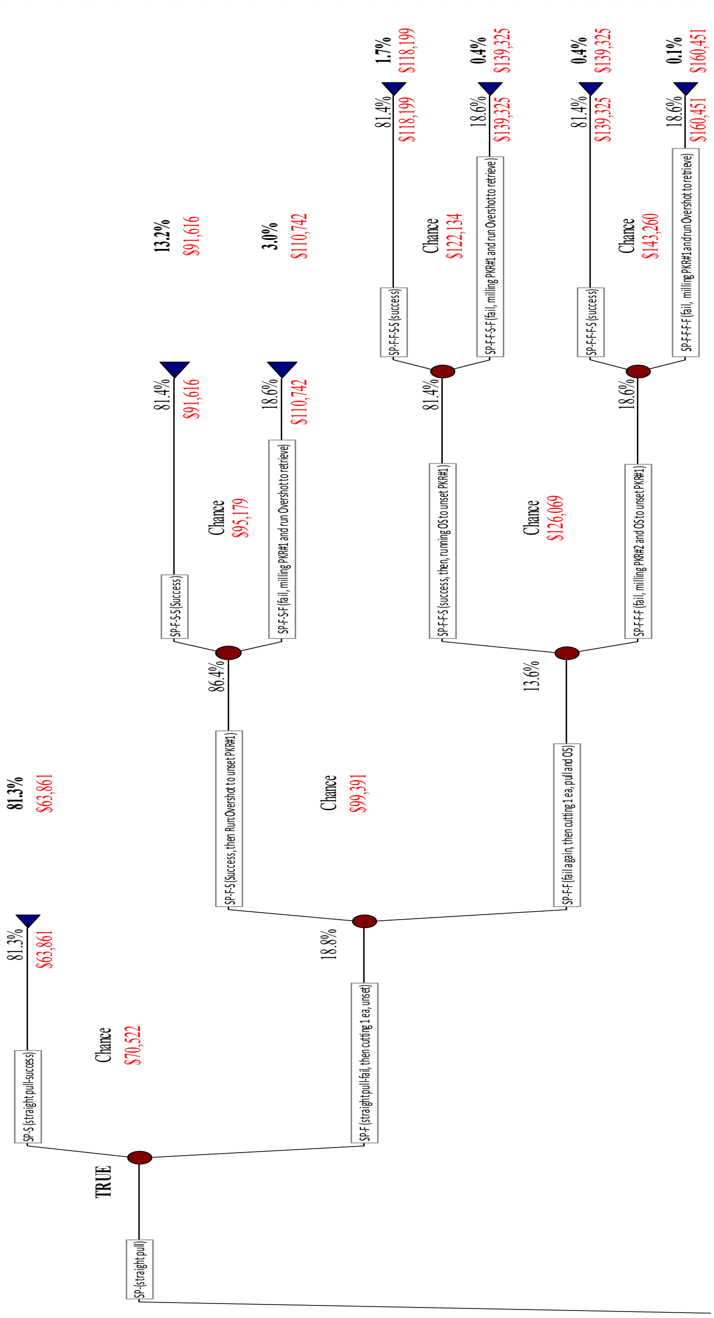

Figure 4.9a [1]Decision tree for “model 2A”

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[1] OS is referred to BHA: Overshot, Milling is referred to process to swallow / grind.

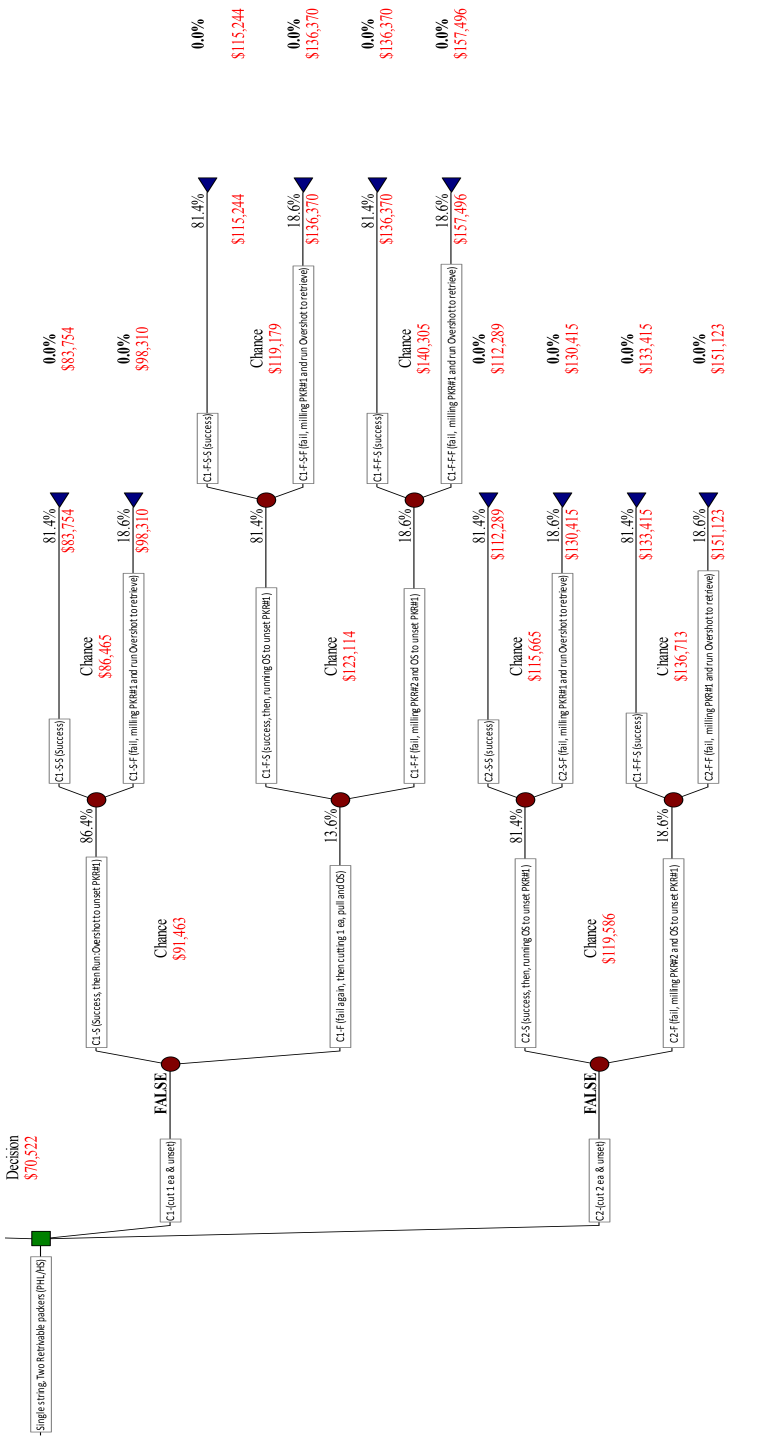

Figure 4.9b Decision tree for “model 2A”

The risk profile is a distribution function. It shows in a discrete density distribution which described the chance associated with all of possible outcome. It also demonstrates the uncertainty of decision using a frequency or cumulative frequency graph.

Figure 4.10 illustrates the probability chart; the height of the alternative node “SP” line at $160,451 is 0.1%, which is equal to the probability that the expected cost of alternative node “SP” is $160,451.

Figure 4.11 illustrates the cumulative chart, the probability that the alternative node “SP” a value less than or equal to $63,861 is 100%.

Table 4.3 also illustrated the statistical summary of the risk profile, which provides a statistical summary report of the decision analysis.

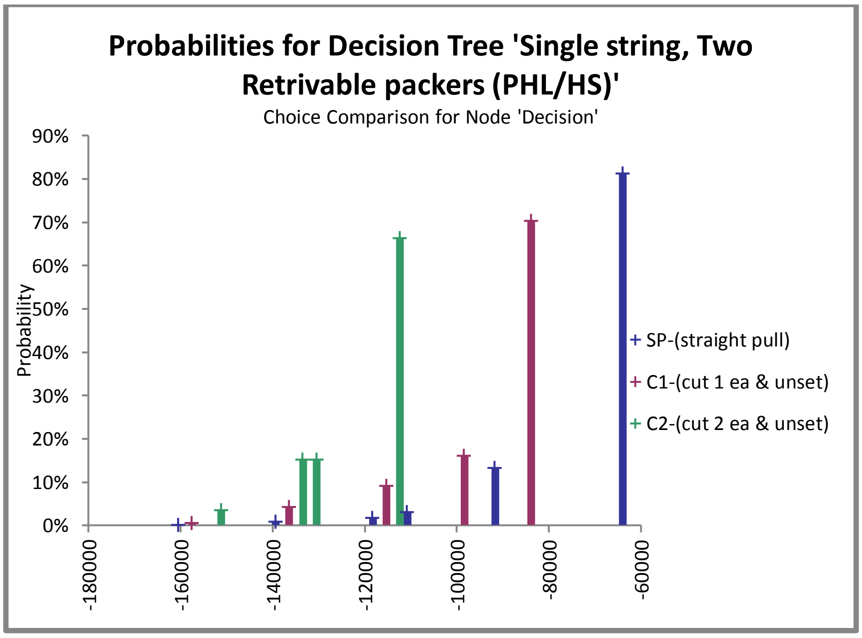

Figure 4.10 Probability decision for decision tree “model 2A”

Table 4.5 Summary data of probability decision for decision tree “model 2A”

Expected cost	Alternative SP-(straight pull)		Alternative C1-(cutting 1 cut & pull)		Alternative C2-(cutting 2 cut & pull)	
	Value	Probability	Value	Probability	Value	Probability
#1	$160,451	0.10%	$157,496	0.50%	$151,123	3.50%
#2	$139,325	0.80%	$136,370	4.10%	$133,415	15.20%
#3	$118,199	1.70%	$115,244	9.00%	$130,415	15.20%
#4	$110,742	3.00%	$98,310	16.10%	$112,289	66.20%
#5	$91,616	13.20%	$83,754	70.30%		
#6	$63,861	81.30%				

Result of constructing risk profile, alternative “SP” has six expected costs as $63,861, $91,616, $110,742, $118,199, $139,325, $160,451 and probability 81.3 %, 13.2 %, 3%, 1.7%, 0.8% and 0.1 %.

Alternative “C1” has five expected costs as $83,754, $98,310, 115,244, 136,370 and $157,496 and probability 70.3 %, 16.1%, 9.0%, 4.1 % and 0.5 % respectively as shown in Table 4.5.

Alternative “C2” has four expected costs as $151,123, $133,415, 130,415 and $112,289 and probability 3.5 %, 15.2%, 15.2% and 66.2 % respectively as shown in Table 4.5 respectively.

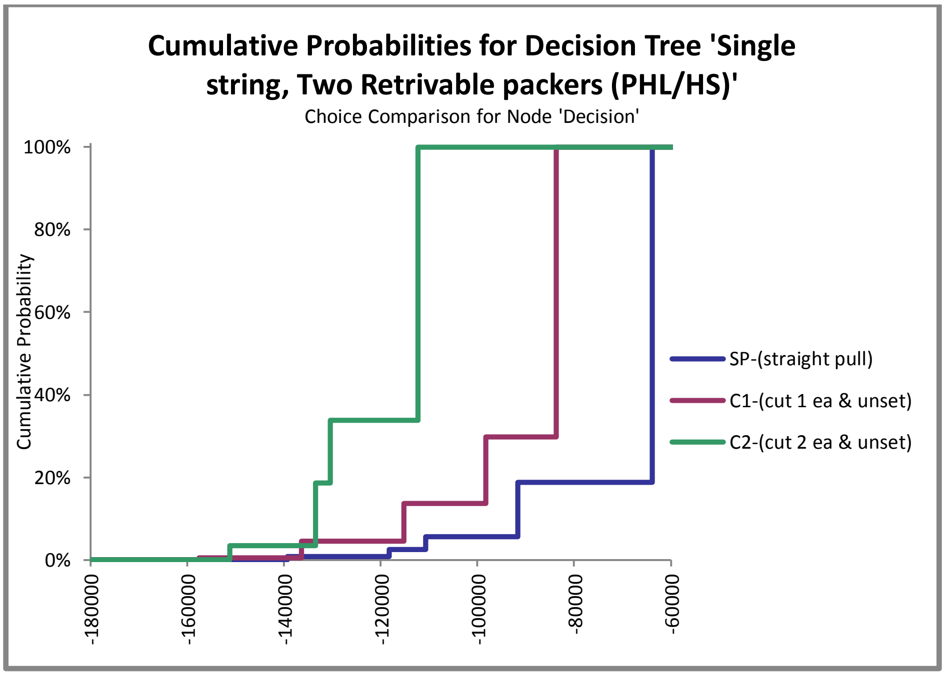

Figure 4.11 Cumulative probabilities for decision tree "model 2A"

Refer decision tree Figure 5.9a, 5.9b, at alternative "SP", the expected cost of unsetting retrievable packer by straight pulling on rig is $70,522. where alternative "C1", the expected cost of cutting 1 cut, above PKR #1, and unsetting retrievable packer (PKR#2) by straight pulling. After that, running BHA: overshot to unset PKR#1, is $91,463 and the expected cost of alternative C2 "cutting 2 cut, above PKR #1, 2, then pulling above part and running BHA: overshot to unset each PKR # 2, 1, respectively" is $119,586.

After calculating, the expected cost of alternative "SP" is saving investment cost more than alternative "C1" and "C2", Therefore, choosing "unsetting retrievable packer by straight pulling" is most appropriate. It can provide benefit $49,064 over alternative C2 as shown in Fig 4.12, illustrated policy suggestion. It presents only the optimum part of decision tree. It shows option was chosen alternative node by illustrating a reduced version of decision tree, with the optimum path highlighted and the expected cost. The probabilities of each path are also displayed. The summary of statistical can be seen in Table 4.6.

Table 4.6 Statistical summary for decision tree “model 2A”

Statistics	Alternative SP-(straight pull)	Alternative C1-(cutting 1 cut & pull)	Alternative C2-(cutting 2 cut & pull)
Mean	$70,522	$91,463	$119,586
Minimum	$160,451	$157,496	$151,123
Maximum	$63,861	$83,754	$112,289
Mode	$63,861	$83,754	$112,289
Std. Deviation	15028	14296	10795
Skewness	-2.3	-2.1	-1.1
Kurtosis	8.3491	6.9385	3.2277

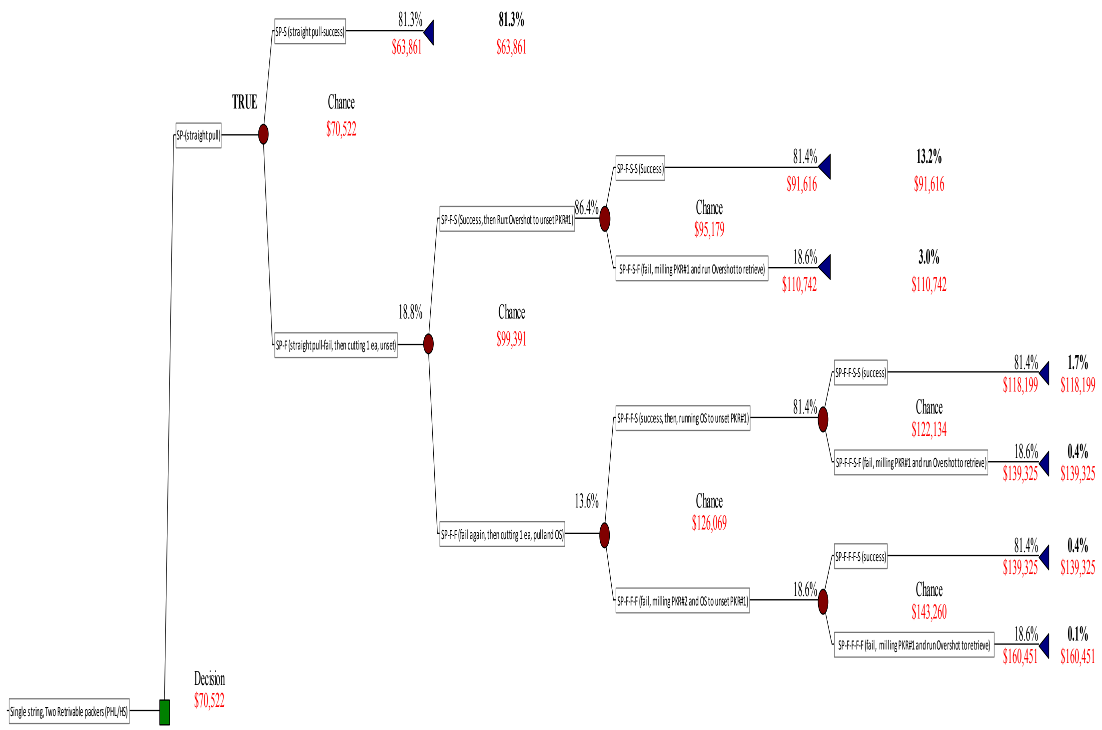

Figure 4.12 Optimum decisions tree suggestion “model 2A”

4.2.2 Result of decision tree analysis model 2B

To construct a decision tree, it is used to find optimum operation cost for workover single zone completion, two zones completion, two retrievable packers – RH/FH packer type, represent by decision node (square). The decision tree has decision node for making decision, represented by square. There are three decision alternatives (SP, C1 and C2) as illustrated in Figure 4.13a, 4.13b which consists of;

- Alternative SP: unsetting all retrievable packers (PKR#2, 1) by straight pulling.
- Alternative C1: cutting 1 cut, above PKR #1, and unsetting retrievable packer (PKR#2) by straight pulling. After that, running BHA: overshot to unset PKR#1.
- Alternative C2: cutting 2 cut, above PKR #1, 2, then pulling above part and running BHA: overshot to unset each PKR # 2, 1, respectively.

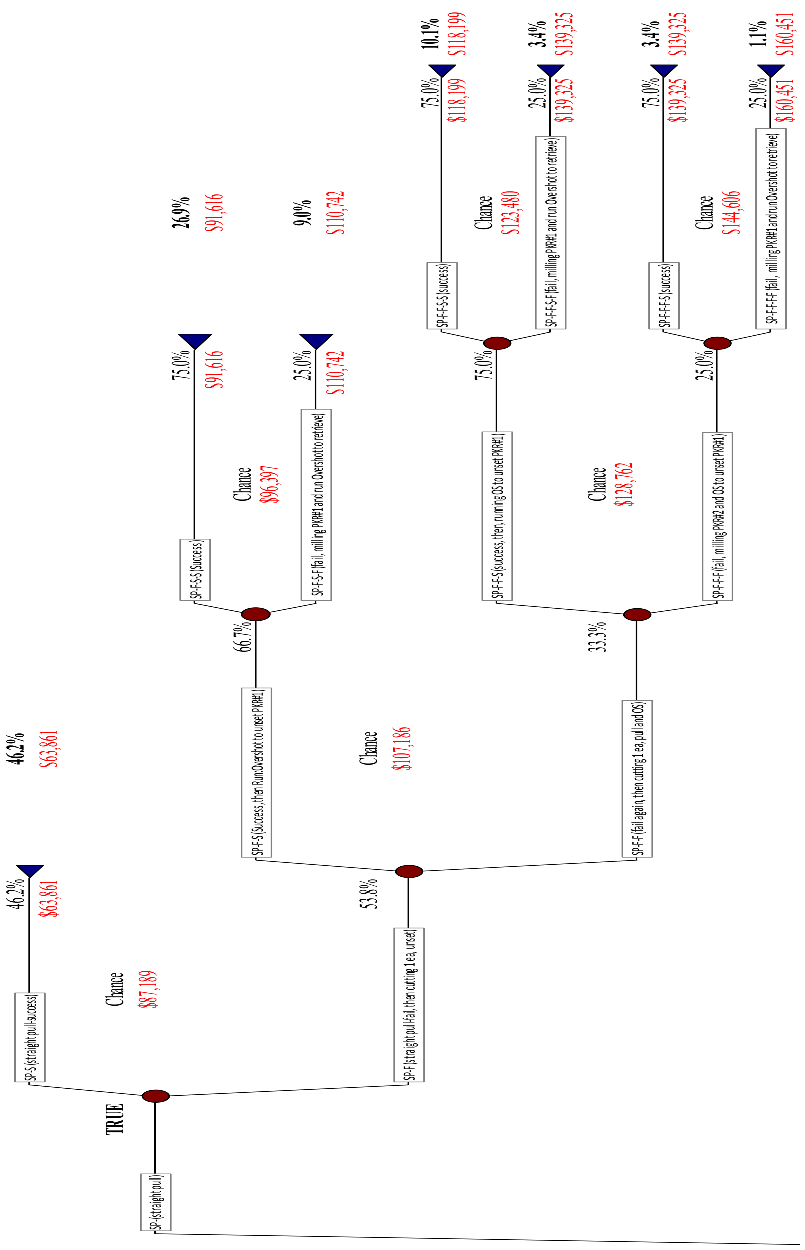

Figure 4.13a Decision tree for “model 2B”

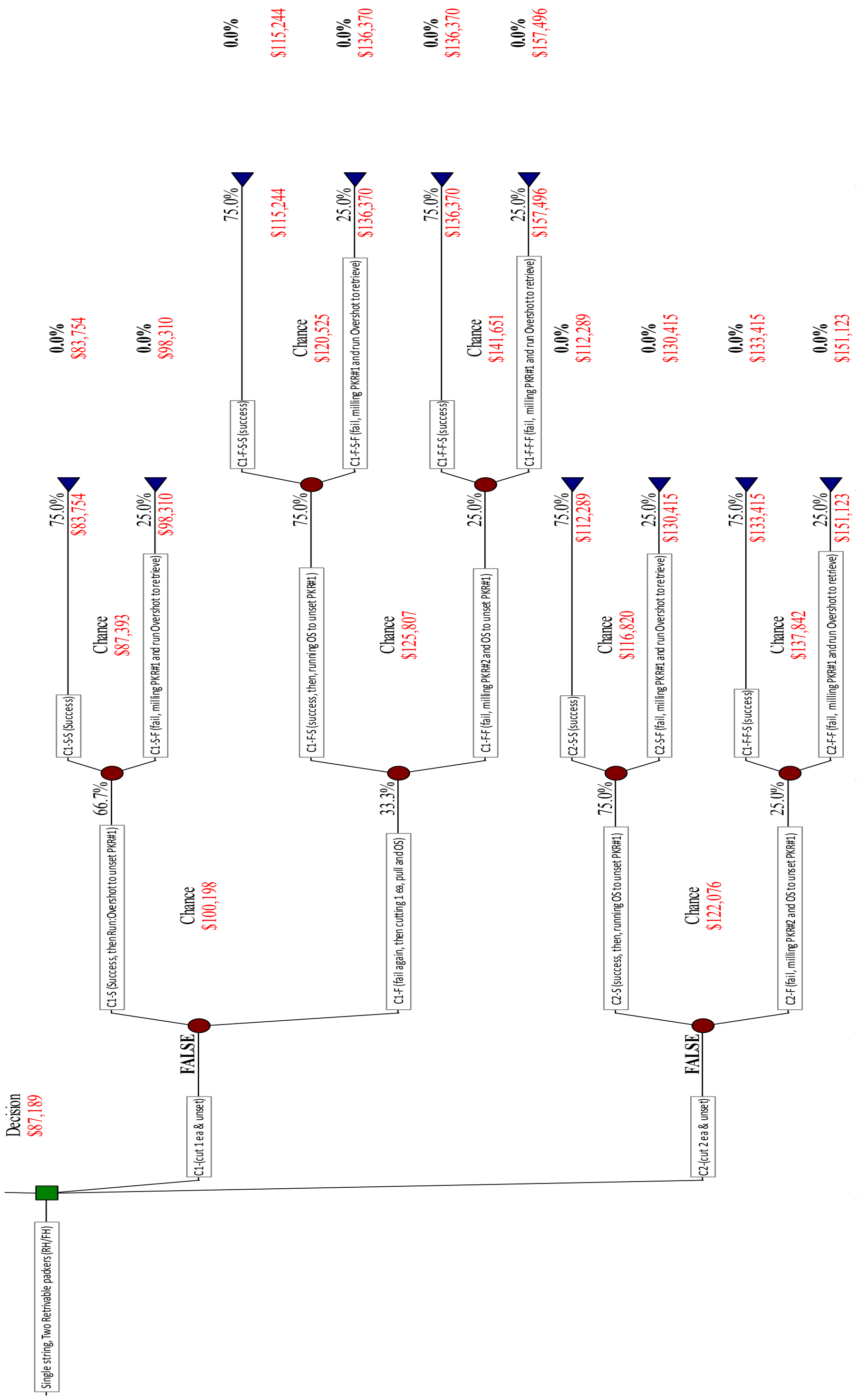

Figure 4.13b Decision tree for “model 2B”

The risk profile is a distribution function. It shows in a discrete density distribution which described the chance associated with all of possible outcome. It also demonstrates the uncertainty of decision using a frequency or cumulative frequency graph.

Figure 4.14 illustrates the probability chart, the height of the alternative node "SP line at $160,451 is 1.10%, which is equal to the probability that the expected cost of alternative node "SP is $160,451.

Figure 4.5 illustrates the cumulative chart, the probability that the alternative node "SP" a value less than or equal to $$63,861 is 100%.

Table 4.7 also illustrated the statistical summary of the risk profile, which provides a statistical summary report of the decision analysis.

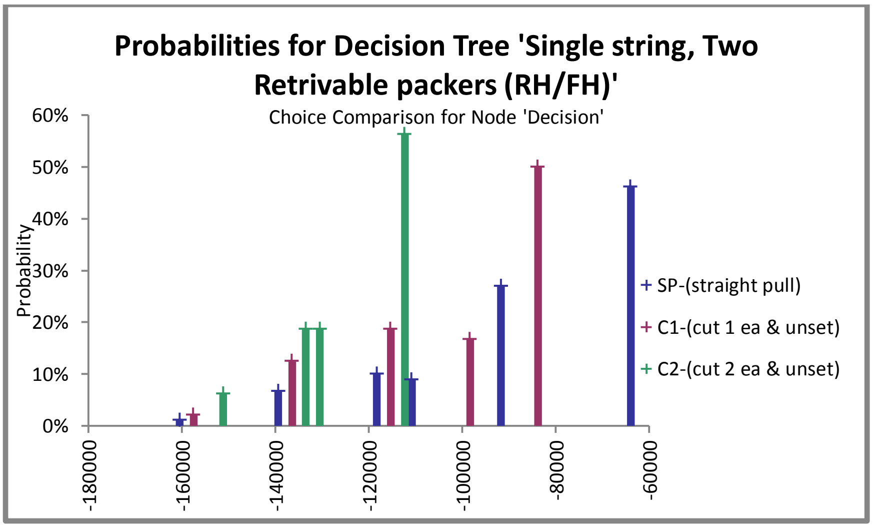

Figure 4.14 Probability decision for decision tree "model 2B"

Table 4.7 Summary data of Probability decision for decision tree "model 2B"

Expected cost	Alternative SP-(straight pull)		Alternative C1-(cutting 1 cut & pull)		Alternative C2-(cutting 2 cut & pull)	
	Value	Probability	Value	Probability	Value	Probability
#1	$160,451	1.10%	$157,496	2.10%	$151,123	6.30%
#2	$139,325	6.70%	$136,370	12.50%	$133,415	18.80%
#3	$118,199	10.10%	$115,244	18.80%	$130,415	18.80%
#4	$110,742	9.00%	$98,310	16.70%	$112,289	56.30%
#5	$91,616	26.90%	$83,754	50.00%		
#6	$63,861	46.20%				

Result of constructing risk profile, alternative "SP" has six expected costs as $63,861, $91,616, $110,742, $118,199, $139,325, $160,451 and probability 46.2 %, 26.9 %, 9.0%, 10.1%, 6.7% and 1.1 %.

Alternative "C1" has five expected costs as $83,754, $98,310, $115,244, $136,370, $157,496 and probability 50.0%, 16.7%, 18.8%, 12.5% and 2.1% respectively as shown in Table 4.7.

Alternative "C2" has four expected costs as $112,289, $130,415, $133,415 and $151,123 with its probability 56.3 %, 18.8%, 18.8% and 6.3 % as shown in Table 4.7 respectively.

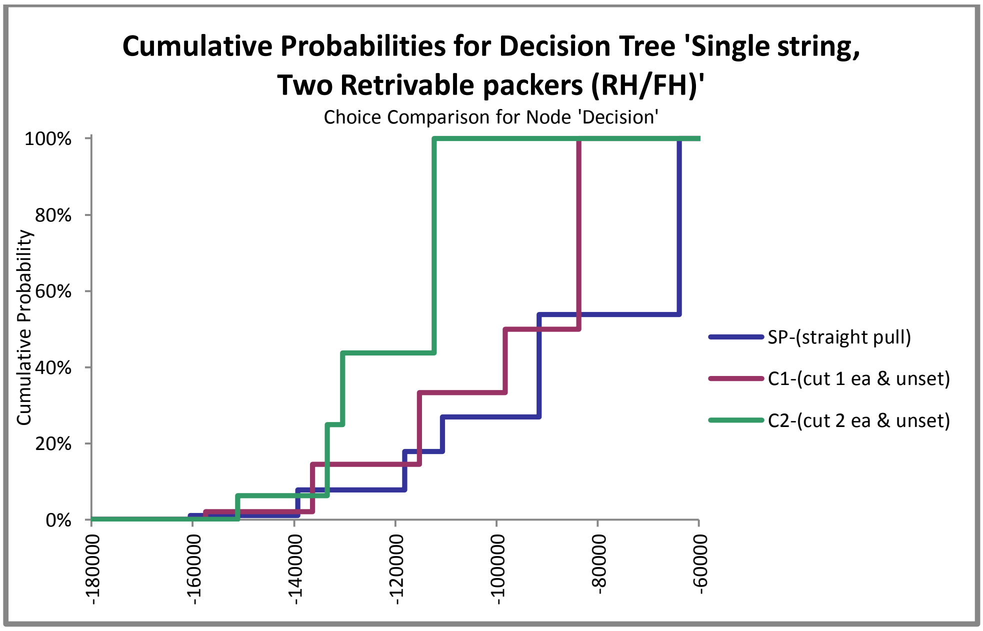

Figure 4.15 Cumulative probabilities for decision tree “model 2B”

Refer decision tree Figure 4.13a, 4.13b, alternative “SP”, the expected cost of unsetting retrievable packer by straight pulling on rig is $87,189, where alternative “C1”, the expected value of cutting 1 cut, above PKR #1, and unsetting retrievable packer (PKR#2) by straight pulling. After that, running BHA: overshot to unset PKR#1, is $100,198 and the expected value of Alternative “C2”, “cutting 2 cut, above PKR #1, 2, then pulling above part and running BHA: overshot to unset each PKR # 2, 1, respectively” is $122,076.

After calculating, the expected cost of alternative “SP” is saving investment cost more than alternative “C1” and “C2”, Therefore, choosing “unsetting retrievable packer by straight pulling” is most appropriate. It can provide benefit $34,886 over alternative “C2” as shown in Fig 4.16, illustrated policy suggestion. It presents only the optimum part of decision tree. It shows option was chosen alternative node by illustrating a reduced version of decision tree, with the optimum path highlighted and the expected cost. The probabilities of each path are also displayed. The summary of statistical can be seen in Table 4.8.

Table 4.8 Statistical summary for decision tree “model 2B”

Statistics	Alternative SP-(straight pull)	Alternative C1-(cutting 1 cut & pull)	Alternative C2-(cutting 2 cut & pull)
Mean	$87,189	$100,198	$122,076
Minimum	$160,451	$157,496	$151,123
Maximum	$63,861	$83,754	$112,289
Mode	$63,861	$83,754	$112,289
Std. Deviation	25426.12	20253.11	11989.98
Skewness	-0.75	-0.99	-0.8
Kurtosis	2.58	2.88	2.6

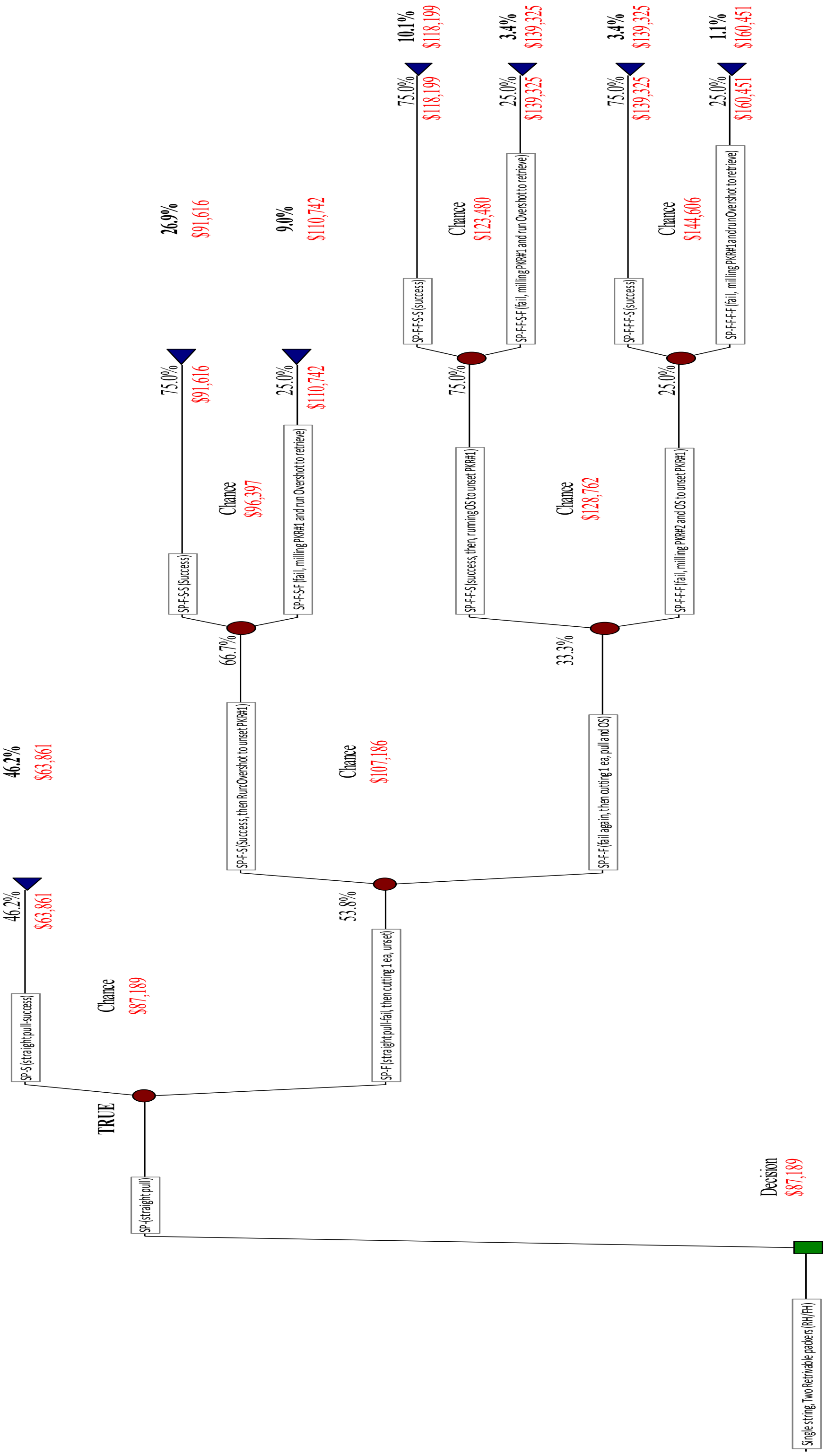

Figure 4.16 Optimum decisions tree suggestion “model 2B”

4.3 Result of decision tree analysis three zones completion

4.3.1 Result of decision tree analysis model 3A

To construct decision tree, it is used to find optimum operation cost for workover three zones completion, three retrievable packers – PHL/HS packer type, represent by decision node (square). There are four decision alternatives (SP, C1, C2 and C3) as illustrated in Figure 4.17a-4.17f, which consists of;

- Decision alternative SP: unsetting all retrievable packers (PKR#3, 2, 1) by straight pulling.
- Decision alternative C1: cutting 1 cut, above PKR#1, and unsetting retrievable packer (PKR#3, 2) by straight pulling. After that, running BHA: overshot to unset PKR#1.
- Decision alternative C2: cutting 2 cut, above PKR#1, 2 and unsetting retrievable packer (PKR#3) by straight pulling. After that, running BHA: overshot to unset PKR#2, 1, respectively.
- Decision alternative C3: cutting 3 cut, above PKR#1, 2, 3 and pulling above part. After that, running BHA: O-shot to unset PKR # 3, 2, 1, respectively.

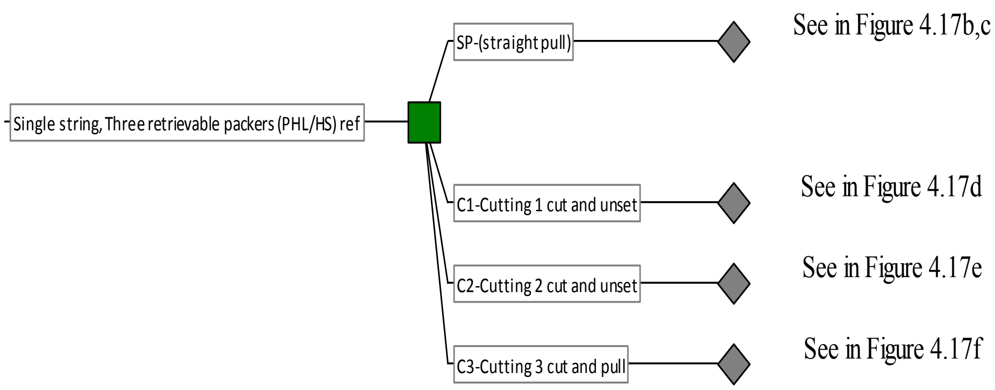

Figure 4.17a Decision tree for “model 3A”

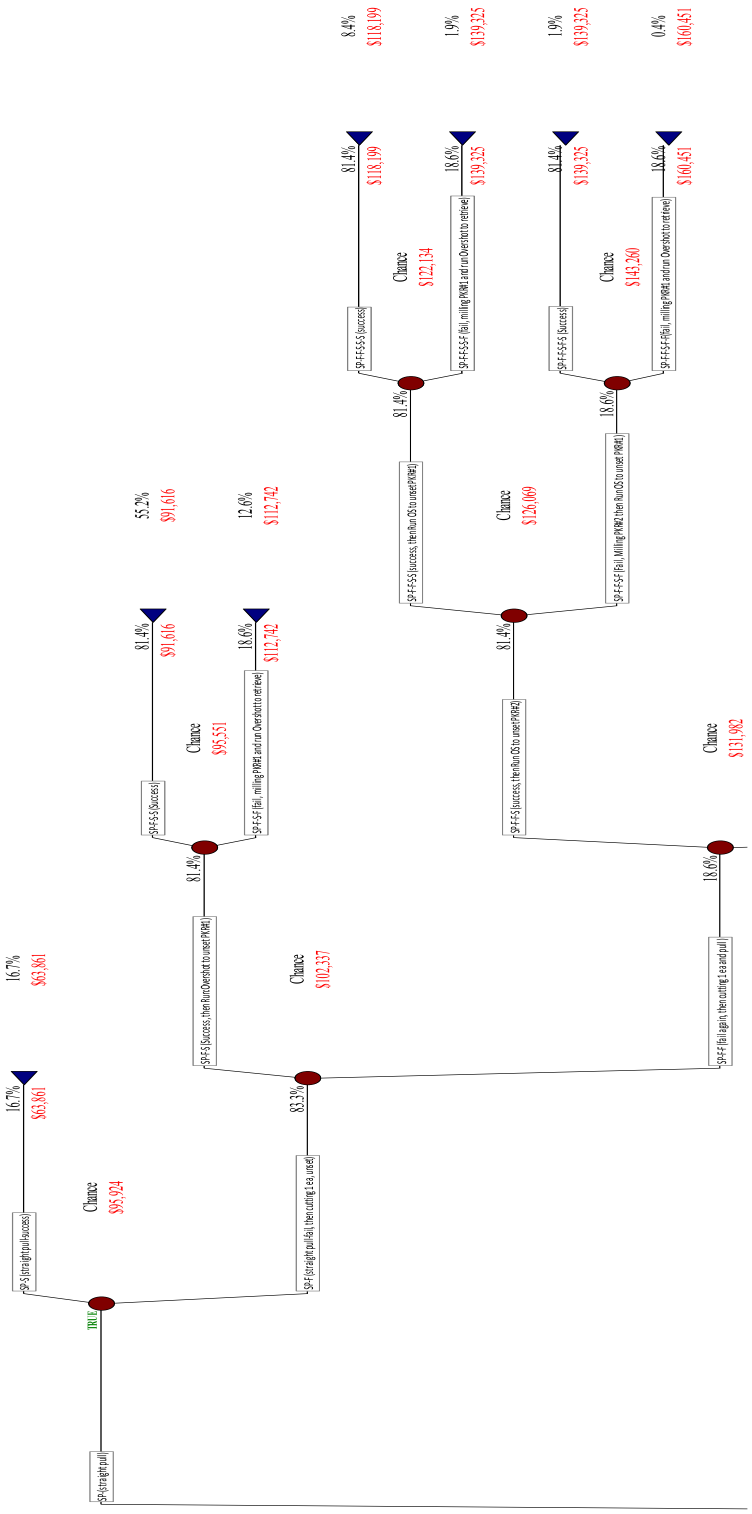

Figure 4.17b Decision tree for “model 3A”

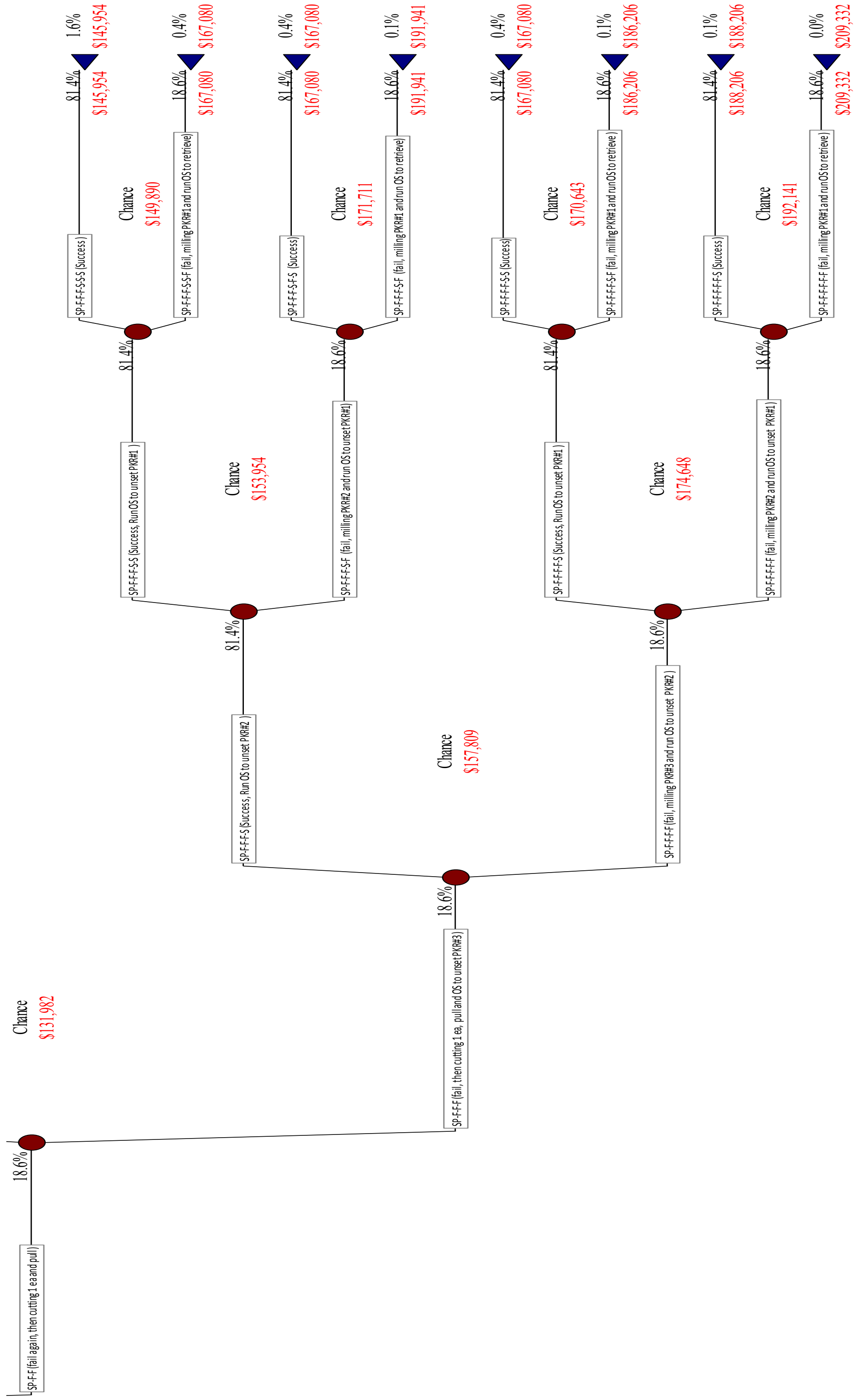

Figure 4.17c Decision tree for “model 3A”

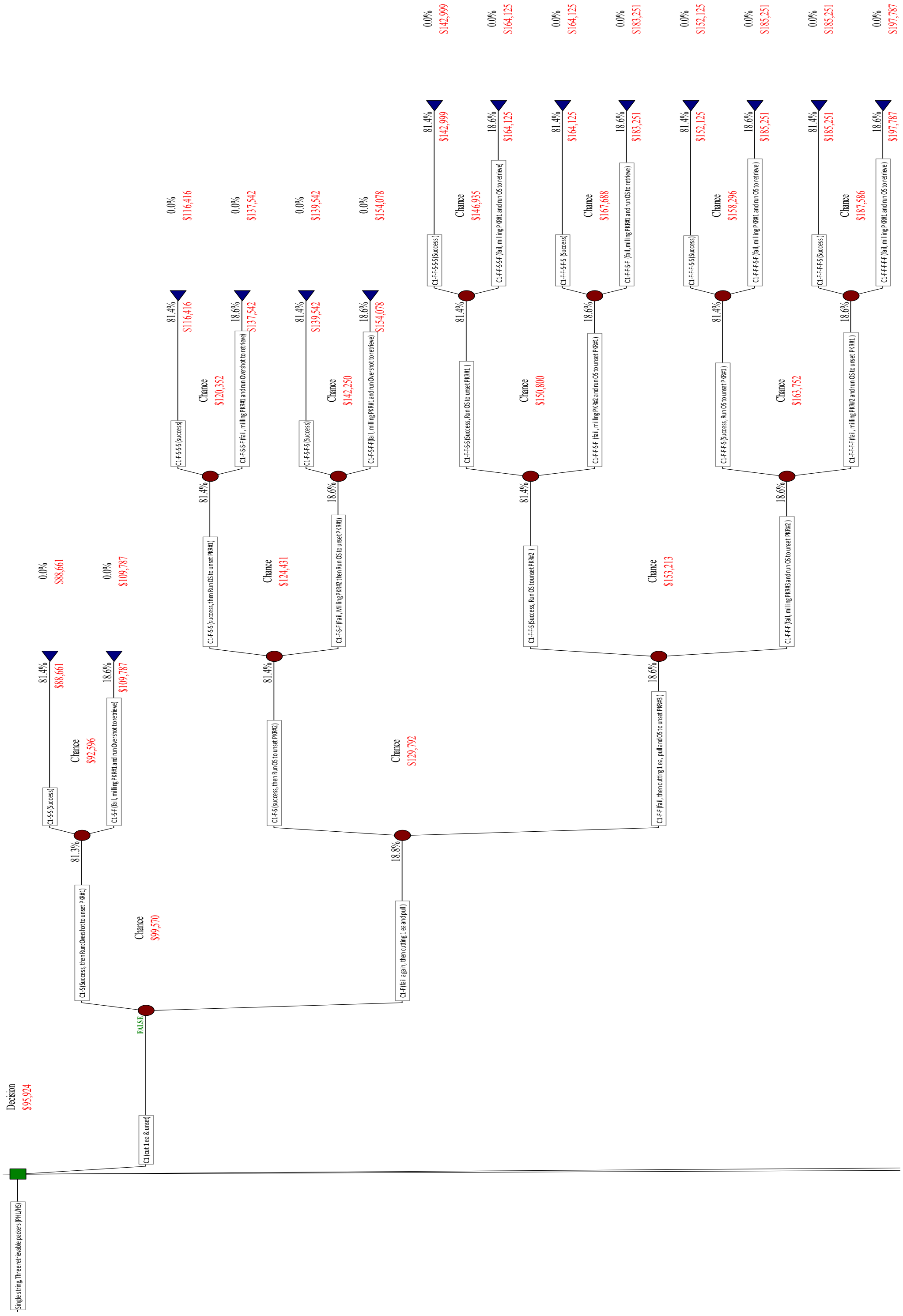

Figure 4.17d Decision tree for “model 3A”

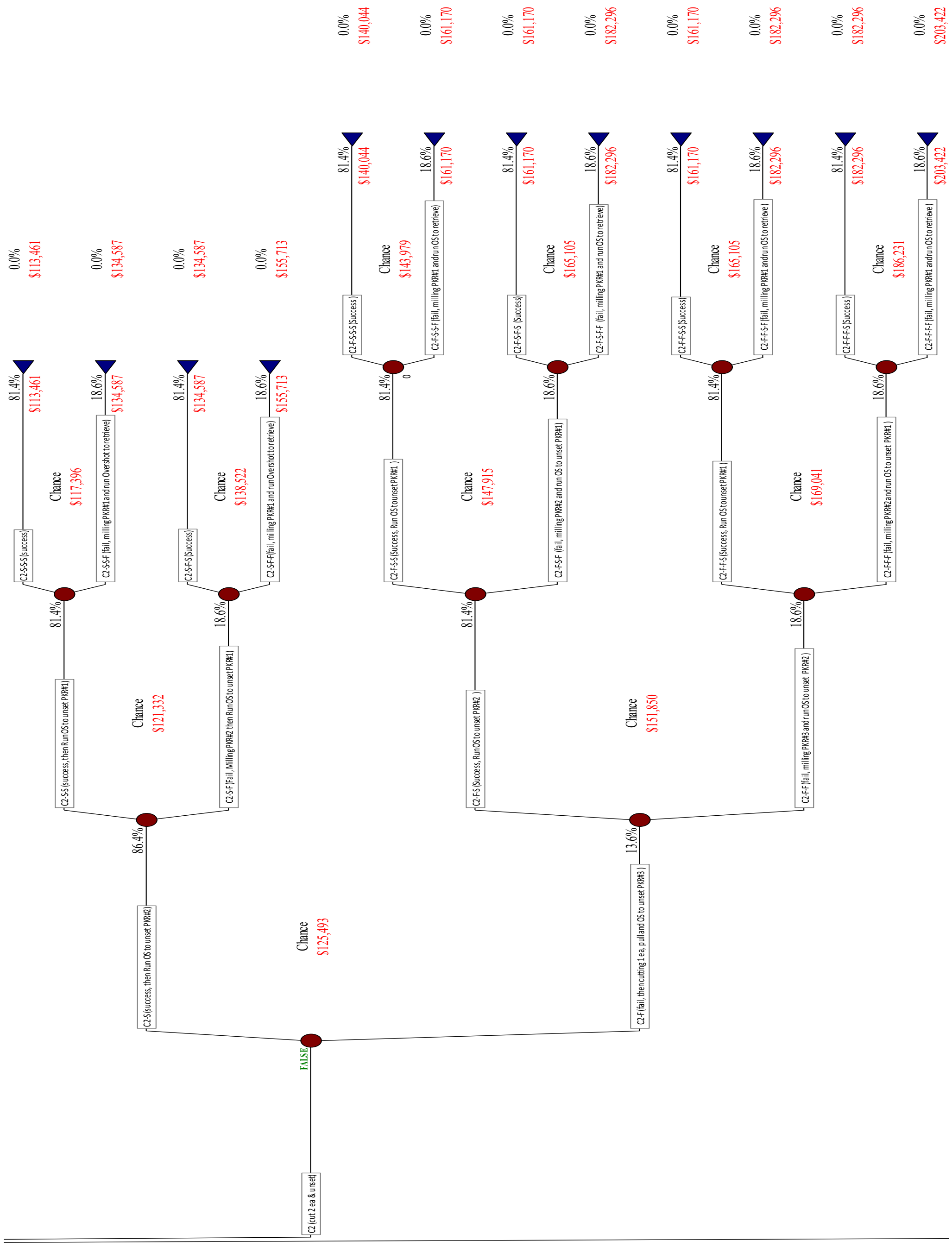

Figure 4.17e Decision tree for “model 3A”

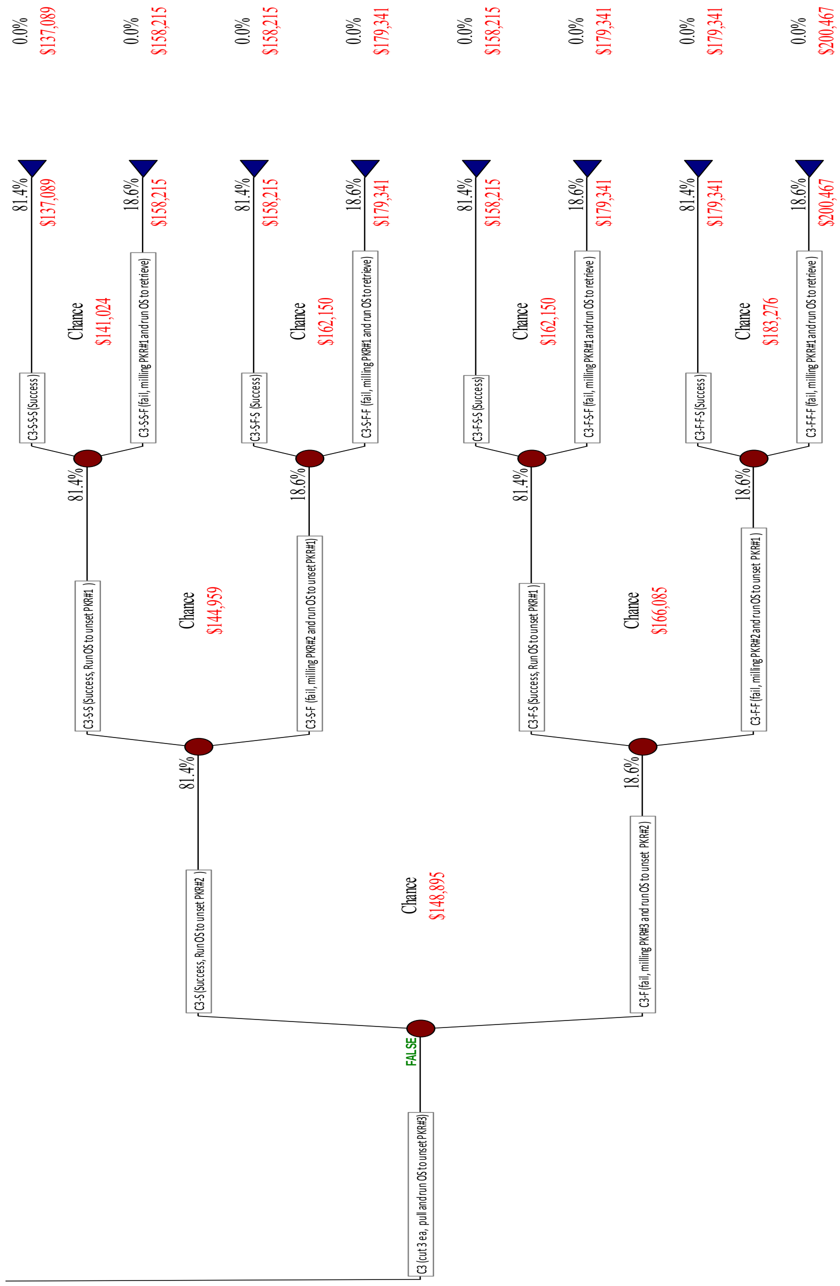

Figure 4.17f Decision tree for “model 3A”

The risk profile is a distribution function. It shows in a discrete density distribution which described the chance associated with all of possible outcome. It also demonstrates the uncertainty of decision using a frequency or cumulative frequency graph.

Figure 4.18 illustrates the probability chart, the height of the alternative node “SP line at $209,332 is 0.019%, which is equal to the probability that the expected cost of alternative node “SP is $209,332.

Figure 4.19 illustrates the cumulative chart, the probability that the alternative node “SP” a value less than or equal to $63,861 is 100%.

Table 4.9 also illustrated the statistical summary of the risk profile, which provides a statistical summary report of the decision analysis.

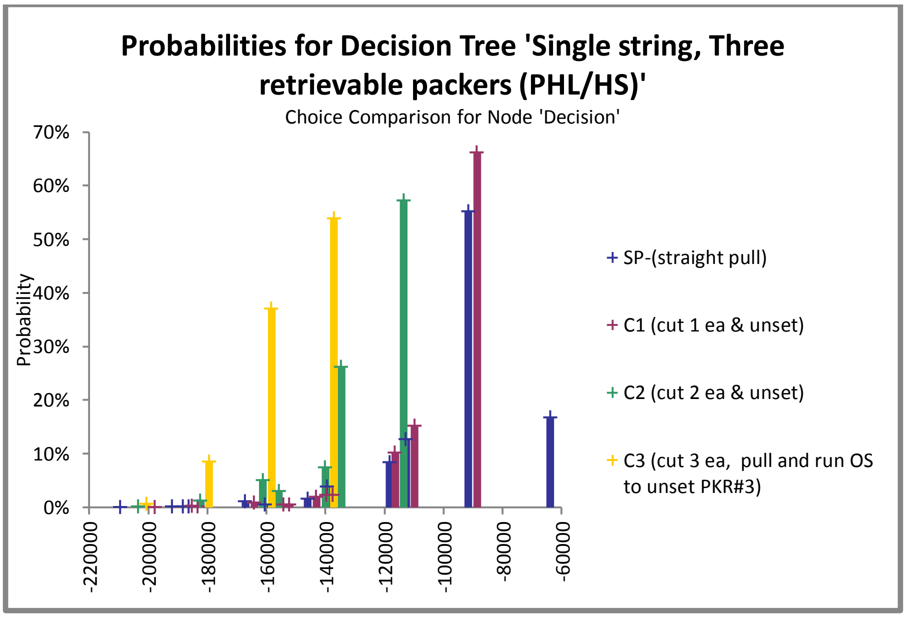

Figure 4.18 Probability decision for decision tree “model 3A”

Table 4.9 Summary data of probability decision for decision tree “model 3A”

Expected cost	Alternative SP-(straight pull)		Alternative C1-(Cut 1 ea and unset)		Alternative C2-(Cut 2 ea and unset)		Alternative C3-(Cut 3 ea and unset)	
	Value	Prob.	Value	Prob.	Value	Prob.	Value	Prob.
#1	$209,332	0.00%	$197,787	0.00%	$203,422	0.10%	$200,467	0.60%
#2	$191,941	0.10%	$185,251	0.20%	$182,296	1.20%	$179,341	8.50%
#3	$188,206	0.10%	$183,251	0.10%	$161,170	5.00%	$158,215	37.00%
#4	$186,206	0.10%	$164,125	0.90%	$155,713	3.00%	$137,089	53.90%
#5	$167,080	1.10%	$154,078	0.50%	$140,044	7.30%		
#6	$160,451	0.40%	$152,125	0.40%	$134,587	26.20%		
#7	$145,954	1.60%	$142,999	1.90%	$113,461	57.20%		
#8	$139,325	3.80%	$139,542	2.30%				
#9	$118,199	8.40%	$137,542	2.30%				
#10	$112,742	12.60%	$116,416	10.10%				
#11	$91,616	55.20%	$109,787	15.10%				
#12	$63,861	16.70%	$88,661	66.10%				

Result of constructing risk profile, alternative “SP” has twelve expected cost and with its probability as summarize in Table 4.9.

Alternative “C1” has twelve expected costs with its probability as summarize in Table 4.9.

Alternative “C2” has seven expected costs with its probability as summarize in Table 4.9.

Alternative “C3” has four expected costs with its probability as summarize in Table 4.9.

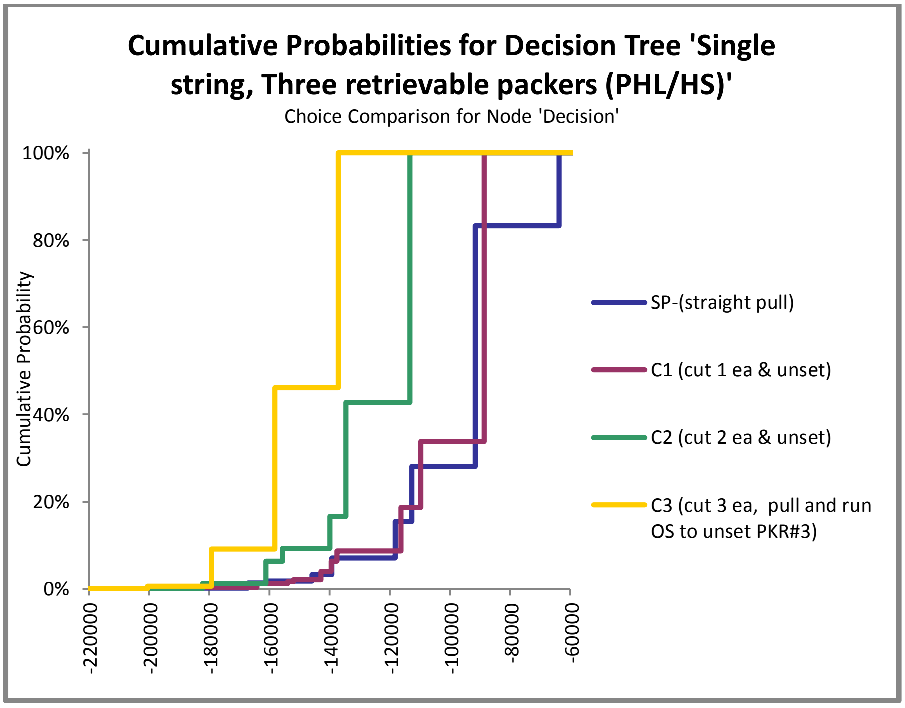

Figure 4.19 Cumulative probabilities for decision tree “model 3A”

Refer decision tree Figure 4.17a-4.17b, at Alternative “SP”, the expected cost of unsetting all retrievable packer (PKR#3, 2, 1) by straight pulling on rig is $95,924.

Where alternative “C1”, the expected cost of cutting 1 cut, above PKR#1, and unsetting retrievable packer (PKR#3, 2) by straight pulling. After that, running BHA: overshot to unset PKR#1 is $99,570.

Alternative “C2”, the expected cost of cutting 2 cut, above PKR#1, 2 and unsetting retrievable packer (PKR#3) by straight pulling. After that, running BHA: overshot to unset PKR#2, 1, respectively, is $125,493.

In the last node, Alternative “C3”, the expected cost of cutting 3 cut above PKR#1, 2, 3 and pulling above part. After that, running BHA: O-shot to unset PKR # 3, 2, 1, respectively, is $148,895.

After calculating, the expected values of decision alternative “SP”, is saving investment cost more than alternative “C1”, “C2” and “C3”, so choosing “unsetting retrievable packer by straight pulling” is most appropriate. It can provide benefit $52,971 over alterative “C2” as shown in Fig 4.20, illustrated policy suggestion. It presents only the optimum part of decision tree. It shows option was chosen alternative node by illustrating a reduced version of decision tree, with the optimum path highlighted and the value and probability of each path displayed. The summary of statistical can be seen in Table 4.10.

Table 4.10 Statistical summary for decision tree "model 3A"

Statistics	Alternative SP-(straight pull)	Alternative C1-(cutting 1 cut & pull)	Alternative C2-(cutting 2 cut & pull)	Alternative C3-(Cut 3 ea and unset)
Mean	$95,924	$99,570	$125,493	$148,895
Minimum	$209,332	$197,787	$203,422	$200,467
Maximum	$63,861	$88,661	$113,461	$137,089
Mode	$91,616	$88,661	$113,461	$137,089
Std. Deviation	21584.63	17777.48	15943.91	14245.94
Skewness	-0.83	-1.76	-1.25	-0.93
Kurtosis	4.63	5.99	4.28	3.2

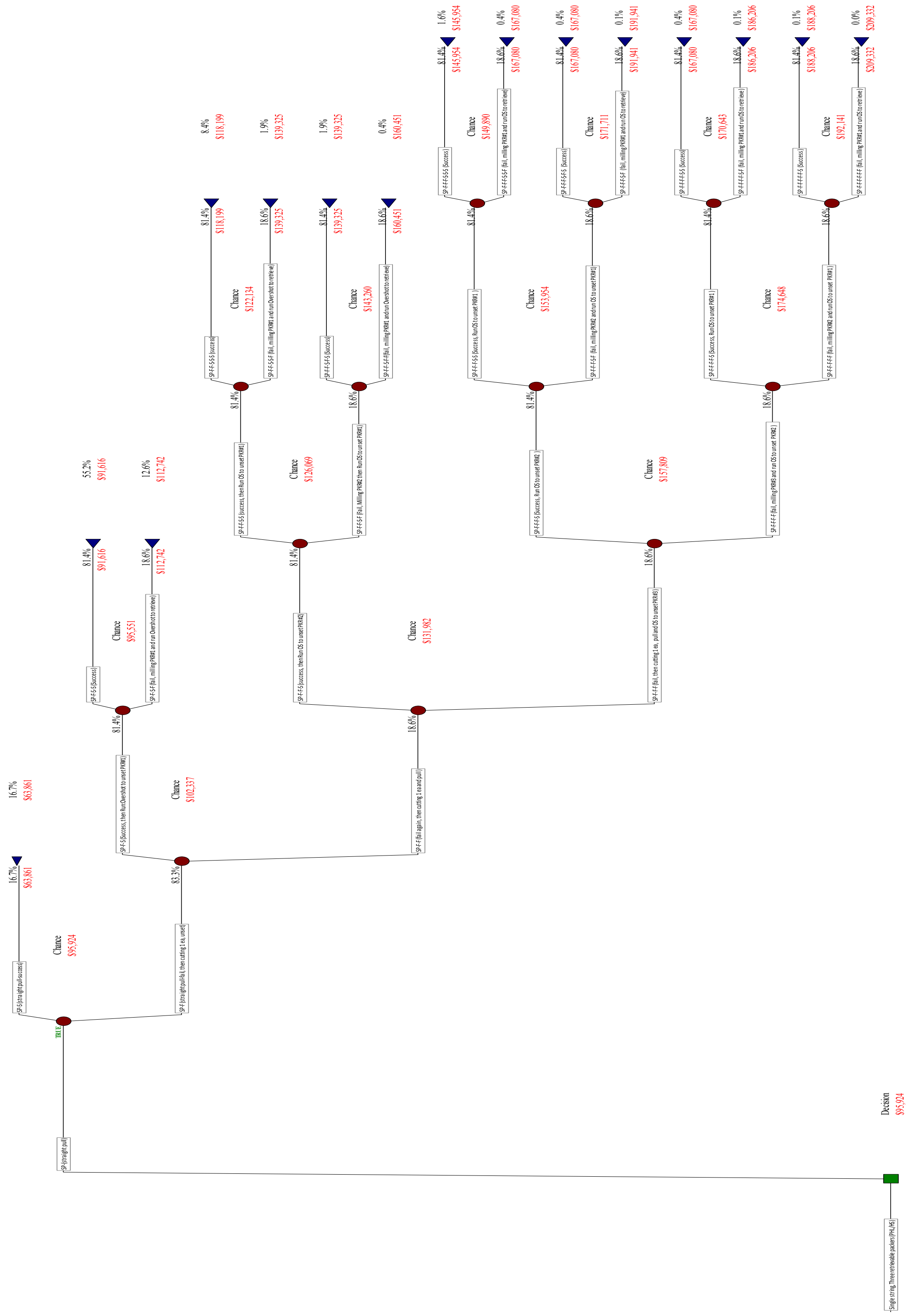

Figure 4.20 Optimum decisions tree suggestion “model 3A”

4.3.2 Result of decision tree analysis model 3B

To construct decision tree, it is used to find optimum operation cost for workover three zones completion, three retrievable packers – RH/FH packer type, represent by decision node (square). There are four decision alternatives (SP, C1, C2 and C3) as illustrated in Figure 4.21a-4.21f, which consists of;

- Decision alternative SP: unsetting all retrievable packers (PKR#3, 2, 1) by straight pulling.
- Decision alternative C1: cutting 1 cut, above PKR#1, and unsetting retrievable packer (PKR#3, 2) by straight pulling. After that, running BHA: overshot to unset PKR#1.
- Decision alternative C2: cutting 2 cut, above PKR#1, 2 and unsetting retrievable packer (PKR#3) by straight pulling. After that, running BHA: overshot to unset PKR#2, 1, respectively.
- Decision alternative C3: cutting 3 cut, above PKR#1, 2, 3 and pulling above part. After that, running BHA: O-shot to unset PKR # 3, 2, 1, respectively.

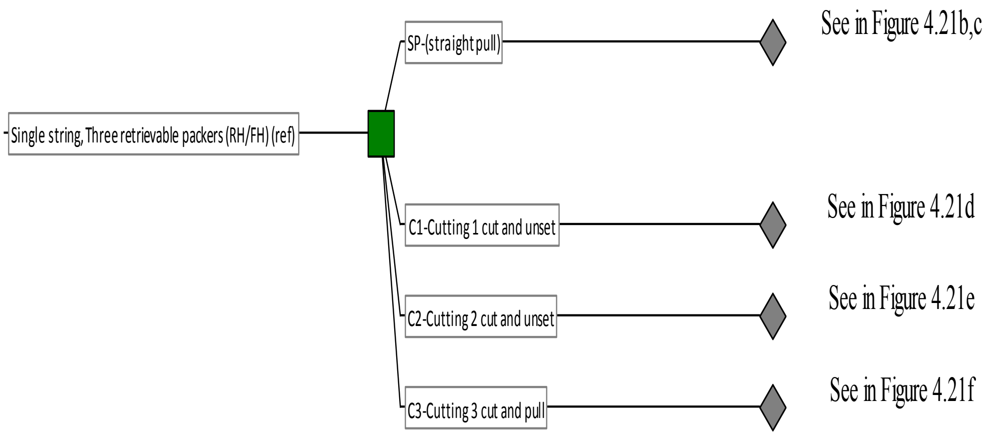

Figure 4.21a Decision tree for “model 3B”

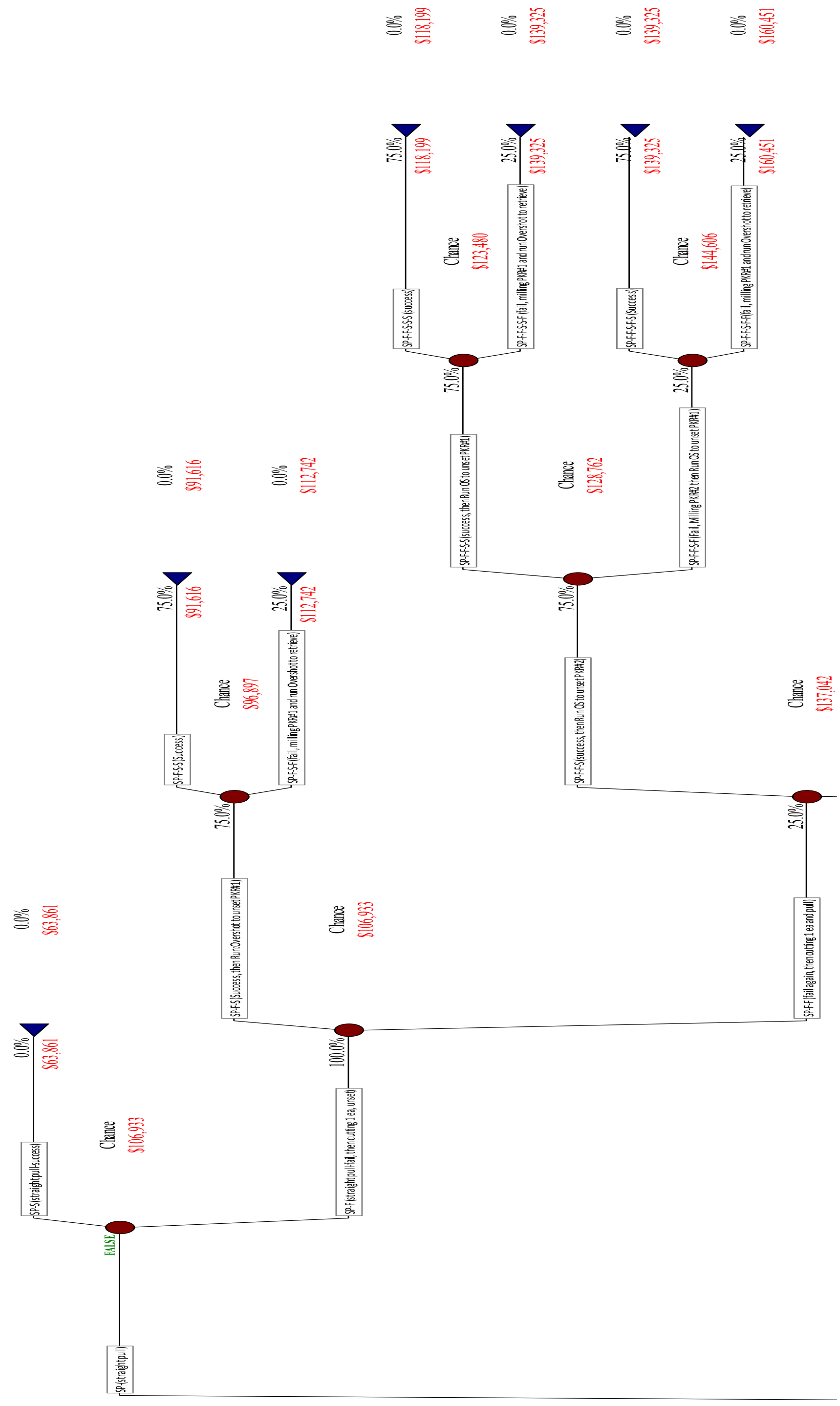

Figure 4.21b Decision tree for “model 3B”

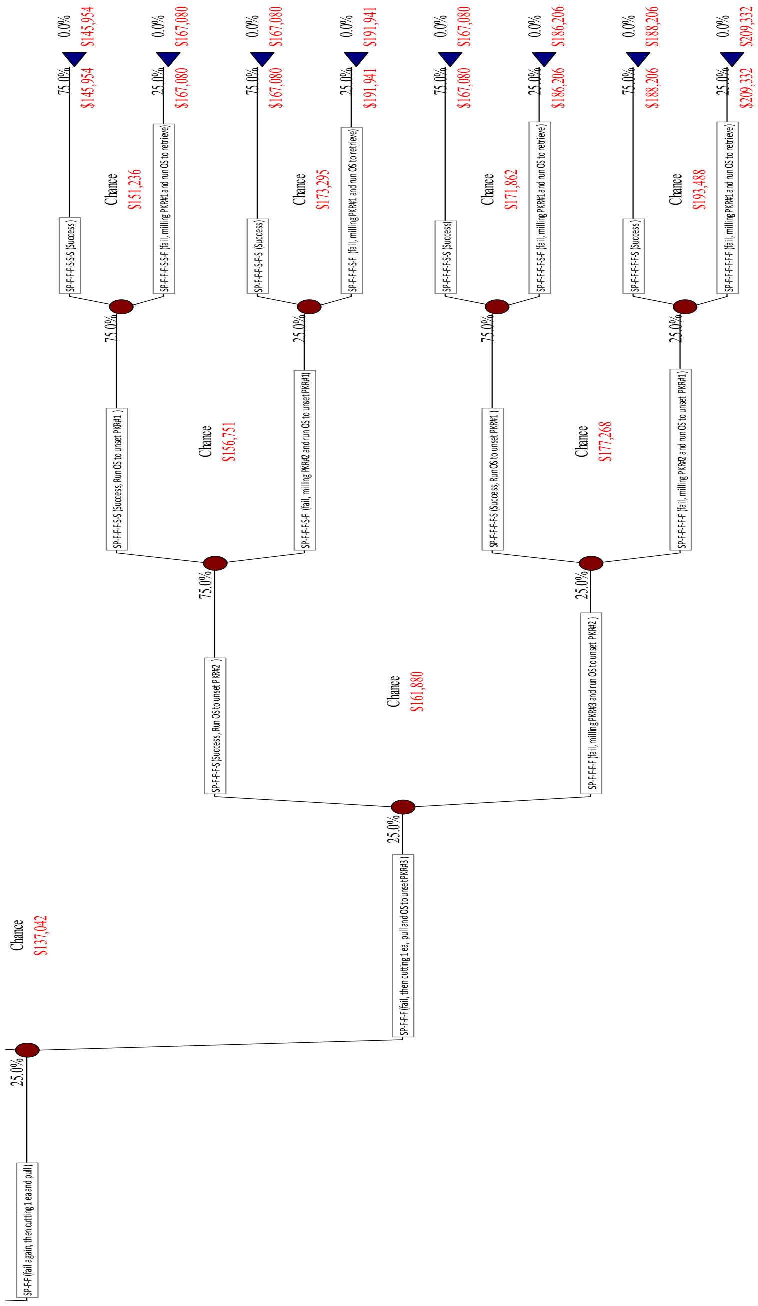

Figure 4.21c Decision tree for “model 3B”

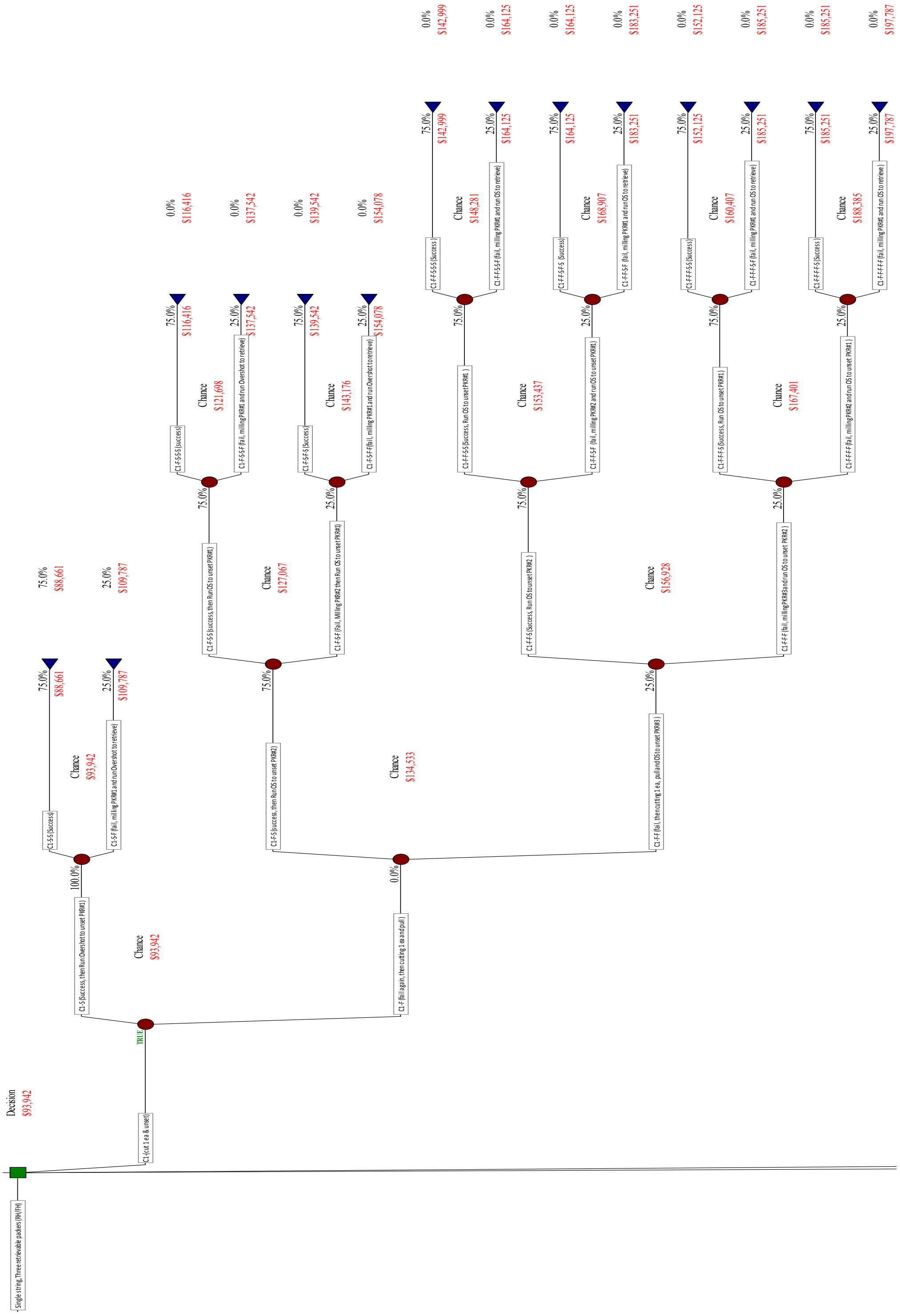

Figure 4.21d Decision tree for "model 3B"

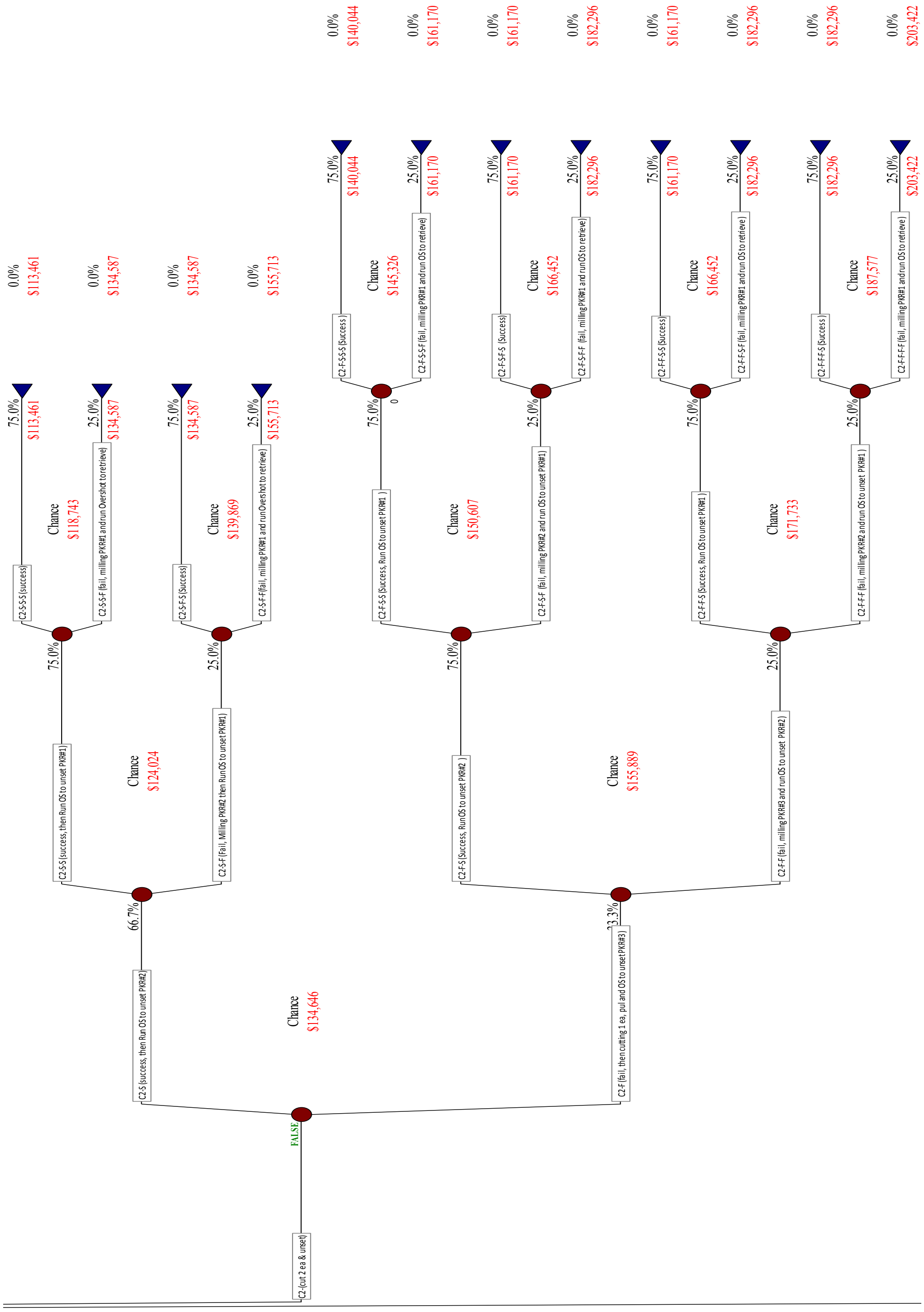

Figure 4.21e Decision tree for “model 3B”

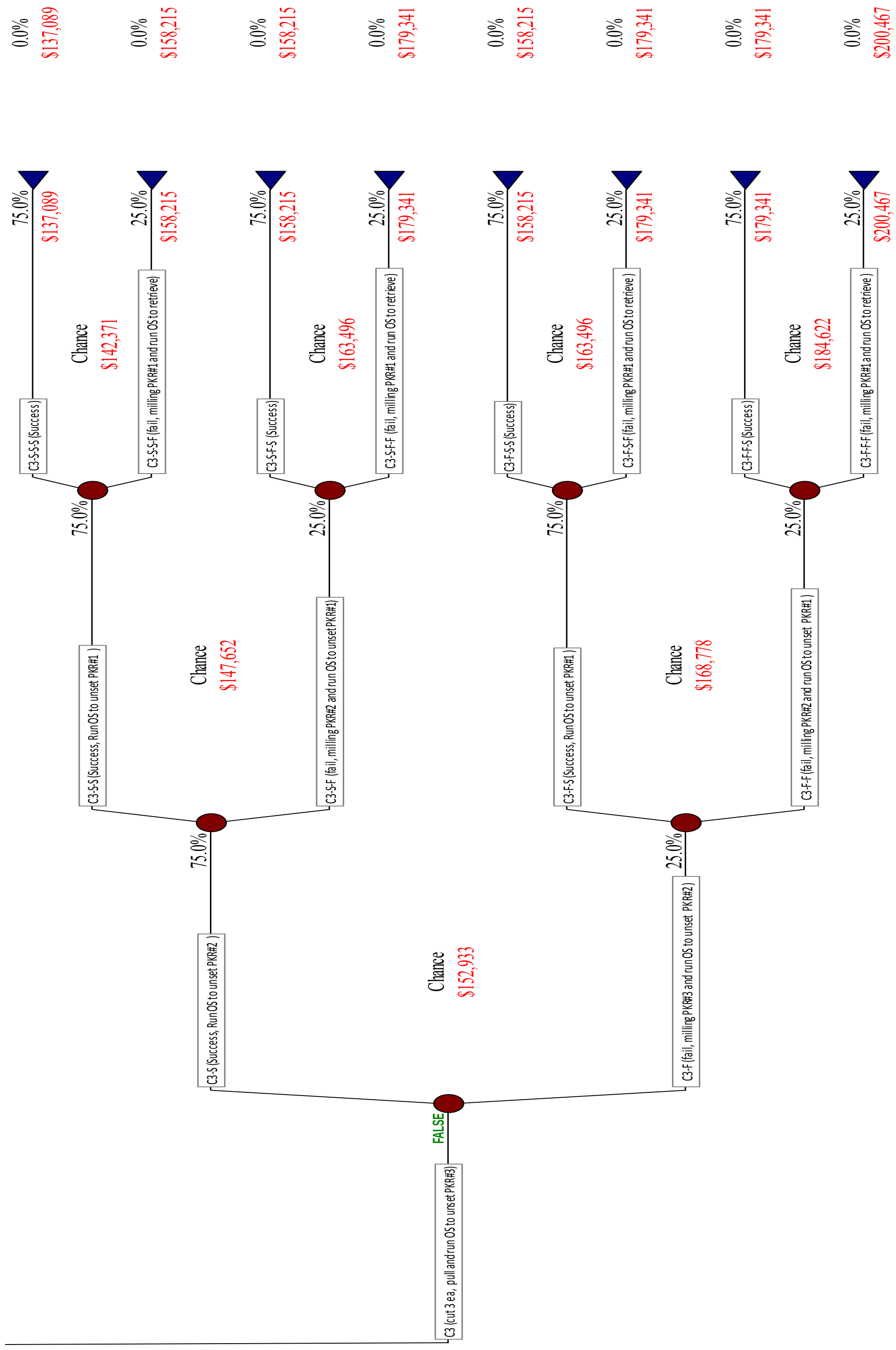

Figure 4.21f Decision tree for “model 3B”

The risk profile is a distribution function. It shows in a discrete density distribution which described the chance associated with all of possible outcome. It also demonstrates the uncertainty of decision using a frequency or cumulative frequency graph.

Figure 4.22 illustrates the probability chart; the height of the alternative node “C1” line at $109,787 is 25.0%, which is equal to the probability that the expected cost of alternative node “SP is $109,787.

Figure 4.23 illustrates the cumulative chart, the probability that the alternative node “C1” a value less than or equal to $88,661 is 100%.

Table 4.11 also illustrated the statistical summary of the risk profile, which provides a statistical summary report of the decision analysis.

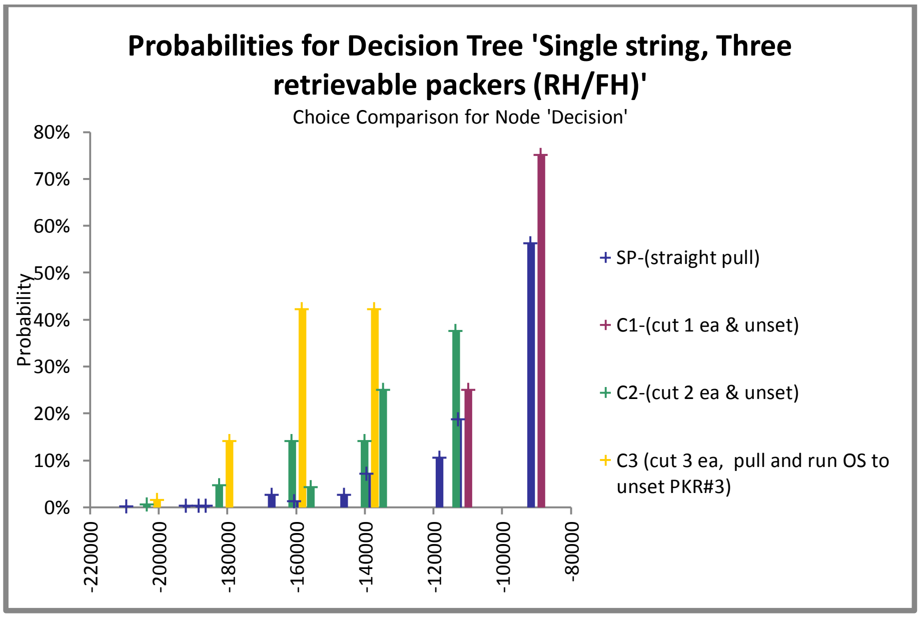

Figure 4.22 Probability decision for decision tree “model 3B”

Table 4.11 Summary data of probability decision for decision tree "model 3B"

Expected cost	Alternative SP-(straight pull)		Alternative C1-(Cutting 1 cut and unset)		Alternative C2-(Cutting 2 cut and unset)		Alternative C3-(Cutting 3 cut and unset)	
	Value	Prob	Value	Prob	Value	Prob	Value	Prob
#1	$209,332	0.10%	$109,787	25.00%	$203,422	0.50%	$200,467	1.60%
#2	$191,941	0.30%	$88,661	75.00%	$182,296	4.70%	$179,341	14.10%
#3	$188,206	0.30%			$161,170	14.10%	$158,215	42.20%
#4	$186,206	0.30%			$155,713	4.20%	$137,089	42.20%
#5	$167,080	2.60%			$140,044	14.10%		
#6	$160,451	1.20%			$134,587	25.00%		
#7	$145,954	2.60%			$113,461	37.50%		
#8	$139,325	7.00%						
#9	$118,199	10.50%						
#10	$112,742	18.80%						
#11	$91,616	56.30%						

Result of constructing risk profile, alternative "SP", has eleven expected cost and with its probability as summarize in Table 4.11.

Alternative "C1" has two expected costs with its probability as summarize in Table 4.11.

Alternative "C2" has seven expected costs with its probability as summarize in Table 4.11.

Alternative "C3" has four expected costs with its probability as summarize in Table 4.11.

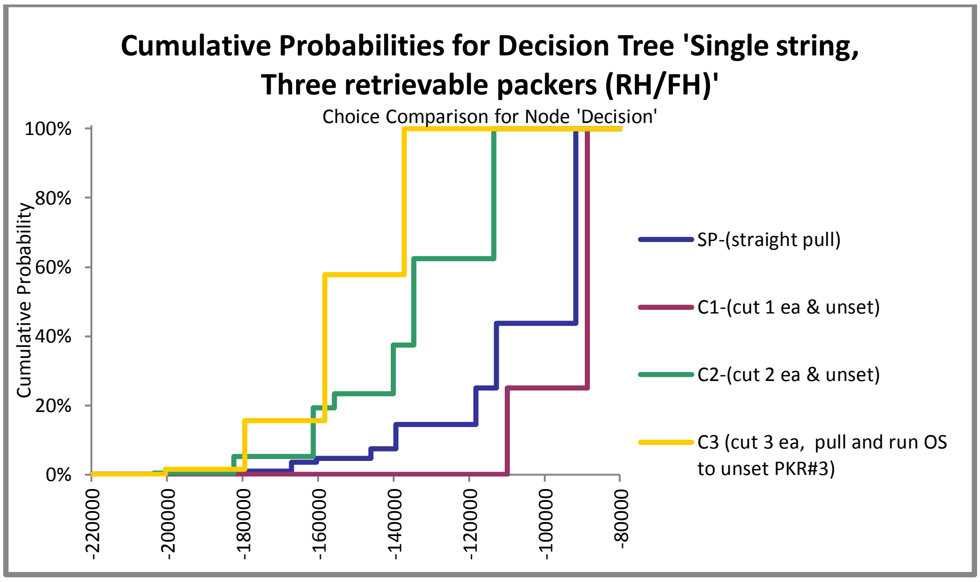

Figure 4.23 Cumulative probabilities for decision tree “model 3B”

At decision tree Figure 4.21a-4.21f, at Alternative “SP” the expected cost of unsetting all retrievable packers (PKR#3, 2, 1) by straight pulling on rig is $106,933.

Where alternative “C1”, the expected cost of cutting 1 cut, above PKR#1, and unsetting retrievable packer (PKR#3, 2) by straight pulling. After that, running BHA: overshot to unset PKR#1 is $93,942.

Alternative “C2”, the expected cost of cutting 2 cut, above PKR#1, 2 and unsetting retrievable packer (PKR#3) by straight pulling. After that, running BHA: overshot to unset PKR#2, 1, respectively, is $134,646.

In the last, Alternative “C3”, the expected cost of cutting 3 cut above PKR#1, 2, 3 and pulling above part. After that, running BHA: O-shot to unset PKR # 3, 2, 1, respectively, is $152,933.

After evaluating, the expected cost of decision alternative “C1”, is saving investment cost more than alternative “SP”, “C2” and “C3”, so choosing “cutting 1 cut above PKR#1, and unsetting retrievable packer (PKR#3, 2) by straight pulling, after that, running BHA: overshot to unset PKR#1” is most appropriate.

It can provide benefit $58,922 over alternative C3 as shown in Fig 4.24, illustrated policy suggestion. It presents only the optimum part of decision tree. It shows option was chosen alternative node by illustrating a reduced version of decision tree, with the optimum path highlighted and the expected cost. The probabilities of each path are also displayed. The summary of statistical can be seen in Table 4.12.

Table 4.12 Statistical summary for decision tree "model 3B"

Statistics	Alternative SP-(straight pull)	Alternative C1-(cutting 1 cut & pull)	Alternative C2-(cutting 2 cut & pull)	Alternative C3-(Cut 3 ea and unset)
Mean	$106,933	$93,942	$134,646	$152,933
Minimum	$209,332	$109,787	$203,422	$200,467
Maximum	$91,616	$88,661	$113,461	$137,089
Mode	$91,616	$88,661	$113,461	N/A
Std. Deviation	21534.42	9147.78	20515.61	15844.41
Skewness	-1.56	-1.15	-0.72	-0.67

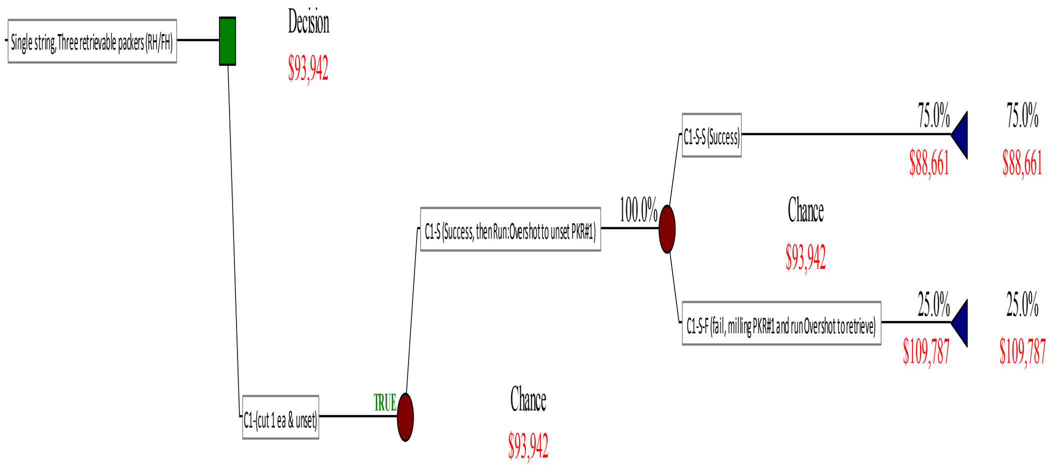

Figure 4.24 Optimum decisions tree suggestion "model 3B"

4.3.3 Result of decision tree analysis model 3C

To construct decision tree, it is used to find optimum operation cost for workover three zones completion, two retrievable packers – RH/FH packer type with one permanent packer, represent by decision node (square). There are four decision alternatives (SP, C1, C2 and C3) as illustrated in Figure 4.25a-4.25g, which consists of;

- Decision alternative SP: unsetting all retrievable packers (PKR#2, 1) and seal by straight pulling.
- Decision alternative C1: cutting 1 cut, above seal and unsetting retrievable packers (PKR #2, 1) by straight pulling. After that, running BHA: overshot to retrieve seal.
- Decision alternative C2: cutting 2 cut, above seal, PKR#1, and unsetting retrievable packer (PKR#2) by straight pulling. After that running BHA: overshot to unset PKR#1 and to retrieve seal, respectively.
- Decision alternative C3: cutting 3 cut, above seal, PKR#1, 2 and then pulling above part. After that, running BHA: O-shot to unset PKR # 2, 1 and seal respectively.

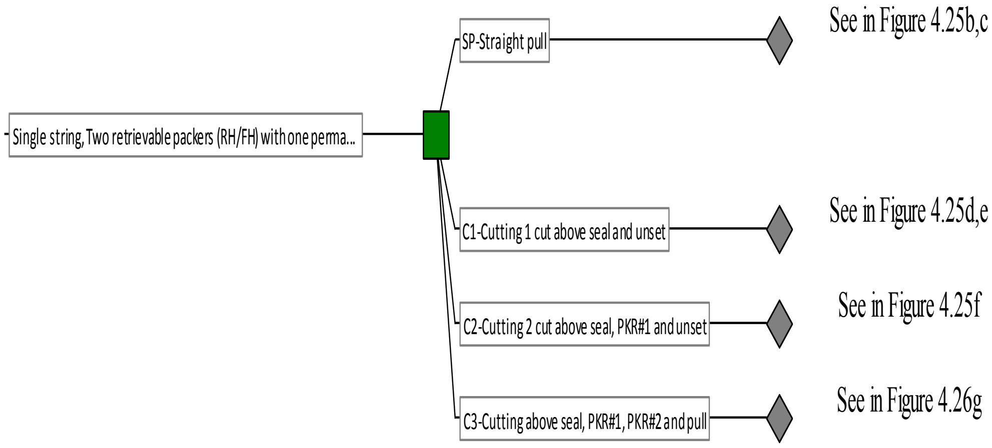

Figure 4.25a Decision tree for “model 3C”

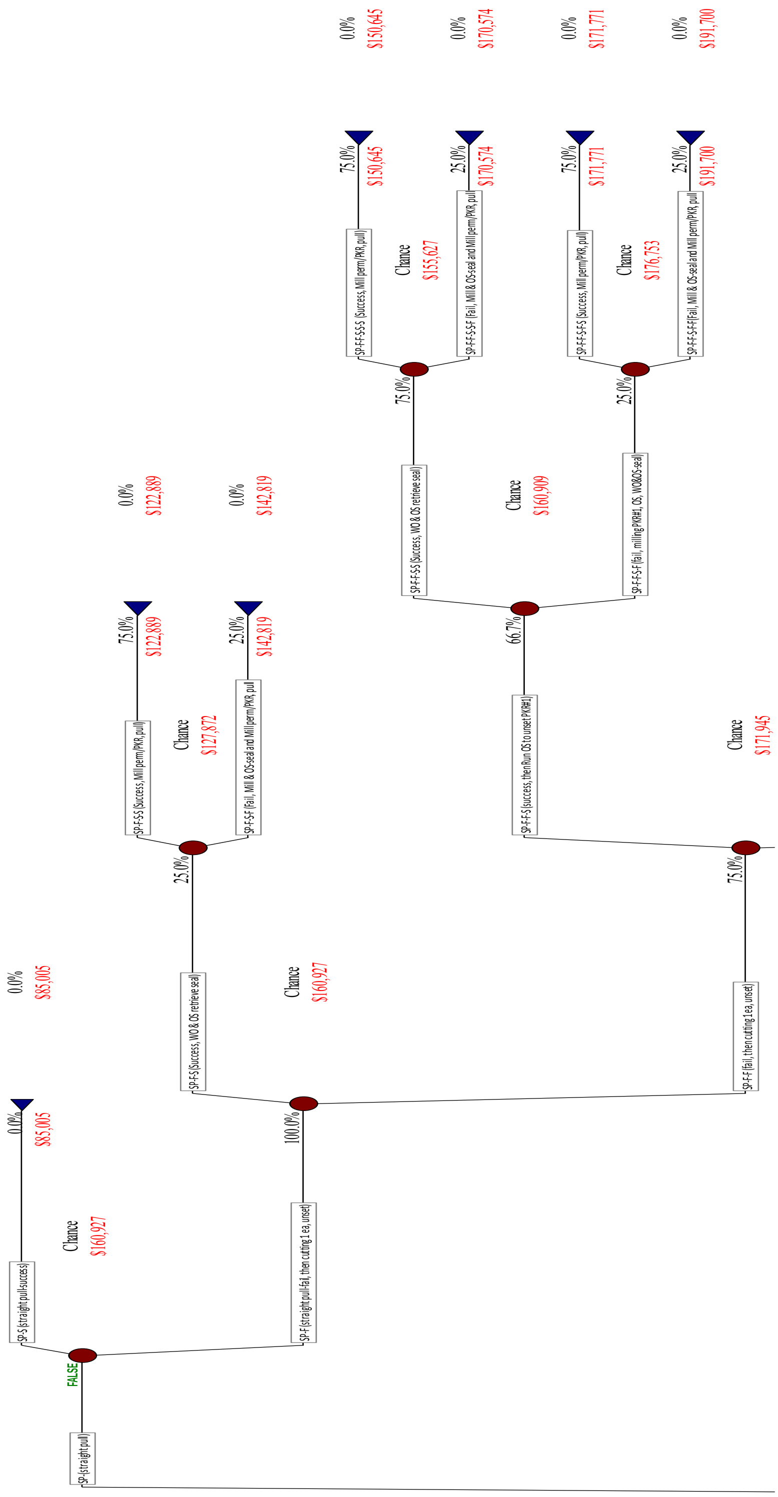

Figure 4.25b Decision tree for “model 3C”

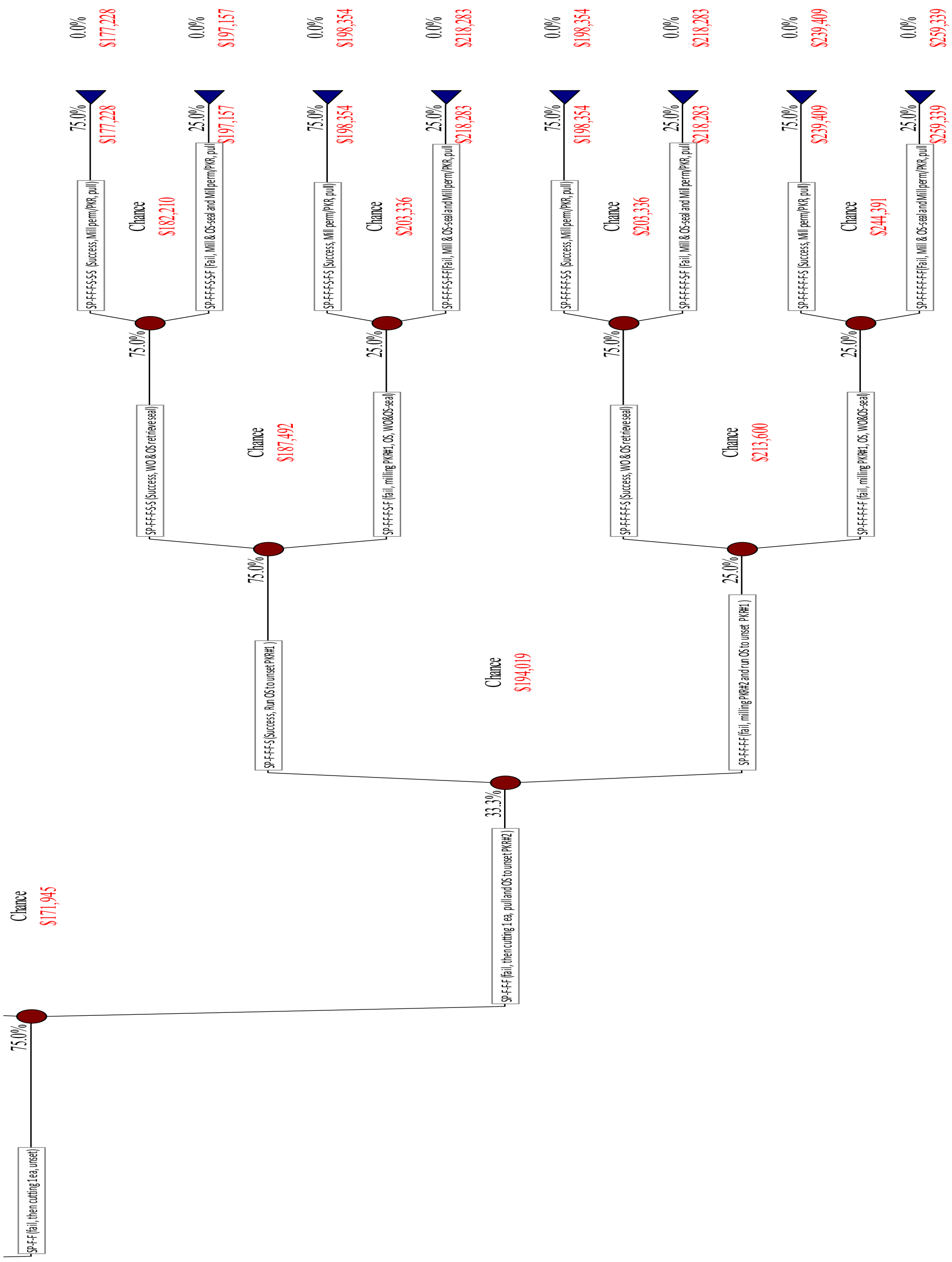

Figure 4.25c Decision tree for “model 3C”

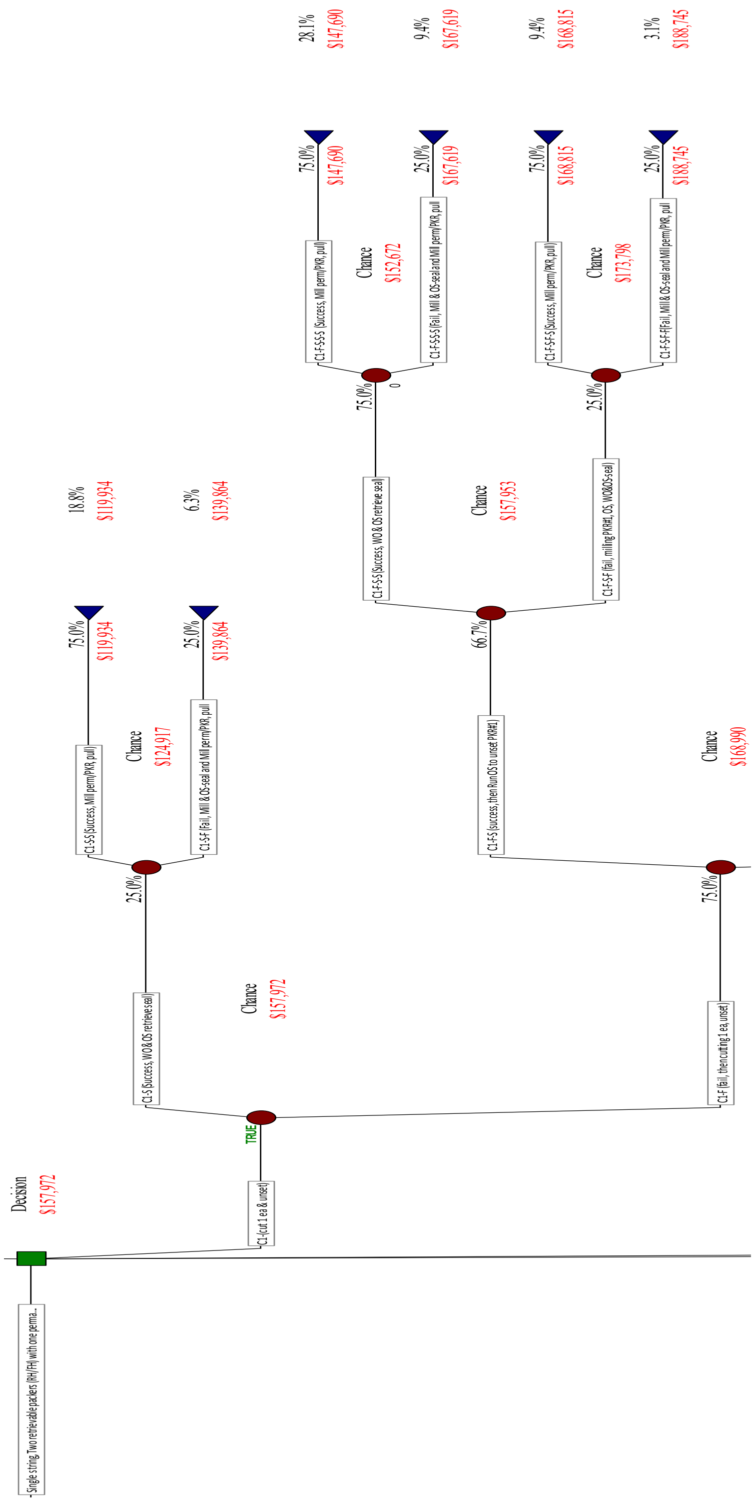

Figure 4.25d Decision tree for “model 3C”

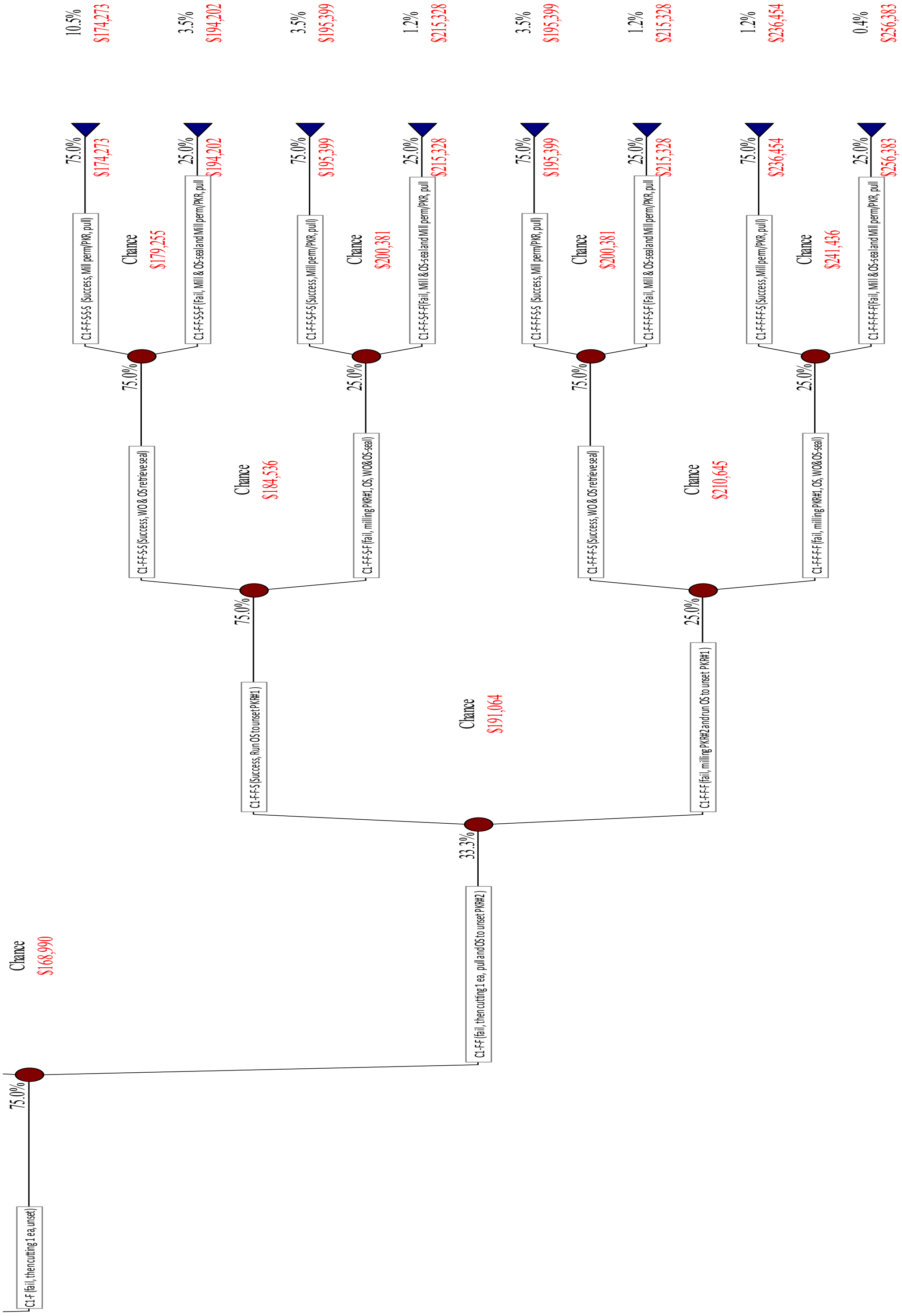

Figure 4.25e Decision tree for “model 3C”

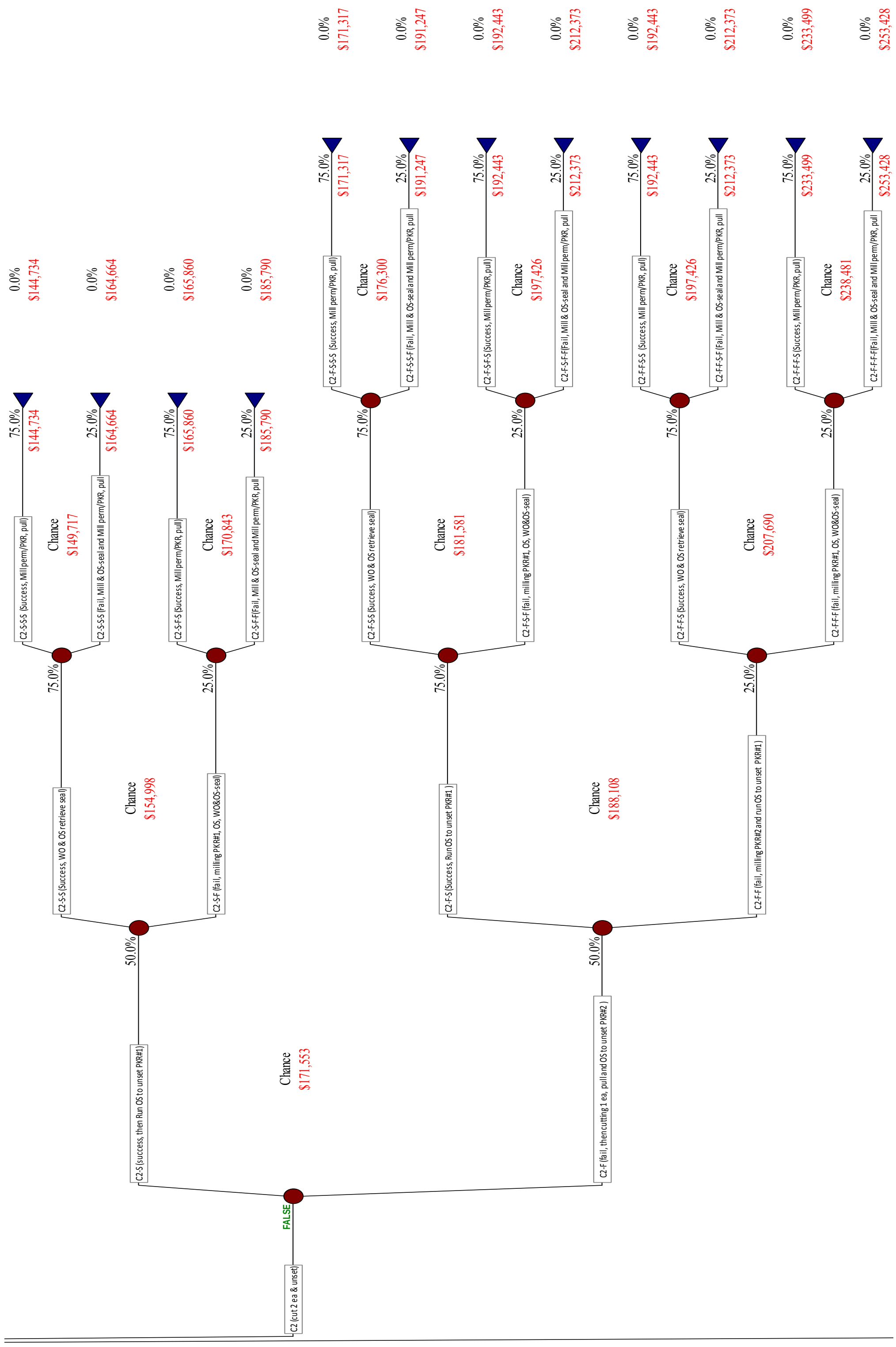

Figure 4.25f Decision tree for "model 3C"

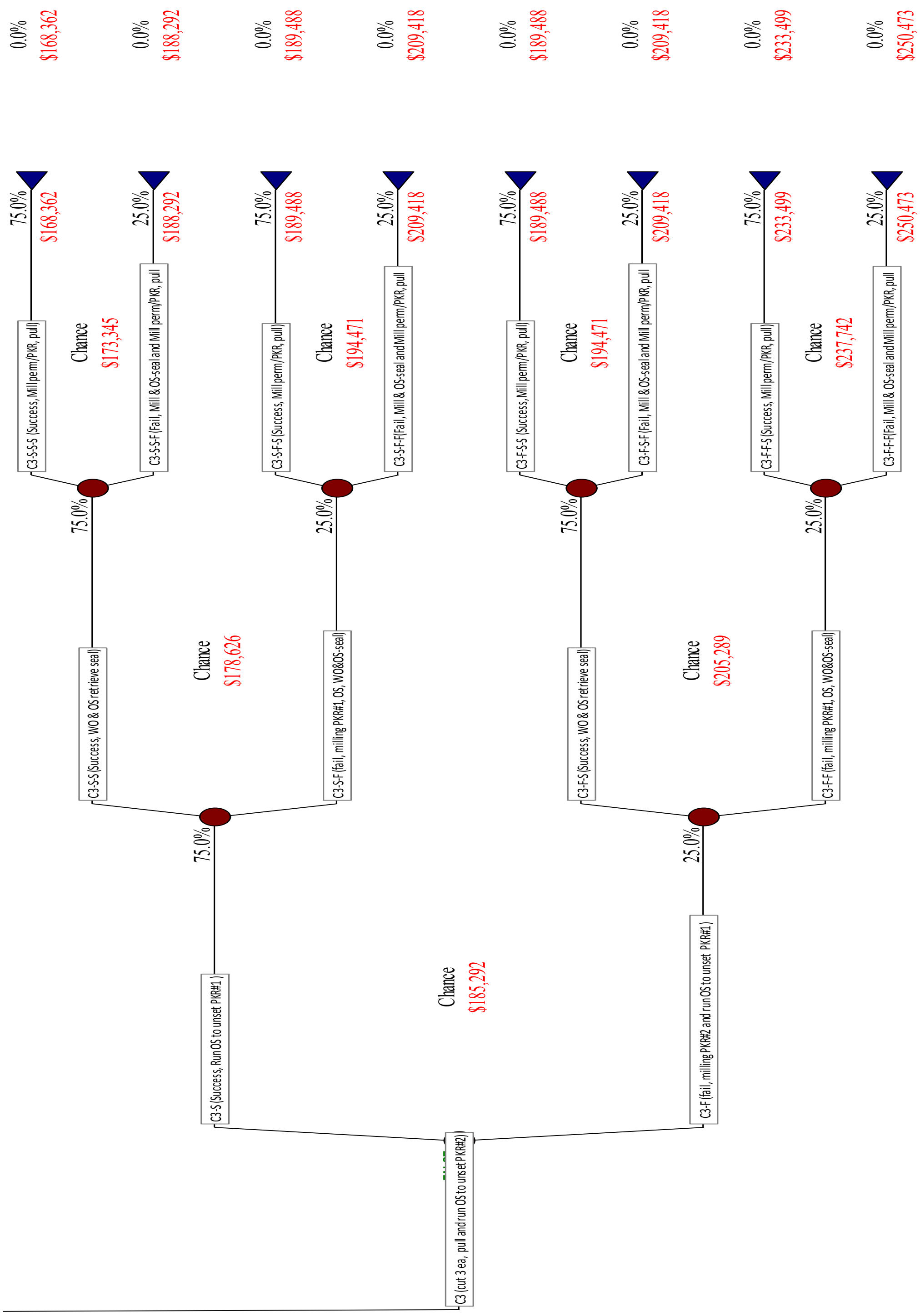

Figure 4.25g Decision tree for “model 3C”

The risk profile is a distribution function. It shows in a discrete density distribution which described the chance associated with all of possible outcome. It also demonstrates the uncertainty of decision using a frequency or cumulative frequency graph.

Figure 4.26 illustrates the probability chart; the height of the alternative node "C1" line at $256,383 is 0.4%, which is equal to the probability that the expected cost of alternative node "SP is $256,383.

Figure 4.27 illustrates the cumulative chart, the probability that the alternative node "C1" a value less than or equal to $119,934 is 100%.

Table 4.13 also illustrated the statistical summary of the risk profile, which provides a statistical summary report of the decision analysis.

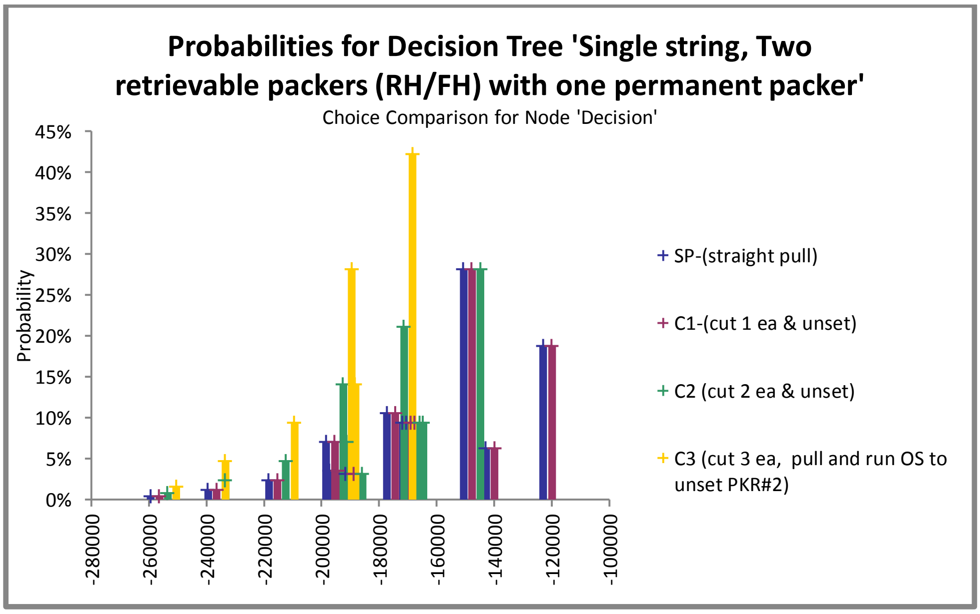

Figure 4.26 Probability decision for decision tree "model 3C"

Table 4.13 Summary data of probability decision for decision tree "model 3C"

Expected cost	Alternative SP-(straight pull)		Alternative C1-(Cutting 1 cut and unset)		Alternative C2-(Cutting 2 cut and unset)		Alternative C3-(Cutting 3 cut and unset)	
	Value	Prob	Value	Prob	Value	Prob	Value	Prob
#1	$259,339	0.40%	$256,383	0.40%	$253,428	0.80%	$250,473	1.60%
#2	$239,409	1.20%	$236,454	1.20%	$233,499	2.30%	$233,499	4.70%
#3	$218,283	2.30%	$215,328	2.30%	$212,373	4.70%	$209,418	9.40%
#4	$198,354	7.00%	$195,399	7.00%	$192,443	14.10%	$189,488	28.10%
#5	$197,157	3.50%	$194,202	3.50%	$191,247	7.00%	$188,292	14.10%
#6	$191,700	3.10%	$188,745	3.10%	$185,790	3.10%	$168,362	42.20%
#7	$177,228	10.50%	$174,273	10.50%	$171,317	21.10%		
#8	$171,771	9.40%	$168,815	9.40%	$165,860	9.40%		
#9	$170,574	9.40%	$167,619	9.40%	$164,664	9.40%		
#10	$150,645	28.10%	$147,690	28.10%	$144,734	28.10%		
#11	$142,819	6.30%	$139,864	6.30%				
#12	$122,889	18.80%	$119,934	18.80%				

Result of constructing risk profile, alternative "SP" has twelve expected cost and with its probability as summarize in Table 4.13.

Alternative "C1" has twelve expected cost with its probability as summarize in Table 5.13.

Alternative "C2" has ten expected cost with its probability as summarize in Table 5.13.

Alternative "C3" has six expected cost with its probability as summarize in Table 5.13.

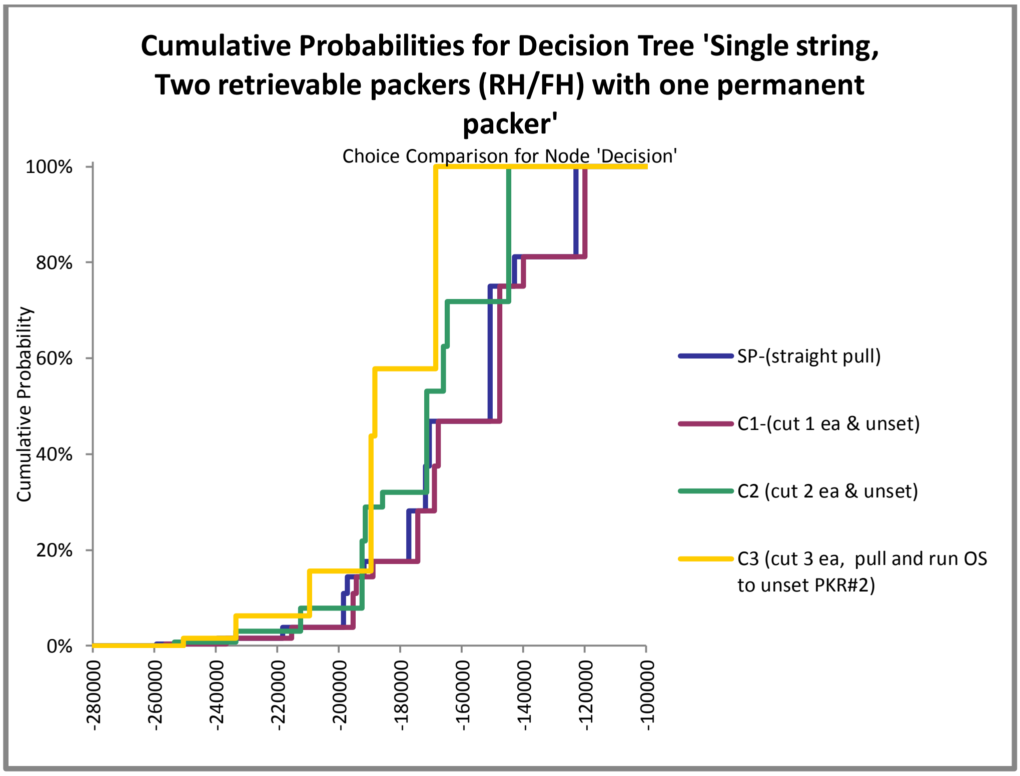

Figure 4.27 Cumulative probabilities for decision tree "model 3C"

Refer decision tree Figure 4.24a-4.25b, at alternative "SP" the expected cost of unsetting all retrievable packer (PKR#2, 1) and seal by straight pulling on rig is $160,927.

Where alternative "C1", the expected cost of cutting 1 cut, above seal and unsetting retrievable packers (PKR #2, 1) by straight pulling. After that, running BHA: overshot to retrieve seal, is $157,972.

Alternative "C2", the expected cost of cutting 2 cut, above seal, PKR#1, and unsetting retrievable packer (PKR#2) by straight pulling. After that running BHA: overshot to unset PKR#1 and to retrieve seal, respectively is $171,553.

In the last node, alternative "C3", the expected cost of cutting 3 cut above seal, PKR#1,2 and then pulling above part. After that, running BHA: O-shot to unset PKR # 2, 1 and seal respectively, is $185,292.

After calculating, the expected cost of decision alternative "C1", is saving investment cost more than alternative "SP", "C2" and "C3", so choosing "cutting 1 cut, above seal, and unsetting retrievable packer (PKR#2, 1) by straight pulling, after that, running BHA: overshot to retrieve seal" is most appropriate.

It can provide benefit $27,320 over alternative "C3" as shown in Fig 4.28, illustrated policy suggestion It presents only the optimum part of decision tree. It shows option was chosen alternative node by illustrating a reduced version of decision tree, with the optimum path highlighted and the expected cost. The probabilities of each path are also displayed. The summary of statistical can be seen in Table 4.14.

Table 4.14 Statistical summary for decision tree "model 3C"

Statistics	Alternative SP-(straight pull)	Alternative C1-(cutting 1 cut & pull)	Alternative C2-(cutting 2 cut & pull)	Alternative C3-(Cut 3 ea and unset)
Mean	$160,927	$157,972	$171,553	$185,292
Minimum	$259,339	$256,383	$253,428	$250,473
Maximum	$122,889	$119,934	$144,734	$168,362
Mode	$150,645	$147,690	$144,734	$168,362
Std. Deviation	27030.3	27030.3	22916.64	18894.88
Skewness	-0.49	-0.49	-0.79	-1.32
Kurtosis	3.19	3.19	3.66	4.72

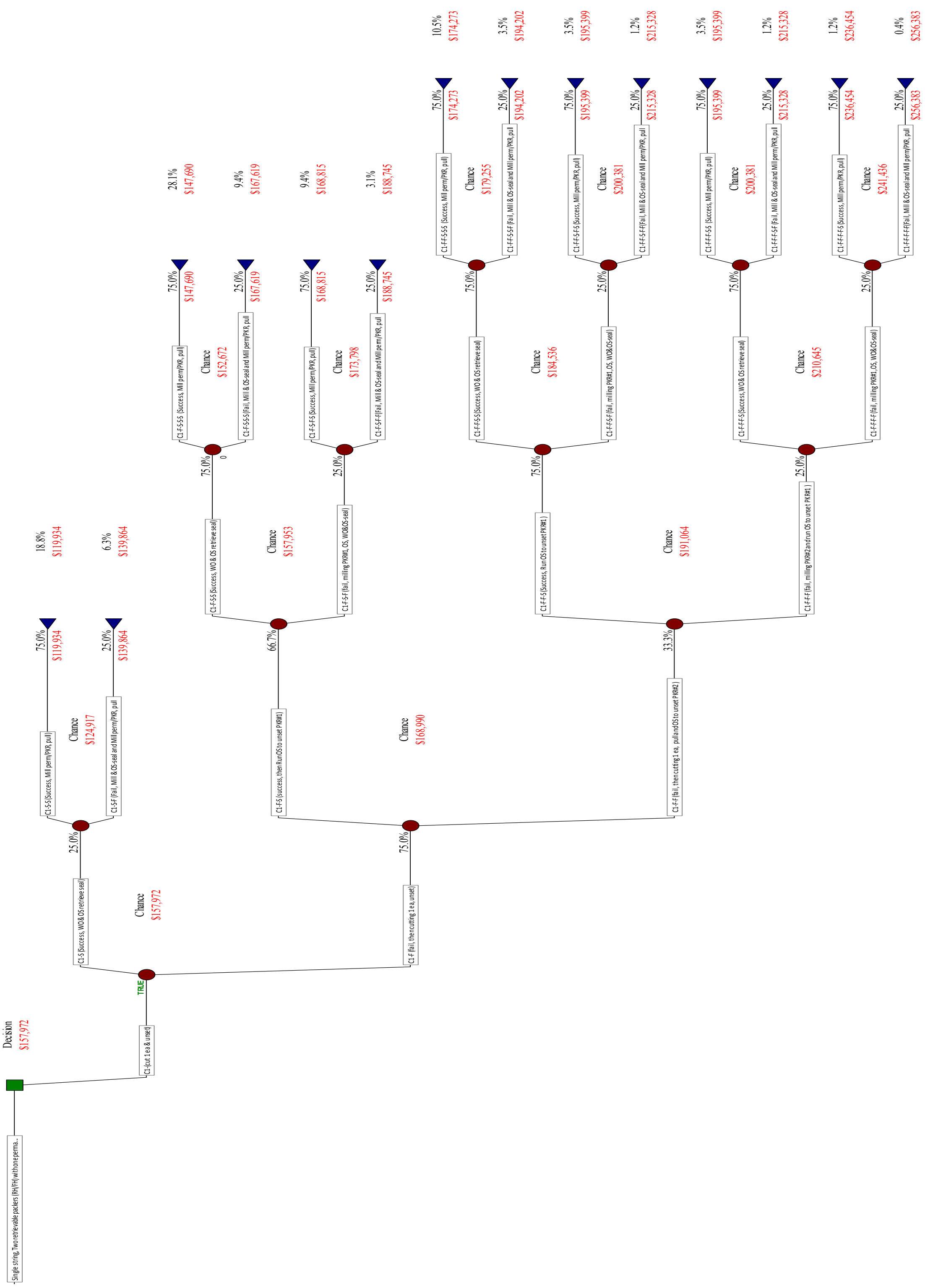

Figure 4.28 Optimum decisions tree suggestion “model 3C”

4.4 Result of decision tree analysis four zones completion

4.4.1 Result of decision tree analysis model 4A

To construct decision tree, it is used to find optimum operation cost for workover four zones completion, four retrievable packers – PHL/HS packer type, represent by decision node (square). There are five decision alternatives (SP, C1, C2, C3 and C4) as illustrated Figure 4.29a-4.29r, which consists of;

- Decision alternative SP: unsetting retrievable packers PKR#4, 3, 2, 1 by straight pulling.
- Decision alternative C1: cutting 1 cut, above PKR#1 and then unsetting retrievable packers (PKR#4, 3, 2) by straight pulling. After that, running BHA: overshot to unset PKR#1.
- Decision alternative C2: cutting 2 cut, above PKR#1, 2 and then unsetting retrievable packers (PKR#4, 3) by straight pulling. After that, running BHA: overshot to unset PKR#2, 1, respectively.
- Decision alternative C3: cutting 3 cut, above PKR#1, 2, 3 and unsetting retrievable packer (PKR#4) by straight pulling. After that running BHA: overshot to unset PKR#3, 2, 1, respectively.
- Decision alternative C4: cutting 4 cut, above PKR#1, 2, 3, 4 and then pulling above part After that running BHA: O-shot to unset PKR#4, 3, 2, 1, respectively.

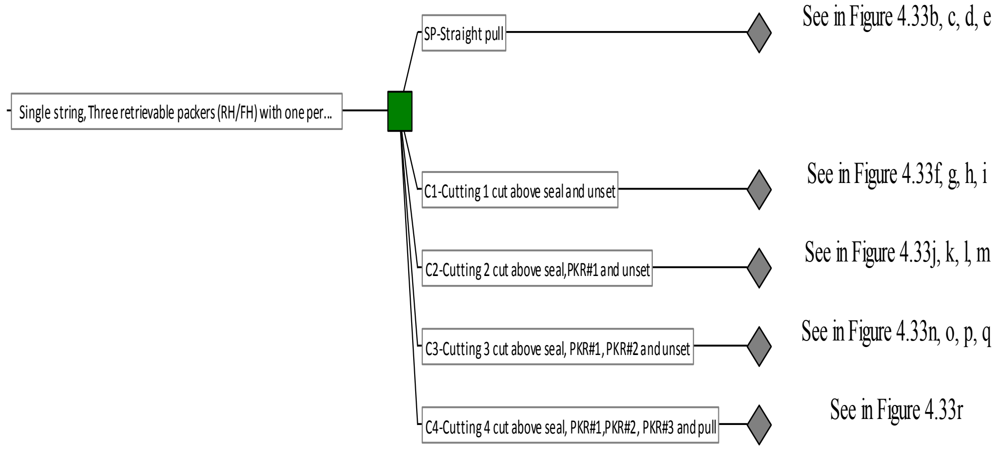

Figure 4.29a Decision tree for “model 4A”

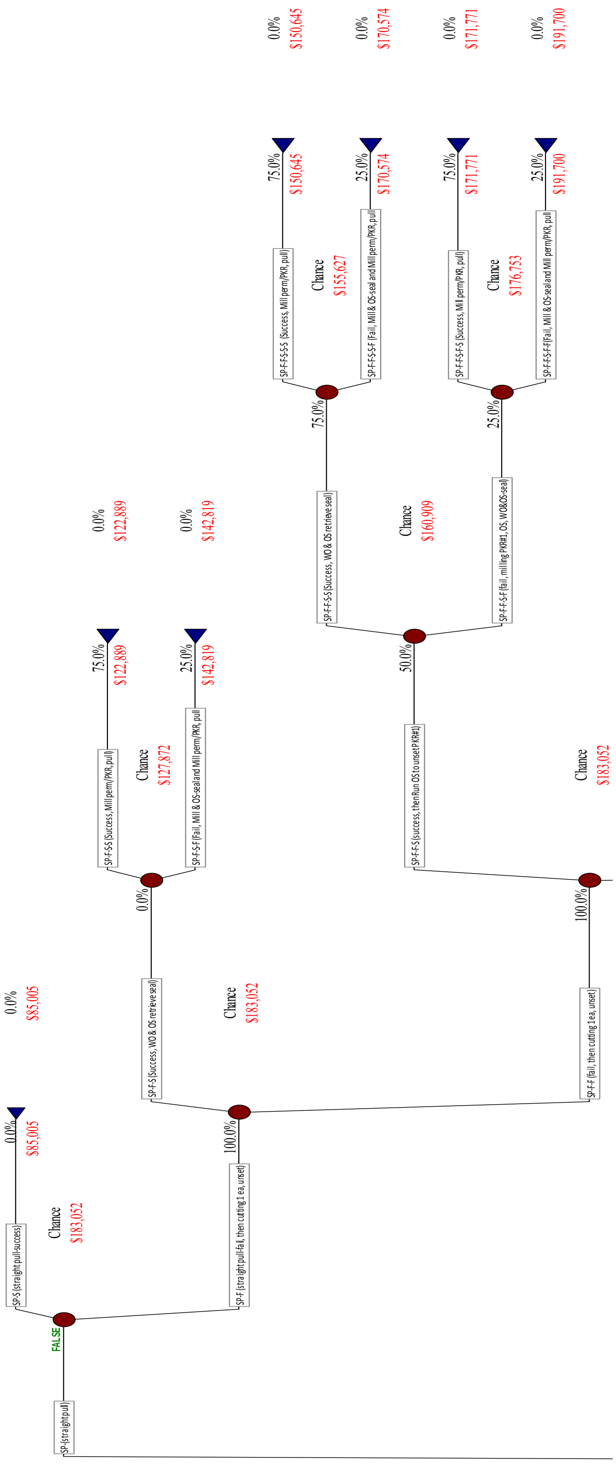

Figure 4.29b Decision tree for “model 4A”

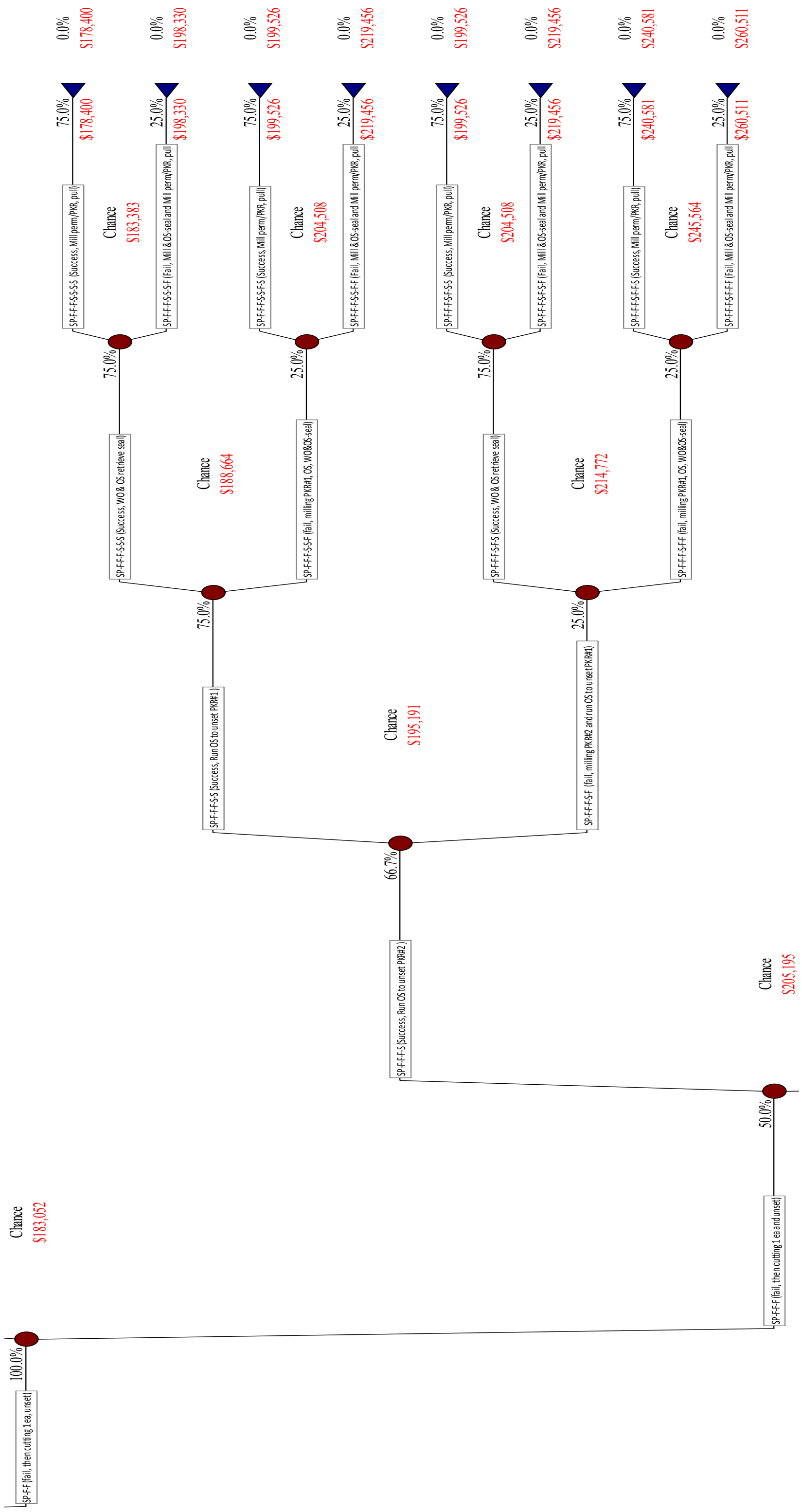

Figure 4.29c Decision tree for "model 4A"

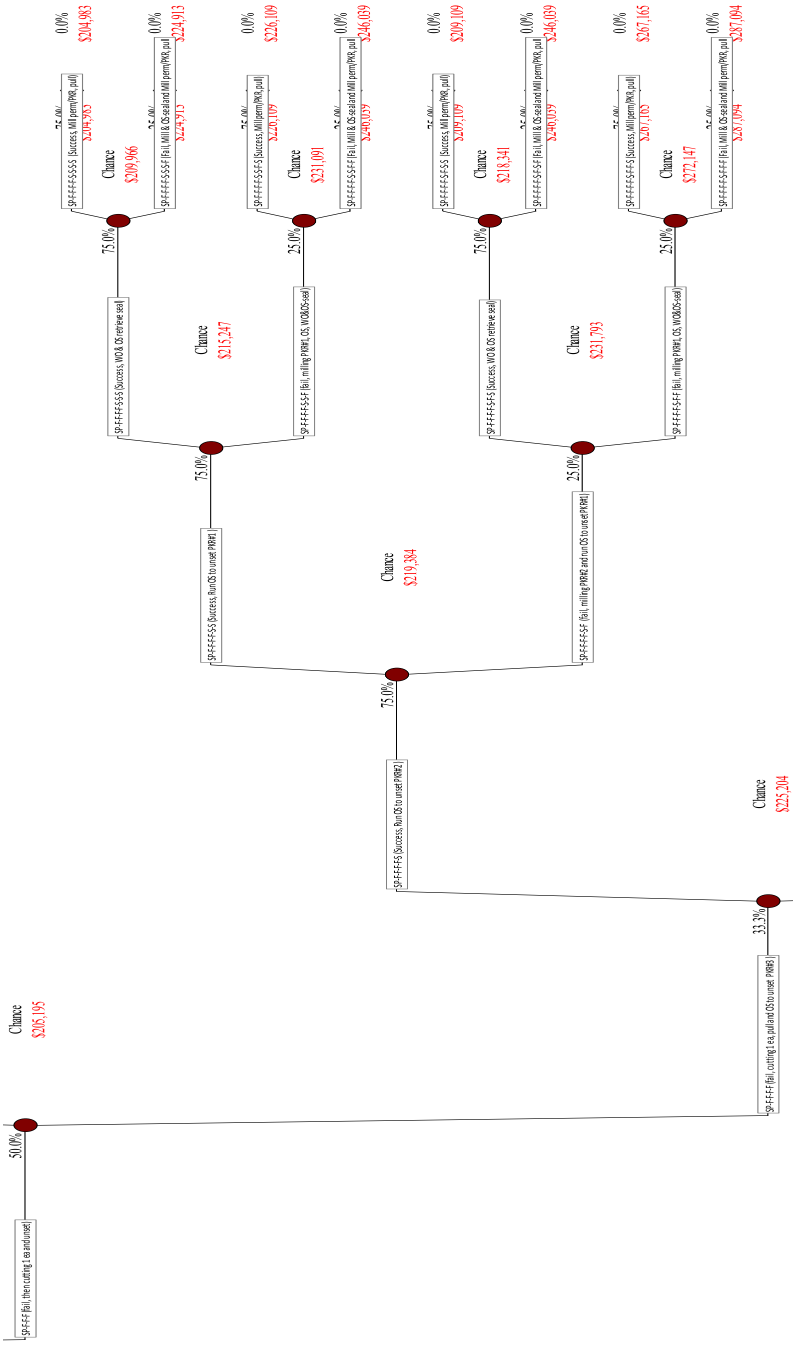

Figure 4.29d Decision tree for “model 4A”

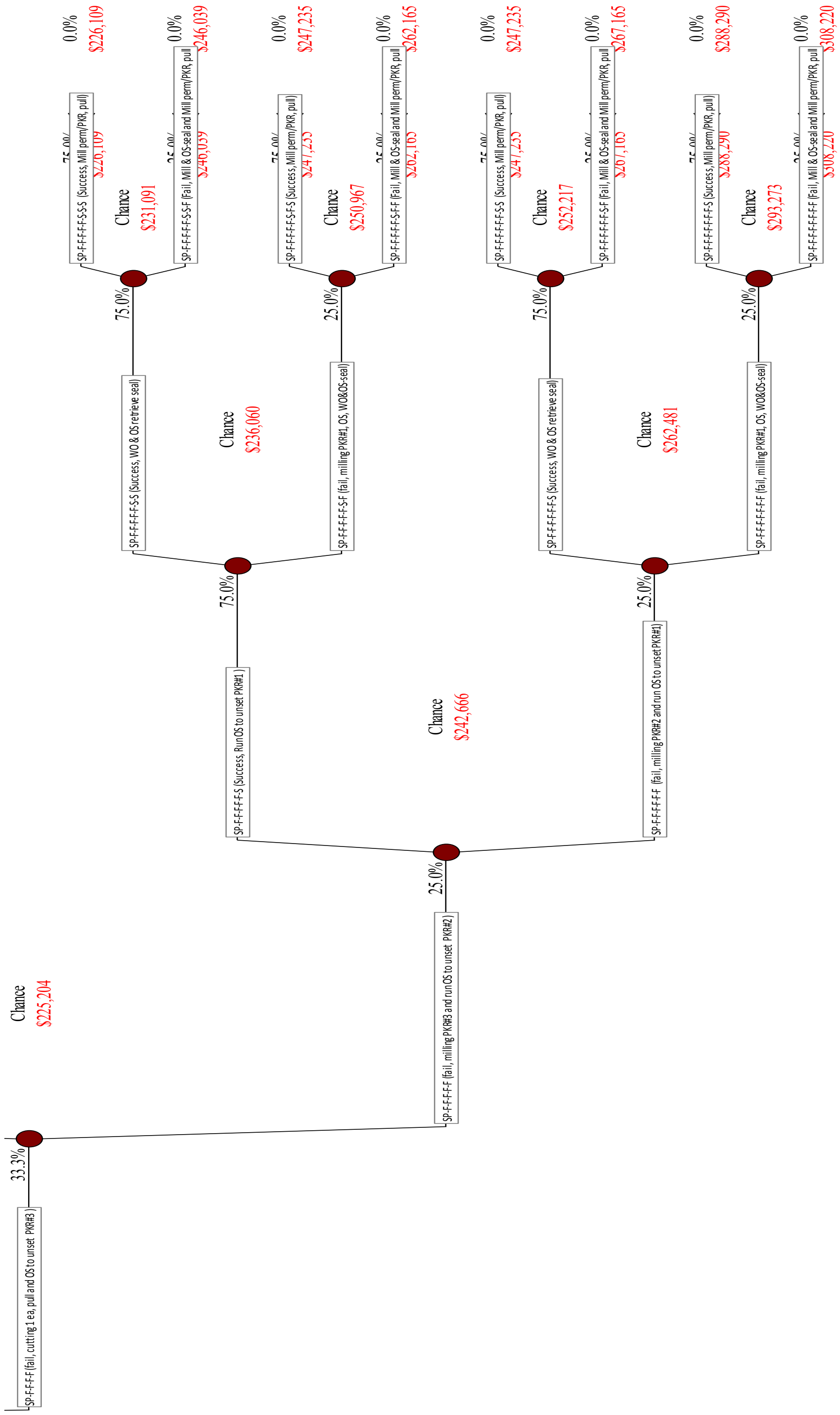

Figure 4.29e Decision tree for “model 4A”

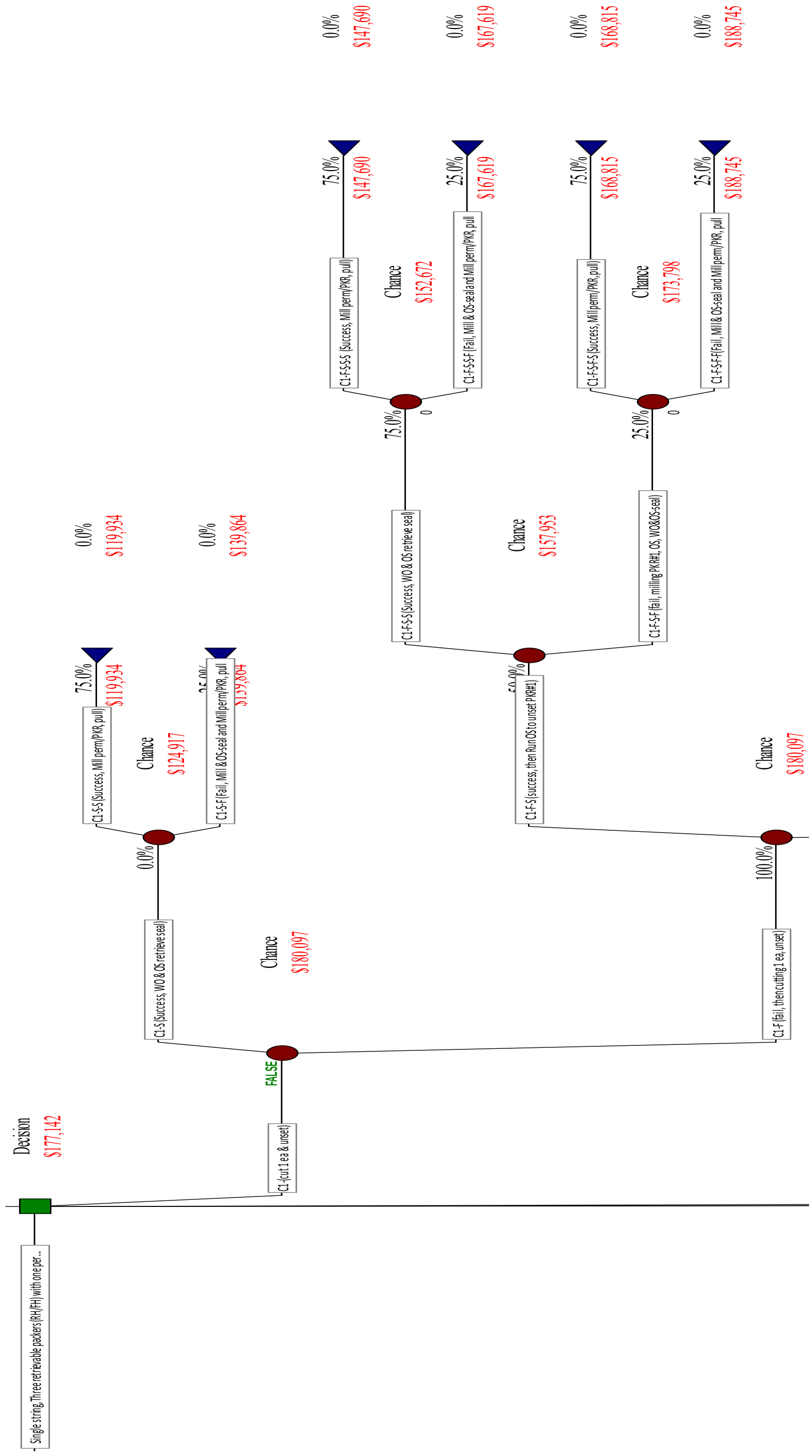

Figure 4.29f Decision tree for “model 4A”

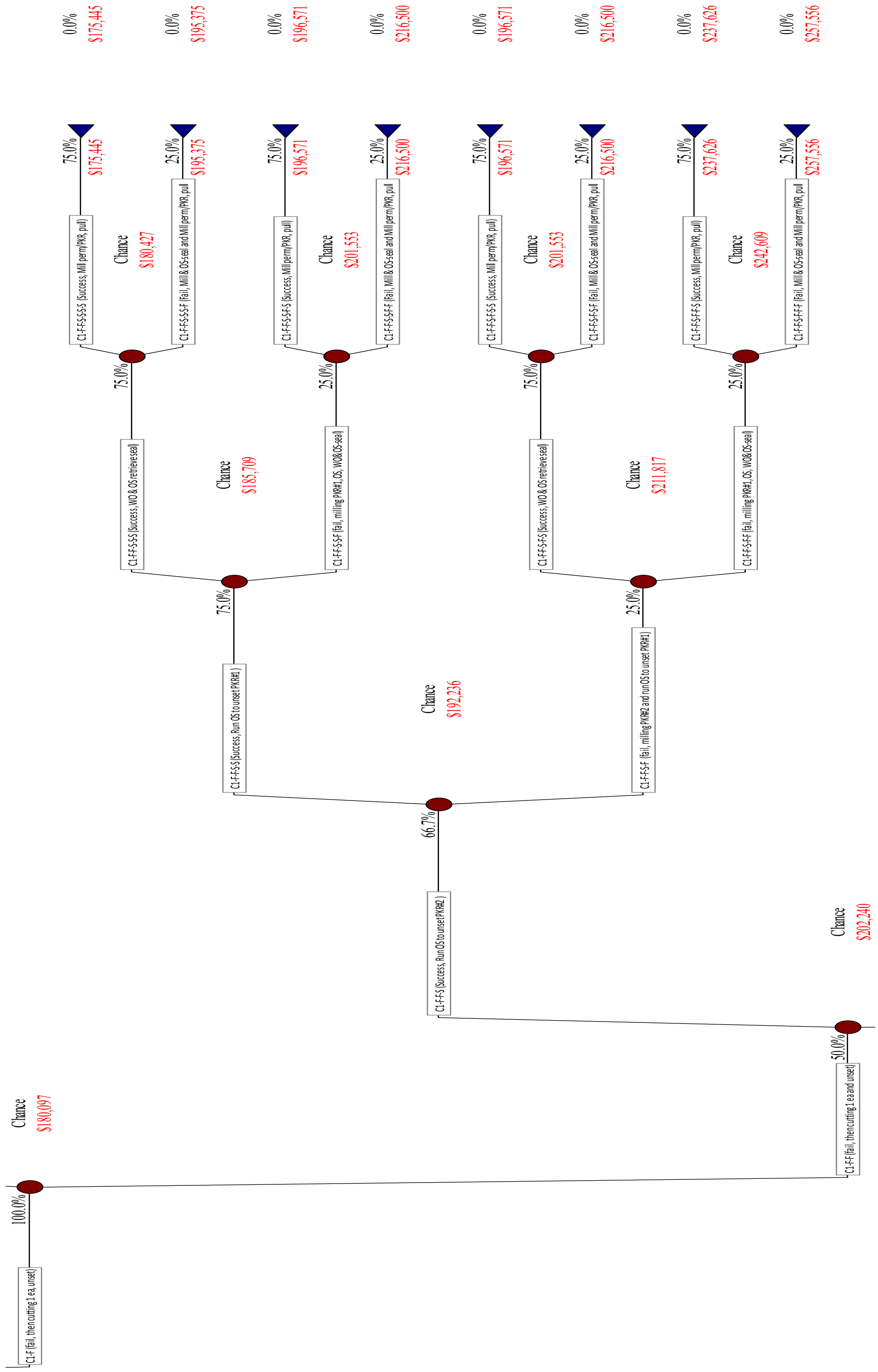

Figure 4.29g Decision tree for “model 4A”

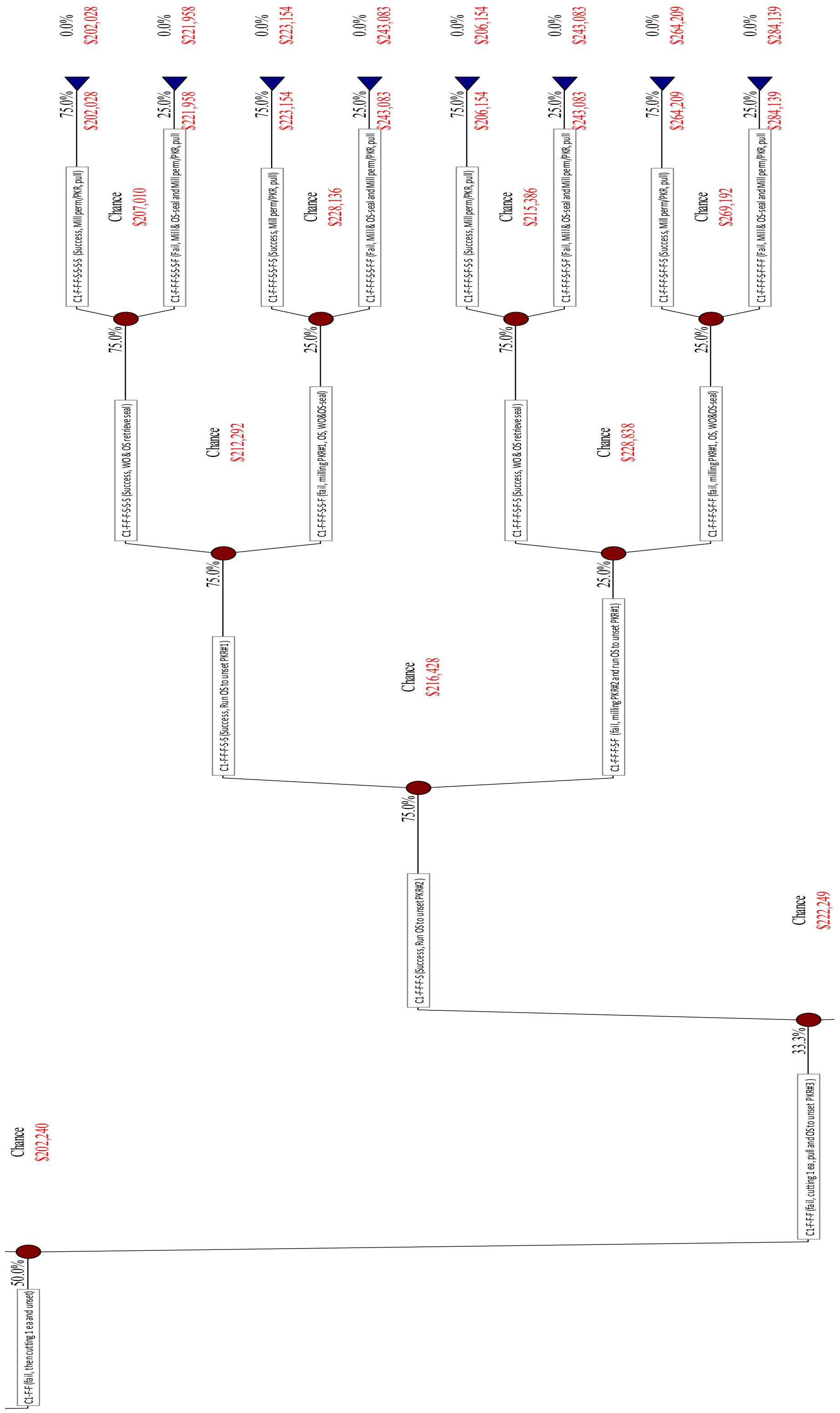

Figure 4.29h Decision tree for “model 4A”

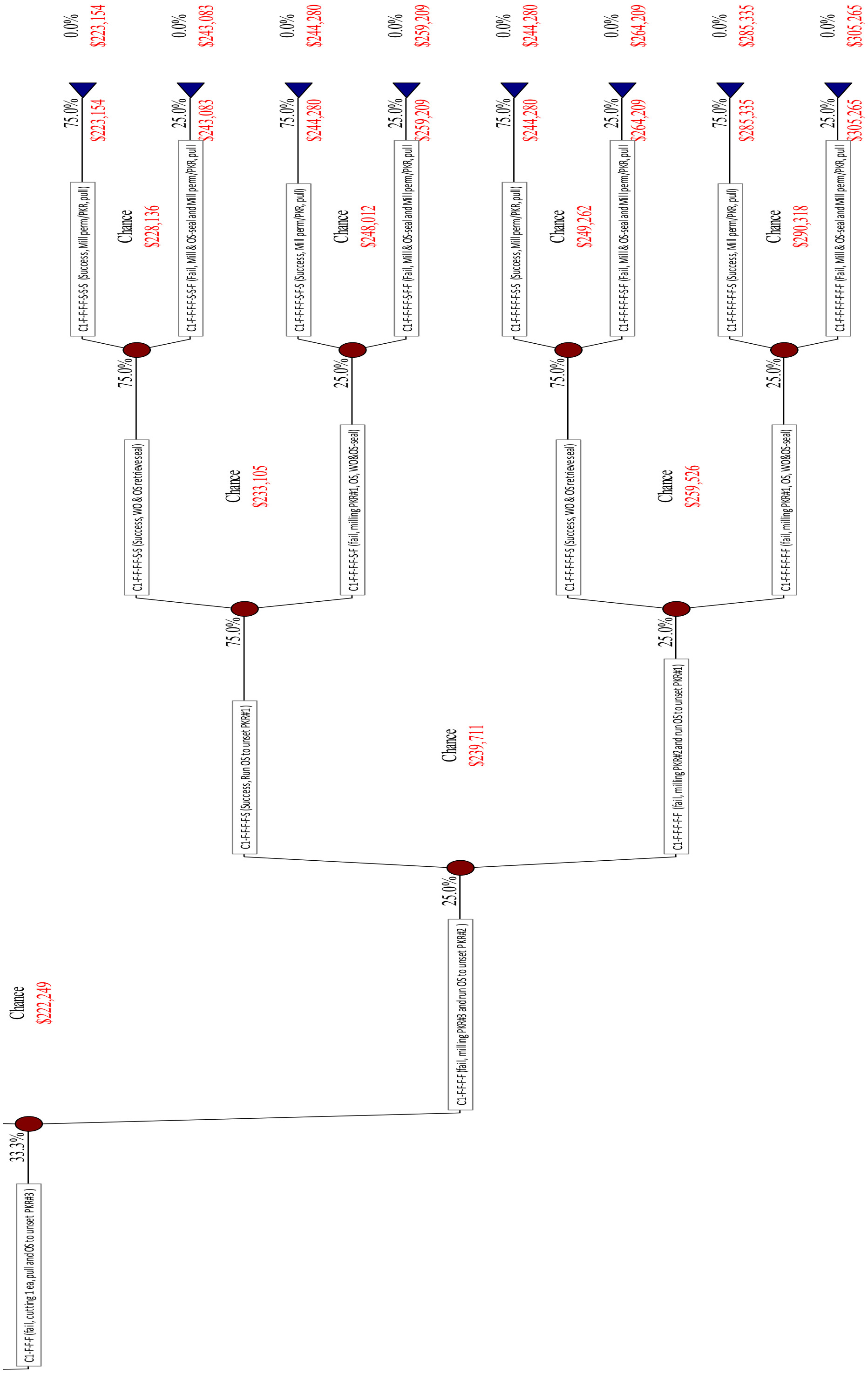

Figure 4.29i Decision tree for “model 4A”

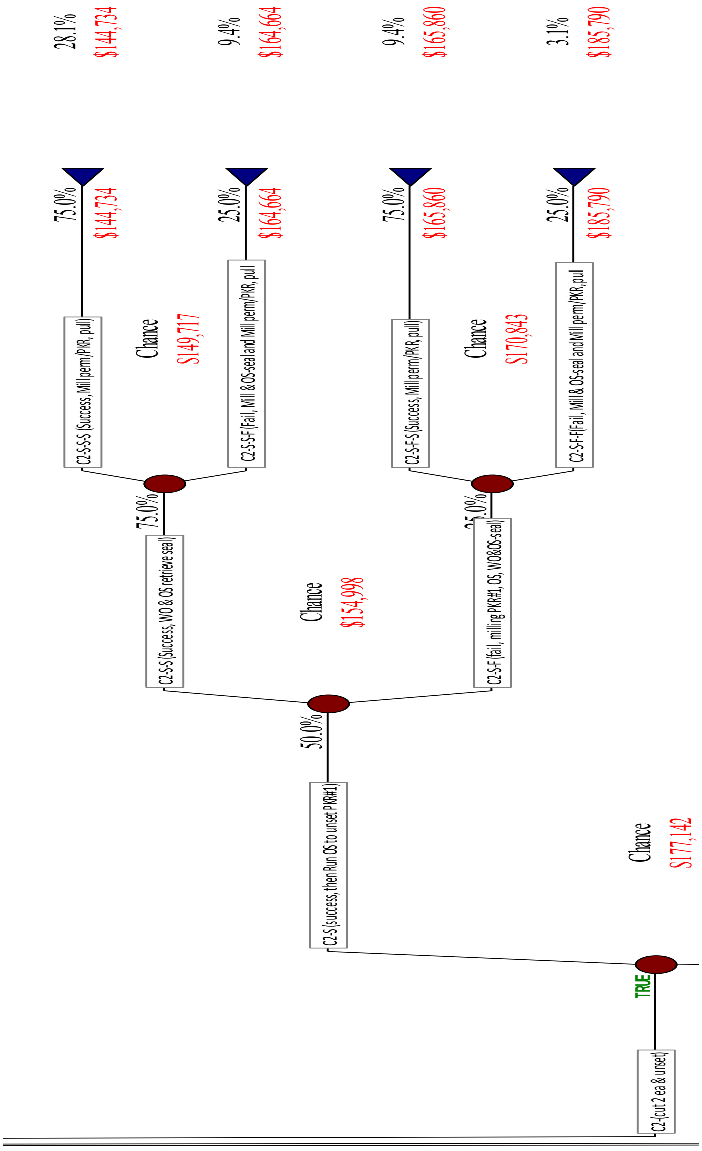

Figure 4.29j Decision tree for “model 4A”

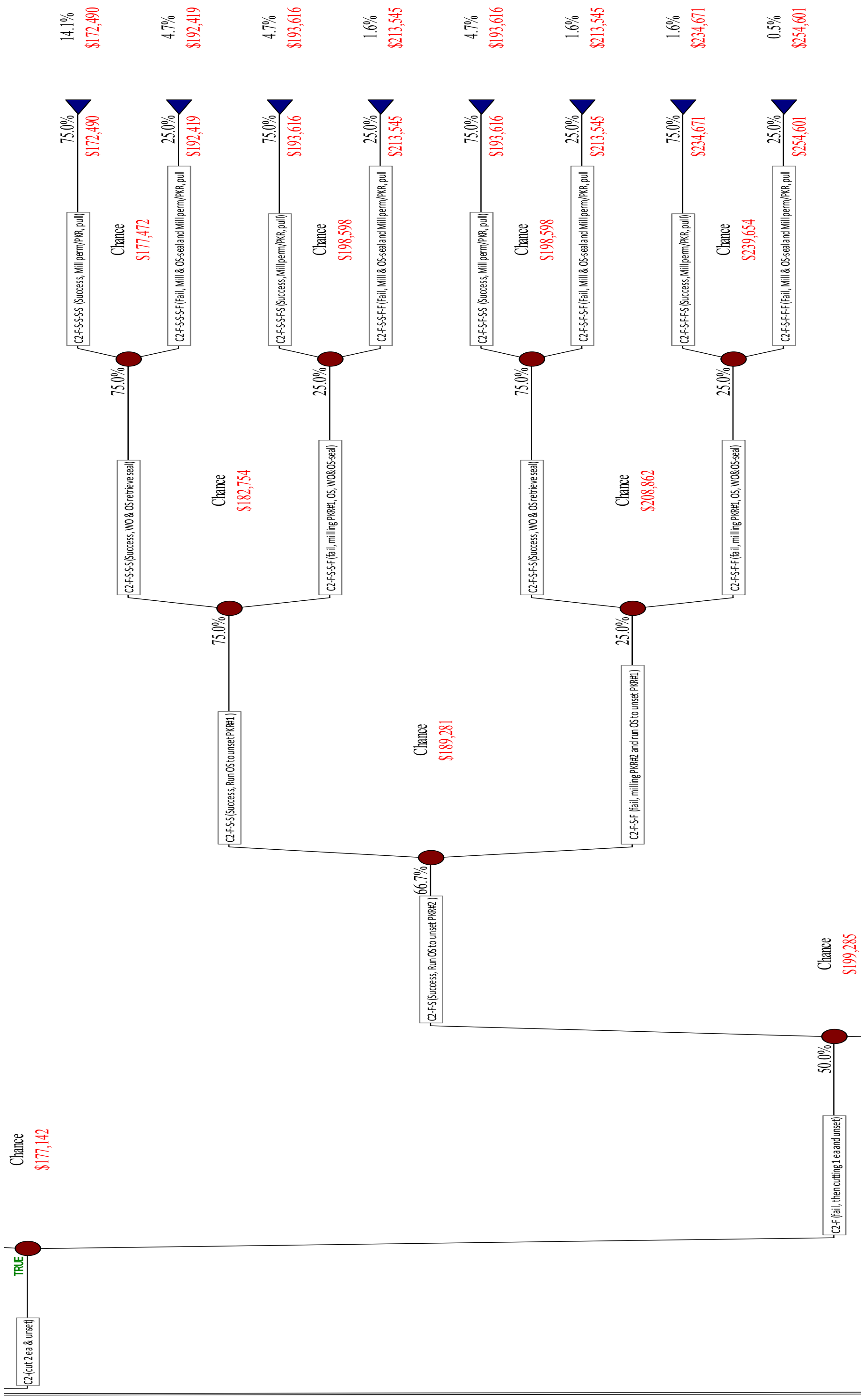

Figure 4.29k Decision tree for “model 4A”

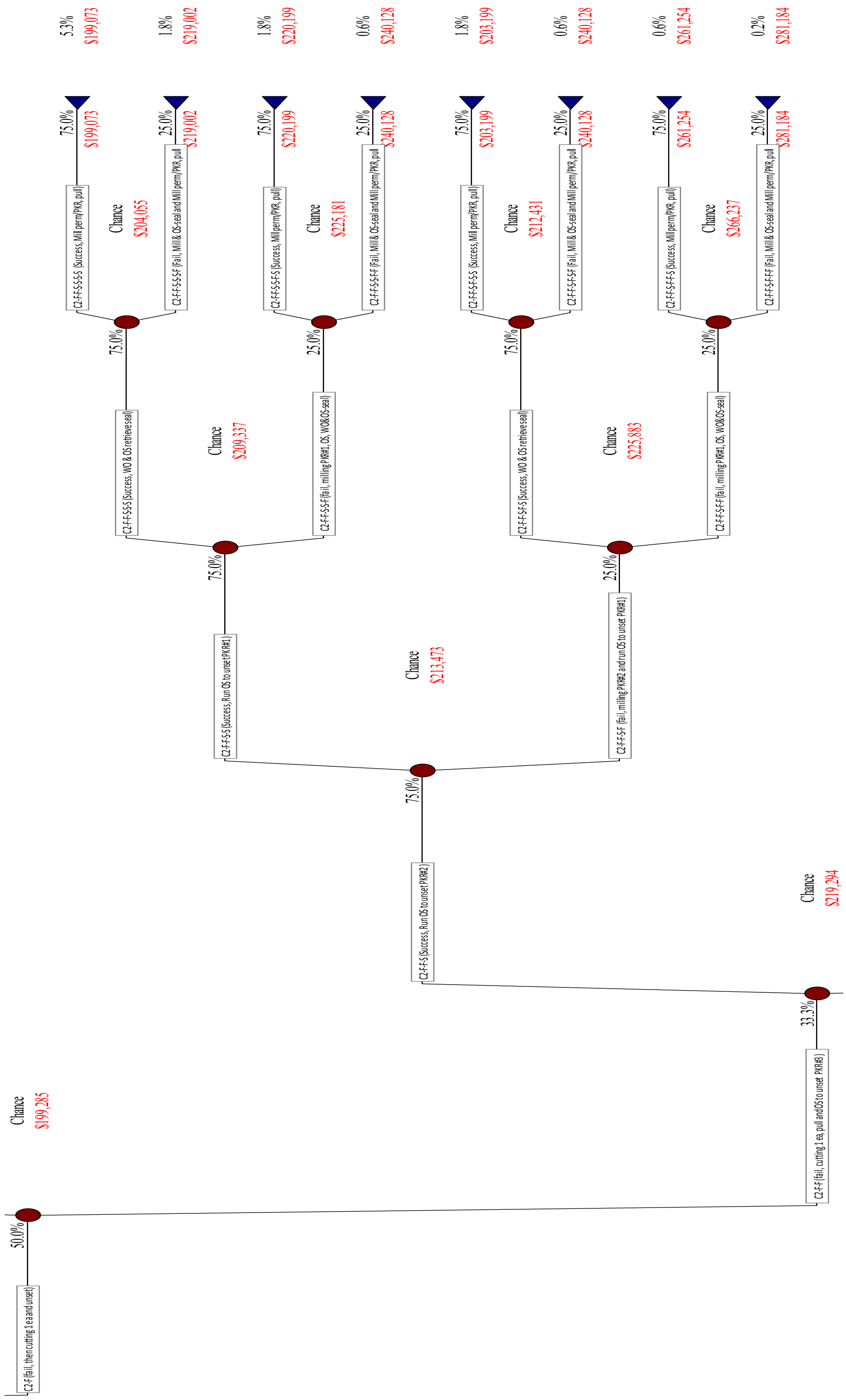

Figure 4.29l Decision tree for “model 4A”

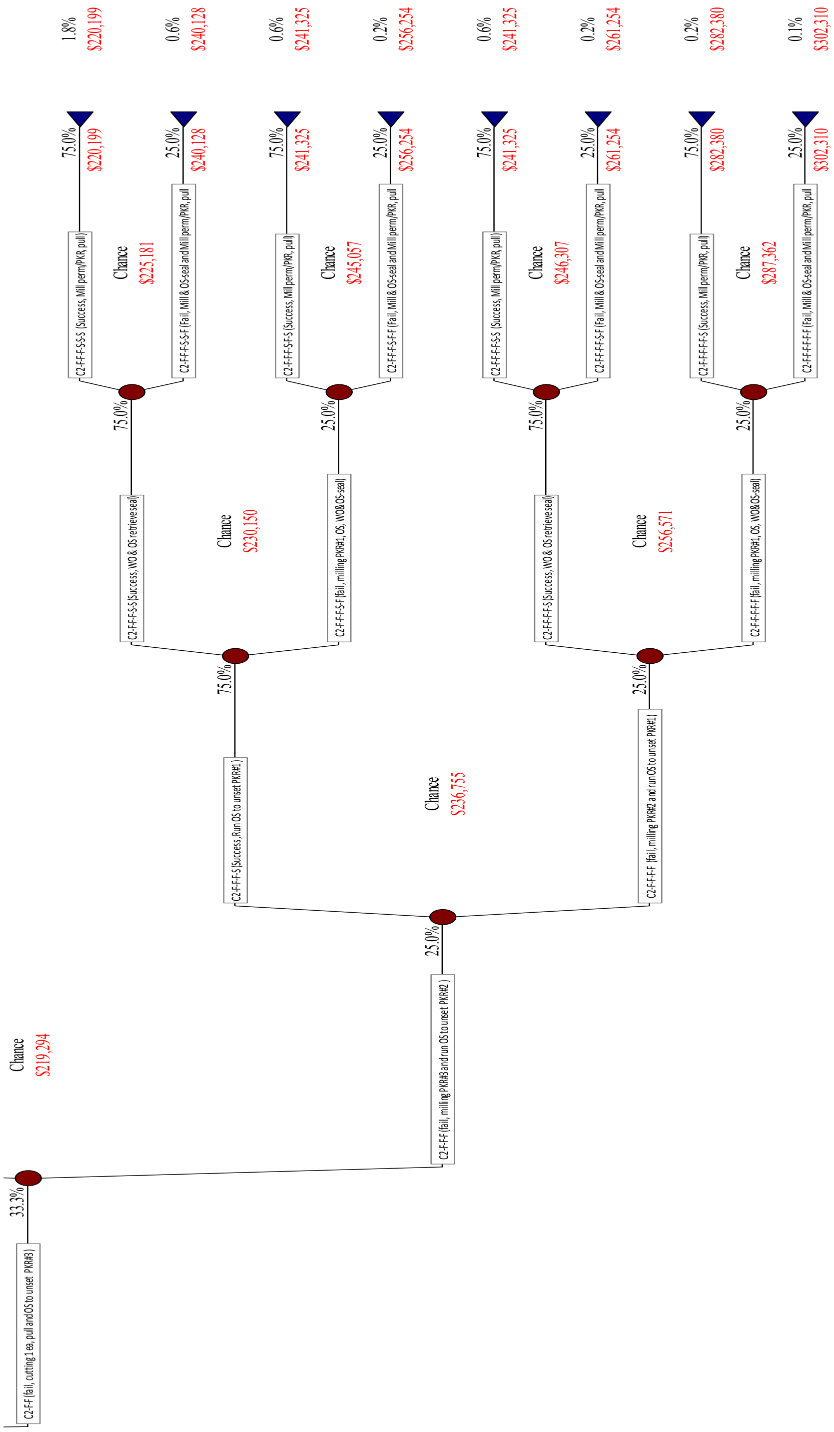

Figure 4.29m Decision tree for “model 4A”

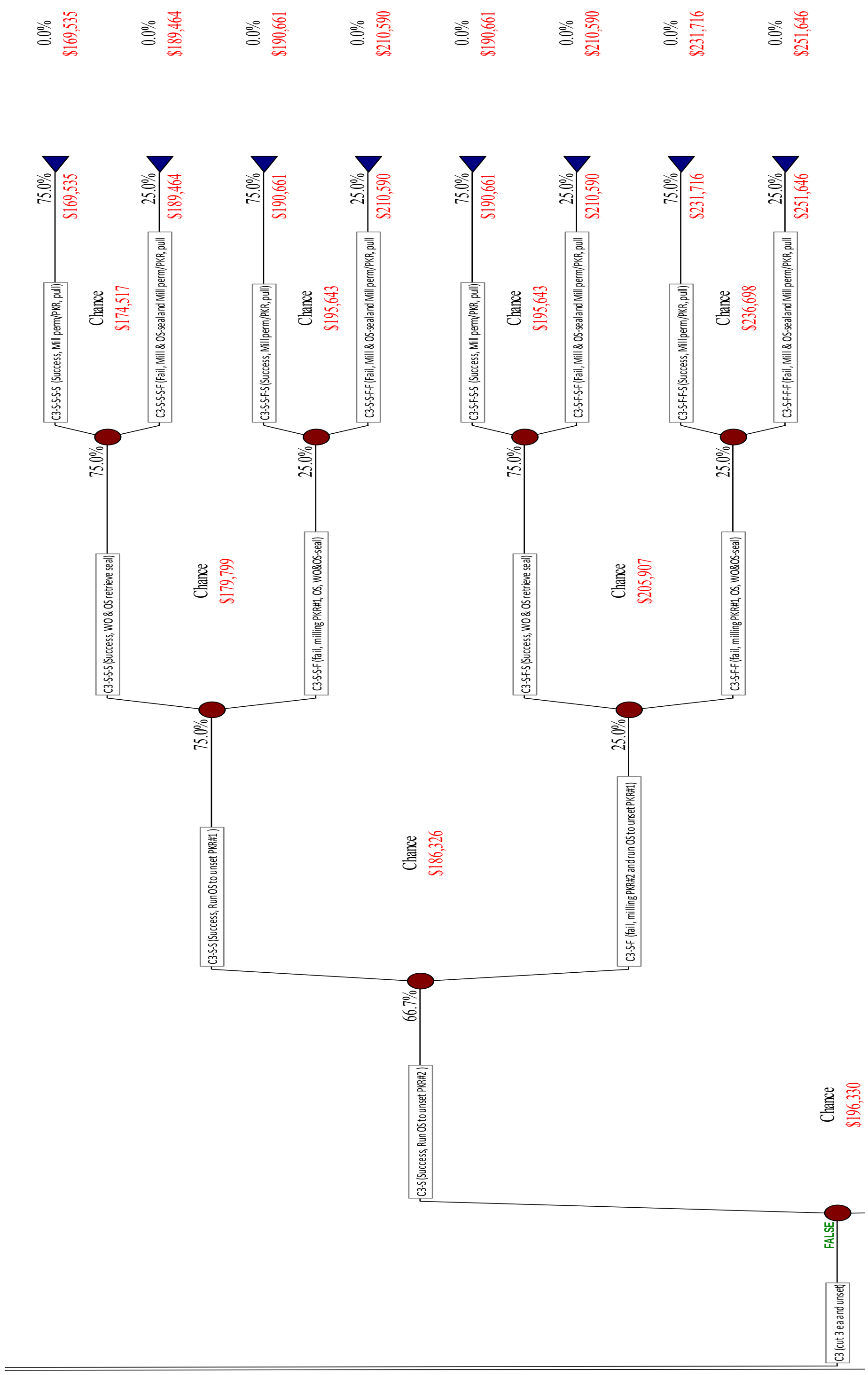

Figure 4.29n Decision tree for “model 4A”

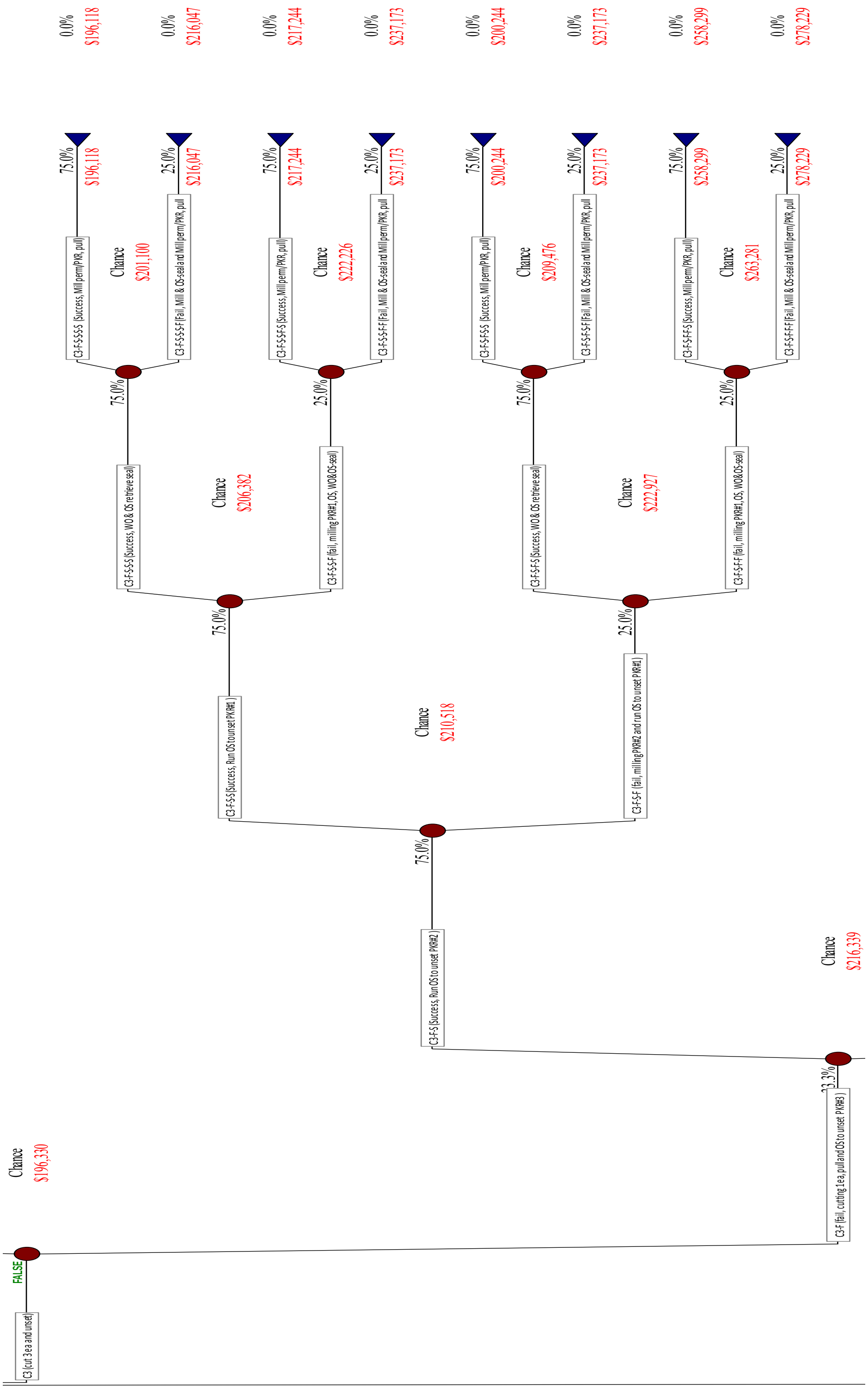

Figure 4.29o Decision tree for “model 4A”

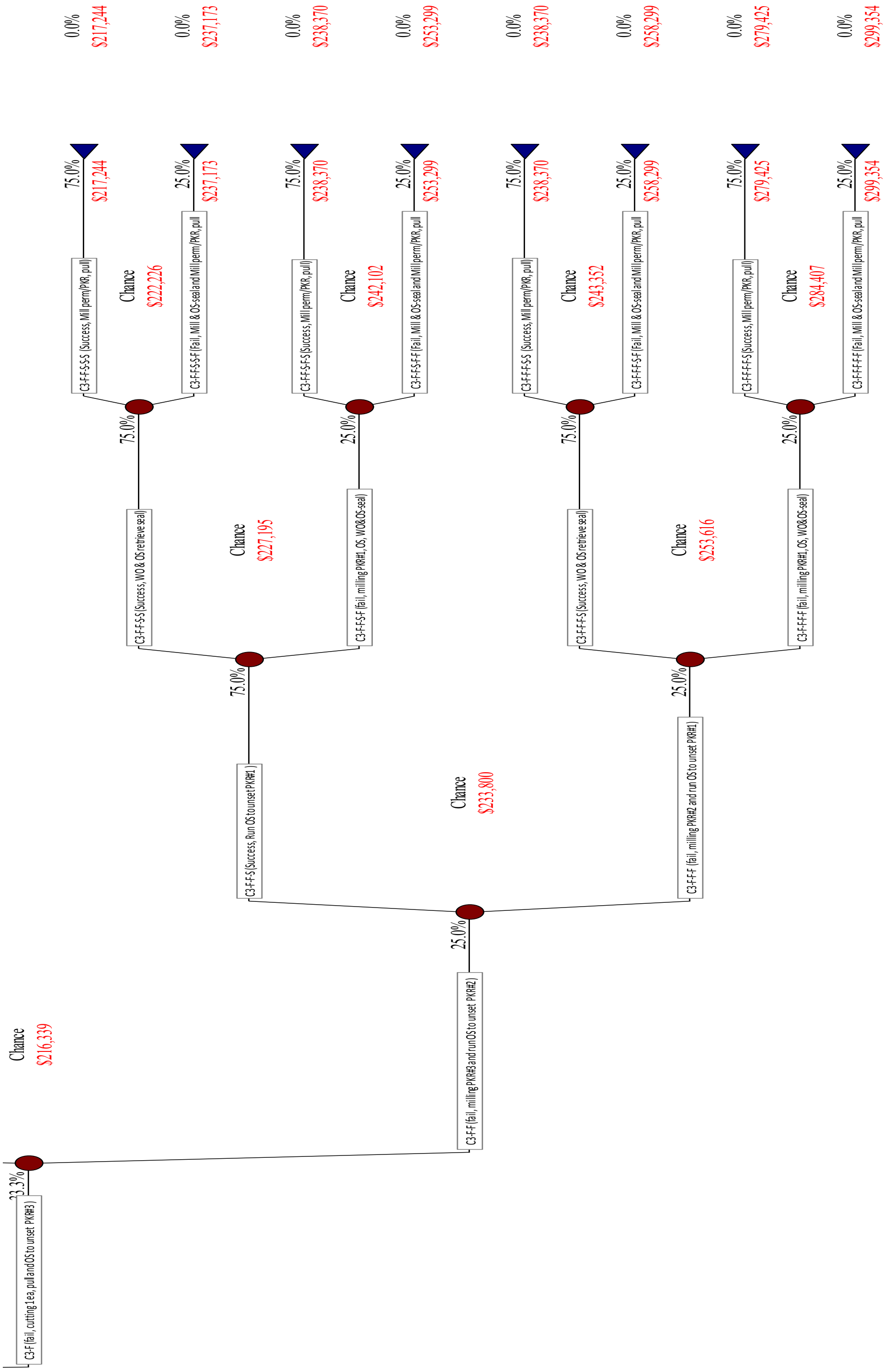

Figure 4.29p Decision tree for “model 4A”

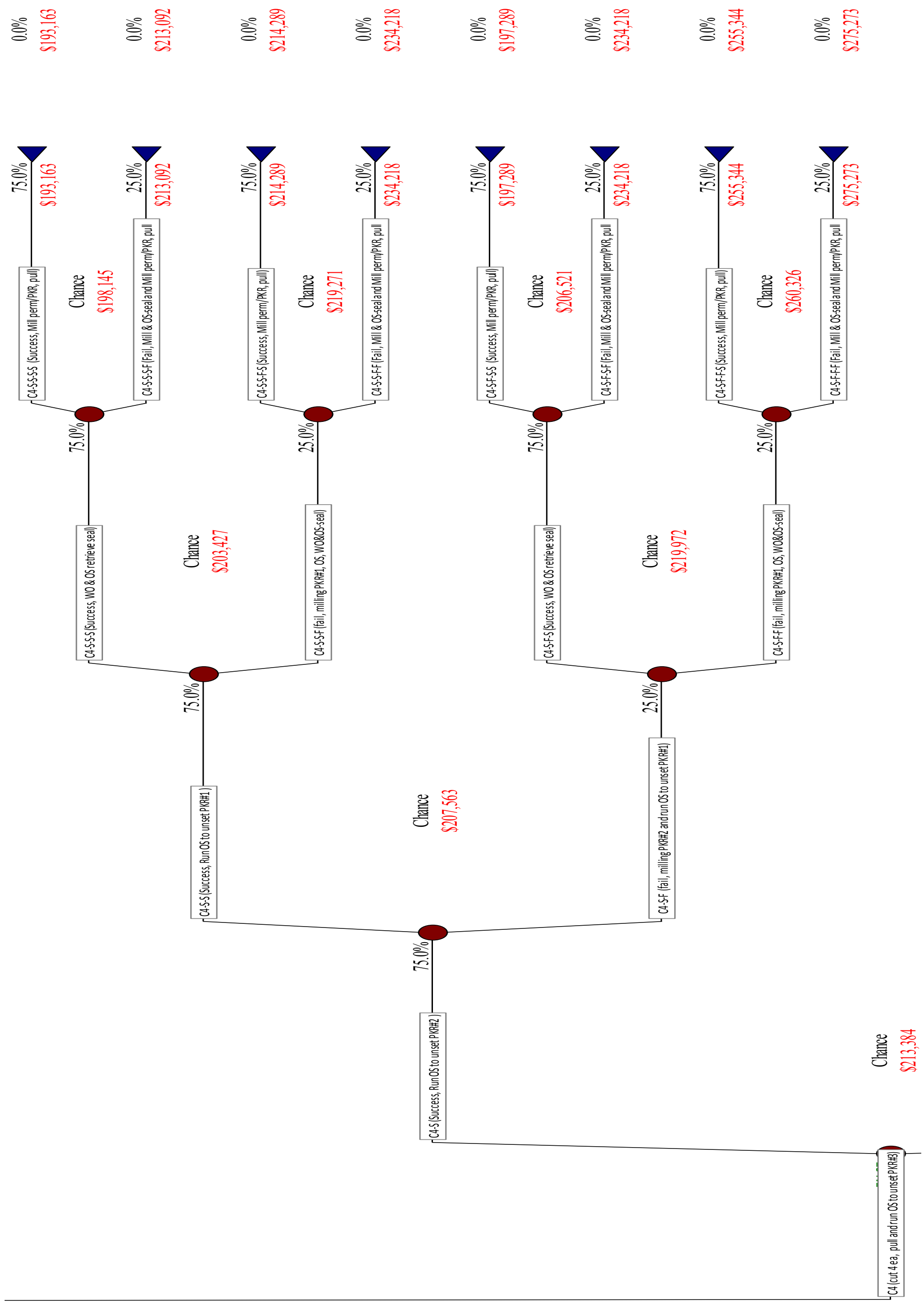

Figure 4.29q Decision tree for “model 4A”

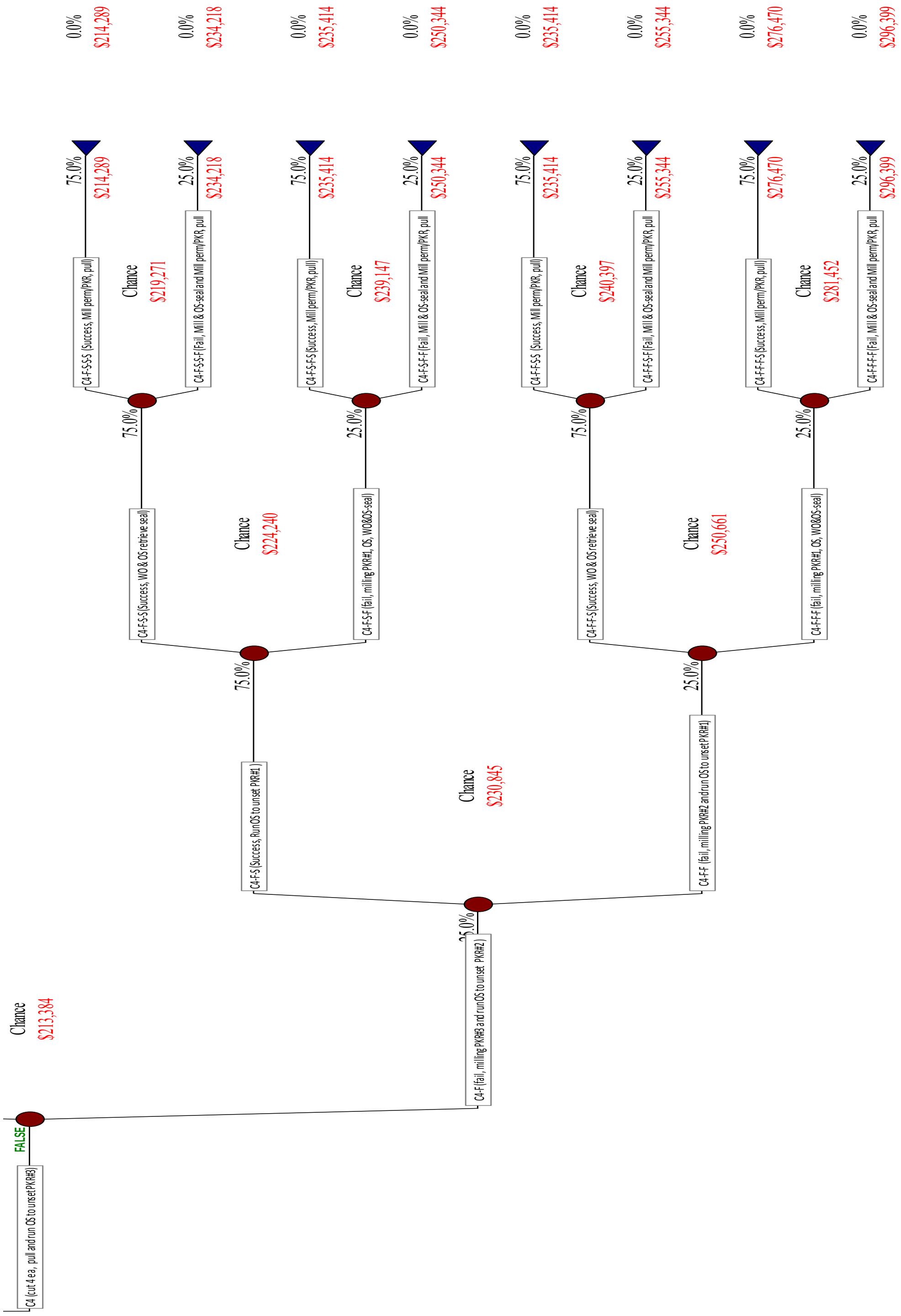

Figure 4.29r Decision tree for “model 4A”

The risk profile is a distribution function. It shows in a discrete density distribution which described the chance associated with all of possible outcome. It also demonstrates the uncertainty of decision using a frequency or cumulative frequency graph.

Figure 4.30 illustrates the probability chart, the height of the alternative node “SP line at $63,861 is 66.7%, which is equal to the probability that the expected cost of alternative node “SP is $63,861.

Figure 4.31 illustrates the cumulative chart, the probability that the alternative node “SP” a value less than or equal to $63,861 is 100%.

Table 4.15 also illustrated the statistical summary of the risk profile, which provides a statistical summary report of the decision analysis.

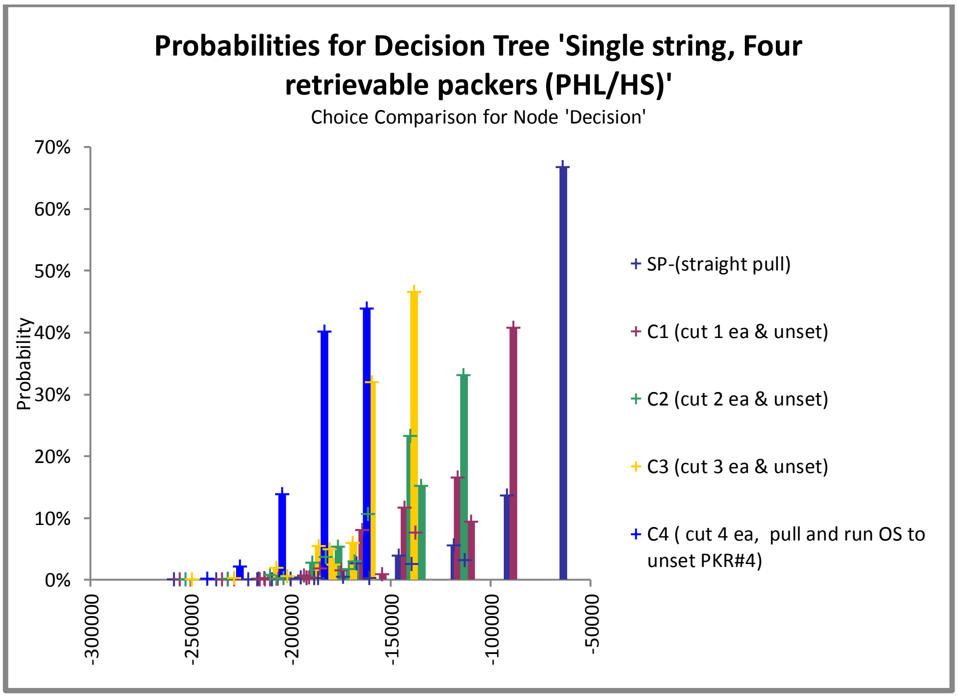

Figure 4.30 Probability decision for decision tree “model 4A”

Table 4.15 Summary data of probability decision for decision tree "model 4A"

Expected cost	Alternative SP-(straight pull)		Alternative C1-(Cutting 1 cut and unset)		Alternative C2-(Cutting 2 cut and unset)		Alternative C3-(Cutting 3 cut and unset)		Alternative -C4 (cutting 4 cut, pull and run OS to unset PKR#4)	
	Value	Prob	Value	Prob	Value	Prob	Value	Prob	Value	Prob.
#1	$258,213	0.00%	$255,258	0.00%	$252,303	0.00%	$249,348	0.00%	$241,393	0.10%
#2	$237,088	0.00%	$234,132	0.00%	$231,177	0.10%	$228,222	0.30%	$225,267	2.10%
#3	$220,962	0.00%	$231,132	0.00%	$210,051	0.80%	$207,096	1.90%	$204,141	13.80%
#4	$216,487	0.00%	$228,132	0.00%	$207,051	0.20%	$201,639	0.60%	$183,015	40.10%
#5	$215,962	0.10%	$215,167	0.10%	$203,422	0.30%	$185,970	5.50%	$161,889	43.80%
#6	$209,332	0.00%	$213,007	0.20%	$188,926	2.70%	$180,513	4.90%		
#7	$199,836	0.10%	$212,709	0.10%	$182,296	3.70%	$178,513	2.40%		
#8	$194,836	0.30%	$210,007	0.10%	$176,170	5.30%	$168,845	6.00%		
#9	$191,941	0.20%	$206,377	0.10%	$170,713	1.70%	$159,387	32.00 %		
#10	$188,206	0.20%	$193,058	0.70%	$167,800	3.00%	$138,261	46.50 %		
#11	$186,206	0.20%	$191,881	0.30%	$161,170	10.70%				
#12	$173,710	0.50%	$190,599	0.30%	$140,044	23.30%				
#13	$167,080	2.70%	$185,251	1.80%	$134,587	15.20%				
#14	$160,451	0.30%	$174,755	1.50%	$113,461	33.10%				
#15	$145,954	3.90%	$164,125	8.00%						
#16	$139,325	2.50%	$154,078	0.90%						
#17	$118,199	5.50%	$142,999	11.60%						
#18	$112,742	3.10%	$137,542	7.60%						
#19	$91,616	13.60%	$116,416	16.60%						
#20	$63,861	66.70%	$109,787	9.30%						
#21			$88,661	40.70%						

Result of constructing risk profile, alternative "SP" has twenty expected cost with its probability as summarize in Table 4.15.

Alternative "C1" has twenty one expected costs with its probability as summarize in Table 4.15.

Alternative "C2" has fourteen expected costs with its probability as summarize in Table 4.15.

Alternative "C3" has ten expected costs with its probability as summarize in Table 4.15.

Alternative "C4" has five expected costs with its probability as summarize in Table 4.15.

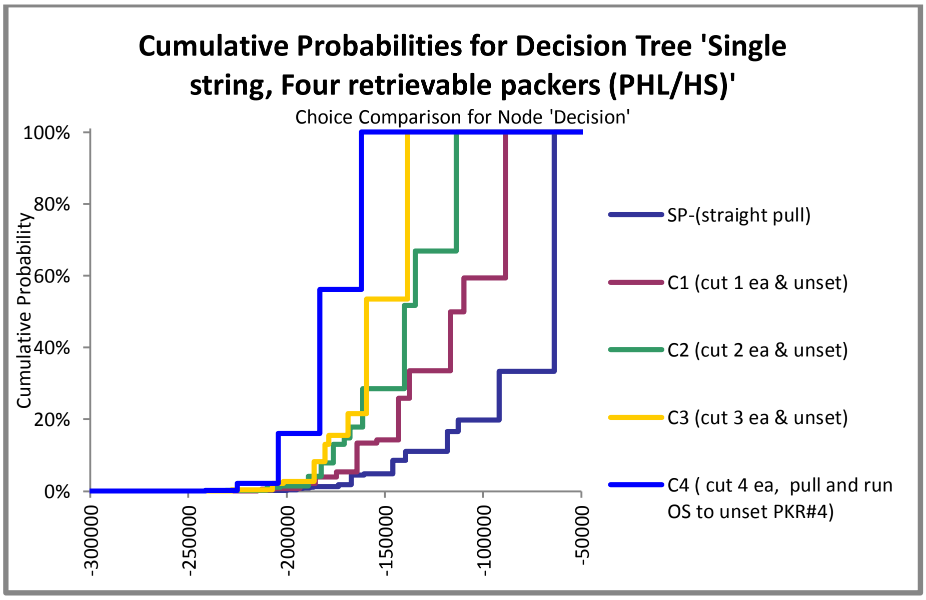

Figure 4.31 Cumulative probabilities for decision tree "model 4A"

Refer decision tree Figure4.29a-4.29b, at alternative "SP" the expected cost of unsetting all retrievable packer (PKR#4, 3, 2, 1) by straight pulling on rig is $82,521.

Where alternative "C1", the expected cost of cutting 1 cut, above PKR#1 and then unsetting retrievable packers (PKR#4, 3, 2) by straight pulling. After that, running BHA: overshot to unset PKR#1, is $117,172.

Alternative "C2", the expected cost of cutting 2 cut, above PKR#1, 2 and then unsetting retrievable packers (PKR#4, 3) by straight pulling. After that, running BHA: overshot to unset PKR#2, 1, respectively, is $139,806.

Alternative "C3", the expected cost of cutting 3 cut, above PKR#1, 2, 3 and unsetting retrievable packer (PKR#4) by straight pulling. After that running BHA: overshot to unset PKR#3, 2, 1, respectively is $154,419.

In the last node, Alternative "C4", the expected cost of cutting 4 cut above PKR#1, 2, 3, 4 and then pulling above part After that running BHA: O-shot to unset PKR#4, 3, 2, 1, respectively , is $177,624.

After calculating, the expected cost of decision alternative “SP”, is saving investment cost more than alternative-C1, C2, C3 and C4, so choosing “unsetting all retrievable packer (PKR#4, 3, 2, 1) by straight pulling” is most appropriate. It can provide benefit $95,104 over alterative “C4” as shown in Fig 4.32a-4.32c illustrated policy suggestion. It presents only the optimum part of decision tree. It shows option was chosen alternative node by illustrating a reduced version of decision tree, with the optimum path highlighted and the expected value. The probabilities of each path are also displayed. The summary of statistical can be seen in Table 4.16.

Table 4.16 Statistical summary for decision tree “model 4A”

Statistics	Alternative SP-(straight pull)	Alternative C1-(cutting 1 cut & pull)	Alternative C2-(cutting 2 cut & pull)	Alternative C3-(Cut 3 ea and unset)	Alternative -C4 (cutting 4 cut, pull and run OS to unset PKR#4)
Mean	$82,521	$117,172	$139,806	$154,419	$177,624
Minimum	$258,213	$255,258	$252,303	$249,348	$241,393
Maximum	$63,861	$88,661	$113,461	$138,261	$161,889
Mode	$63,861	$88,661	$113,461	$138,261	$161,889
Std. Deviation	31593.46	30141.45	24394.51	18038.54	16425.53
Skewness	-1.73	-0.82	-0.68	-0.99	-0.79
Kurtosis	5.22	2.85	2.74	3.69	3.07

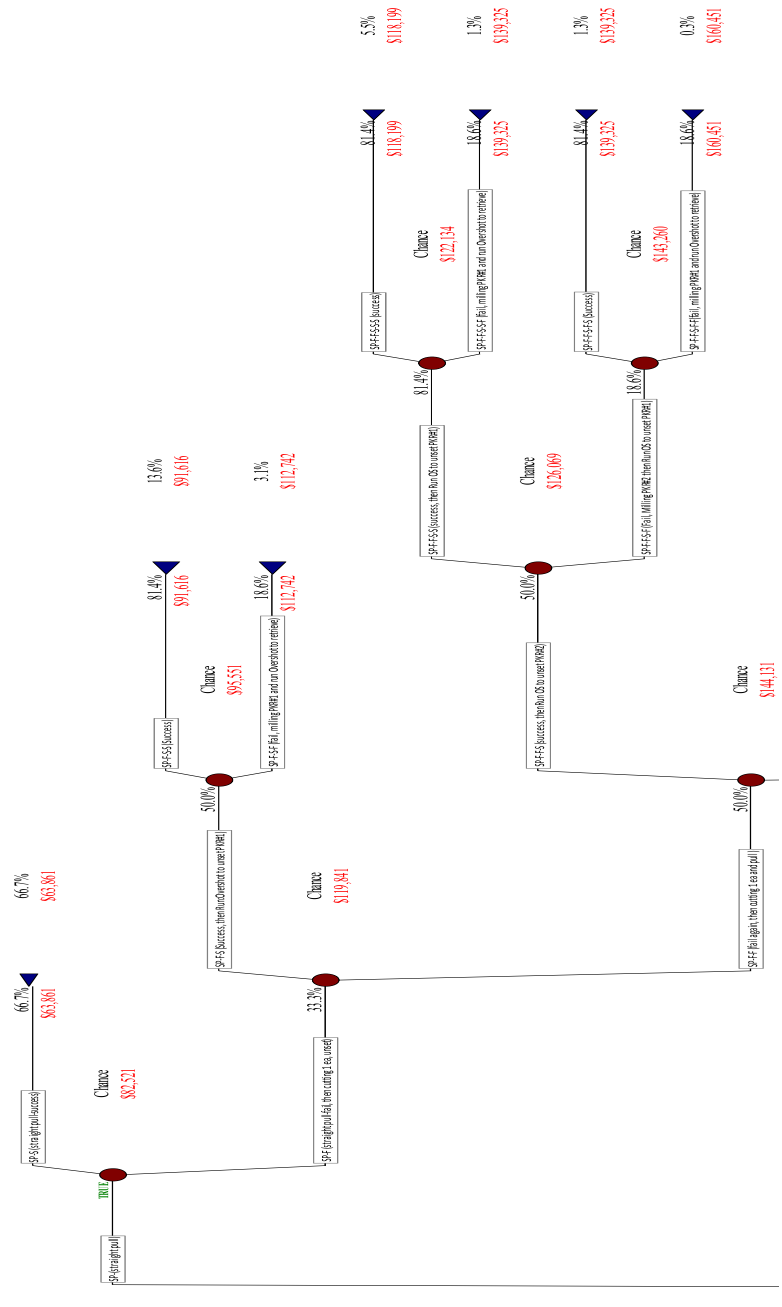

Figure 4.32a Optimum decisions tree suggestion “model 4A”

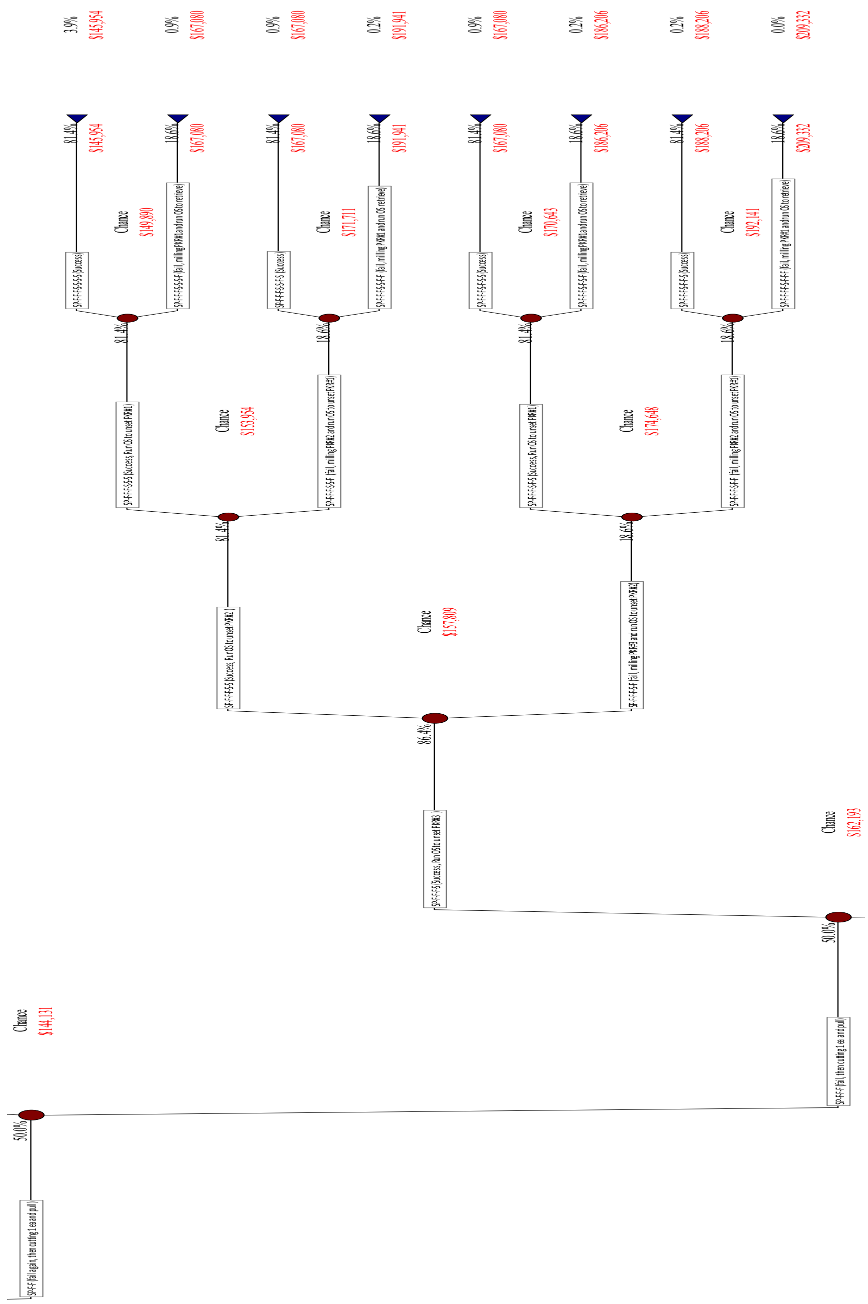

Figure 4.32b Optimum decisions tree suggestion “model 4A”

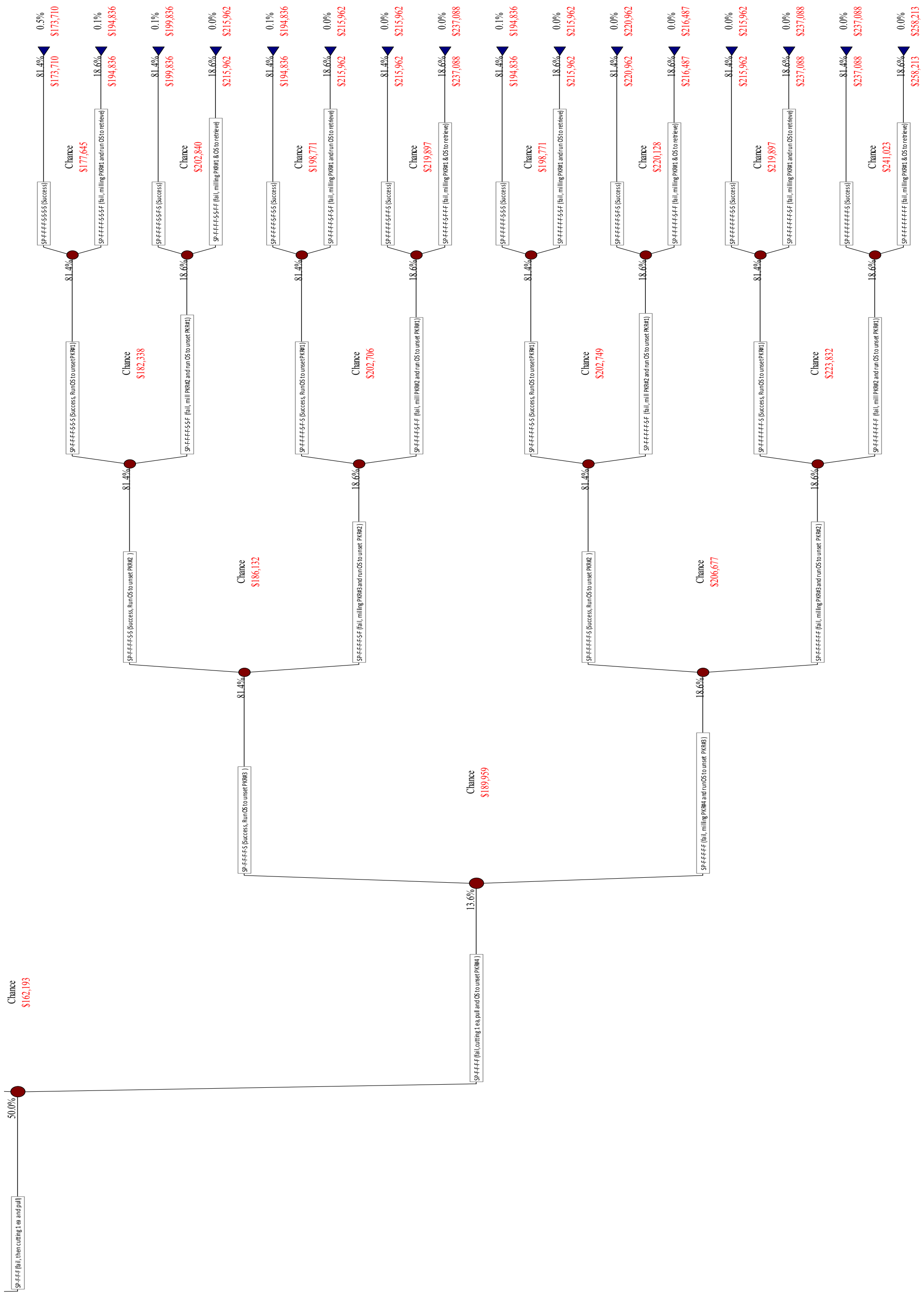

Figure 4.32c Optimum decisions tree suggestion “model 4A”

4.4.2 Result of decision tree analysis model 4B

To construct decision tree, it is used to find optimum operation cost for workover three zones completion, three retrievable packers – RH/FH packer type with one permanent packer, represent by decision node (square). There are five decision alternatives (SP, C1, C2, C3 and C4) as illustrated Figure 4.33a-4.33r, which consists of;

- Decision alternative SP: unsetting retrievable packers (PKR#3, 2, 1) and seal by straight pulling.
- Decision alternative C1: cutting 1 cut, above seal and unsetting retrievable packers (PKR #3, 2, 1) by straight pulling. After that, running BHA: overshot to retrieve seal.
- Decision alternative C2: cutting 2 cut, above seal, PKR#1, and unsetting retrievable packer (PKR#3, 2) by straight pulling. After that running BHA: overshot to unset PKR#1 and to retrieve seal, respectively.
- Decision alternative C3: cutting 3 cut, above seal, PKR#1, 2 and unsetting retrievable packer (PKR#3) by straight pulling. After that, running BHA: overshot to unset PKR#2, 1 and to retrieve seal, respectively.
- Decision alternative C4: cutting 4 cut, above seal, PKR#1, 2, 3 and then pulling above part and RIH O-shot to retrieve each PKRs.

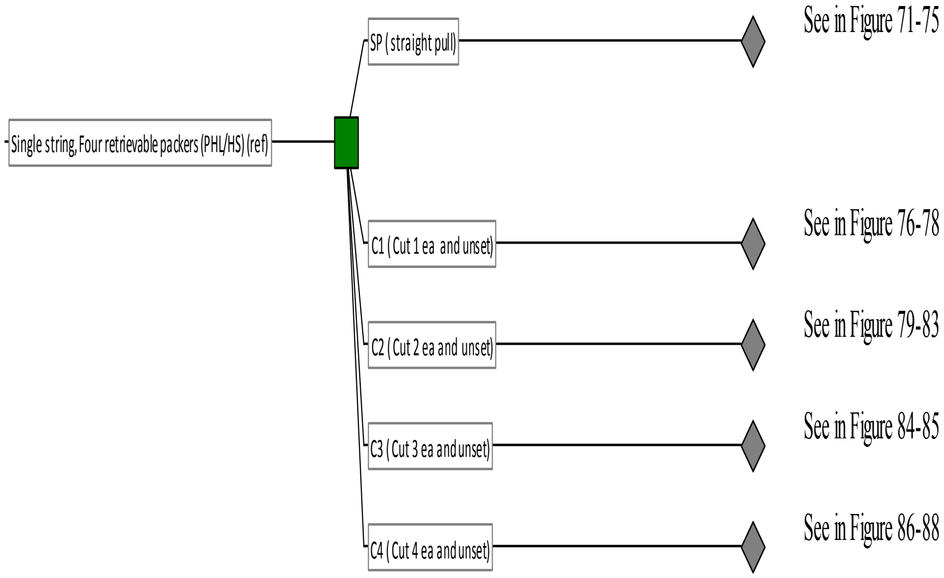

Figure 4.33a Decision [2]tree for "model 4B"

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[2] Perm/Packer is referred permanent packer.

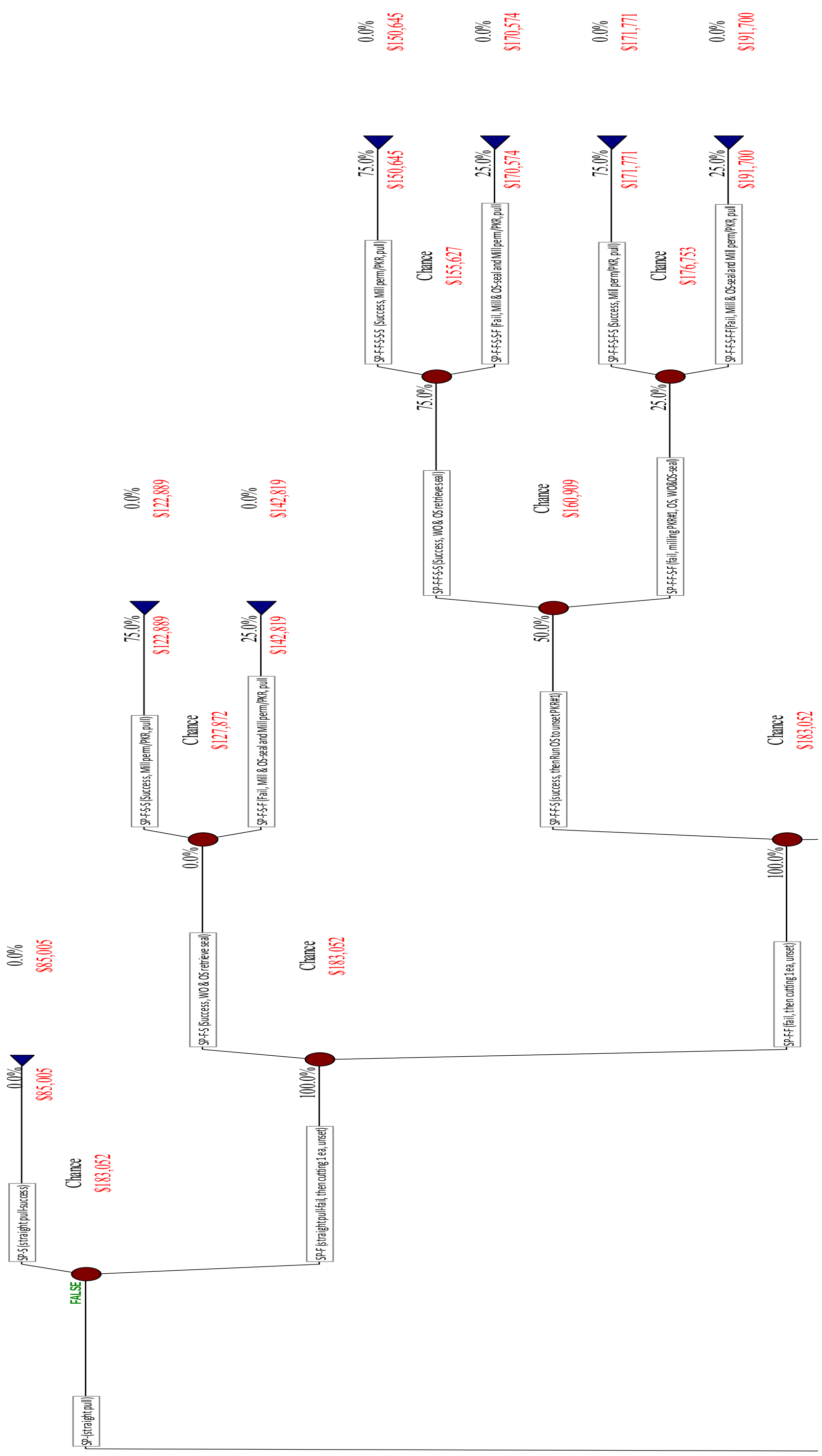

Figure 4.33b Decision tree for “model 4B”

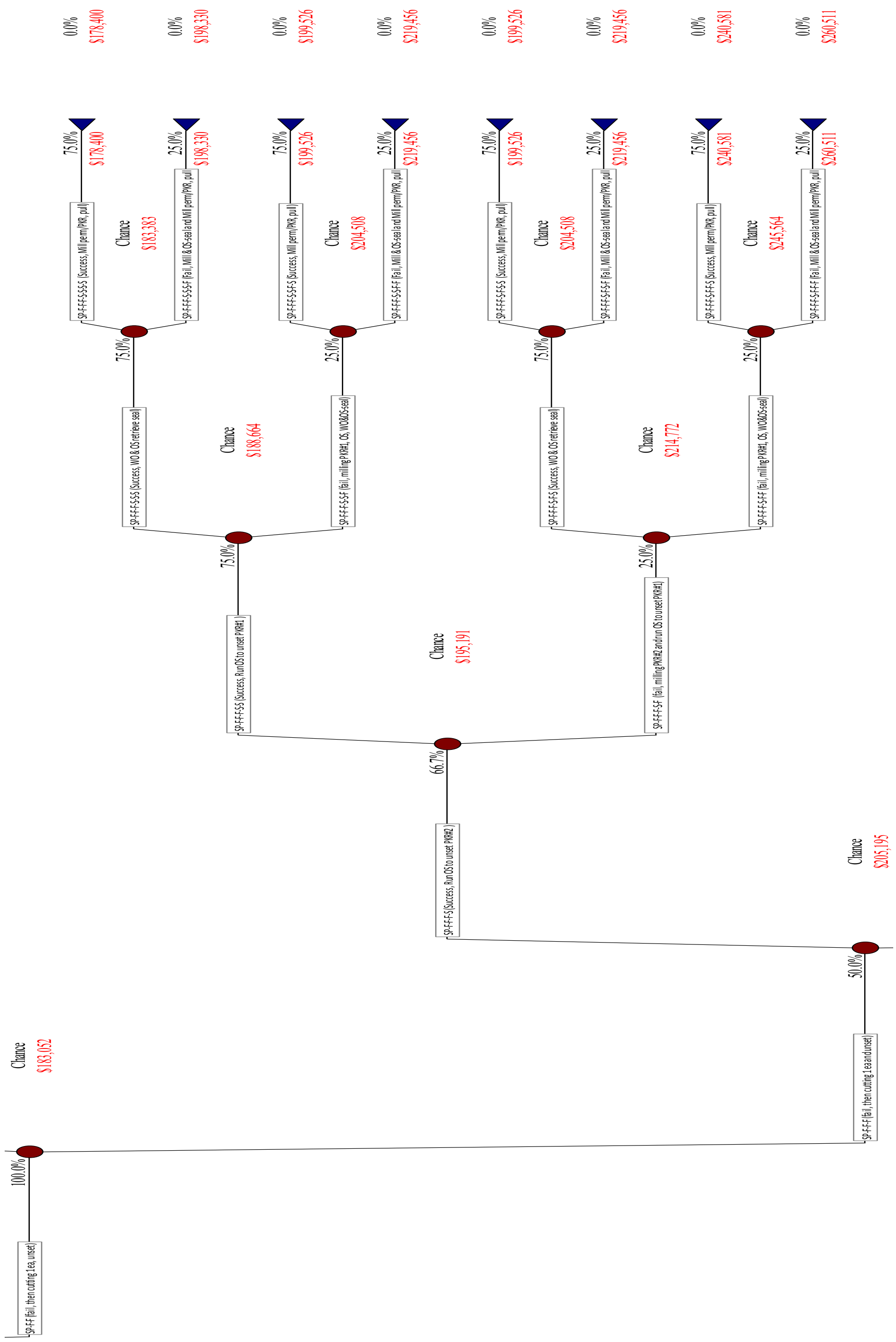

Figure 4.33c Decision tree for “model 4B”

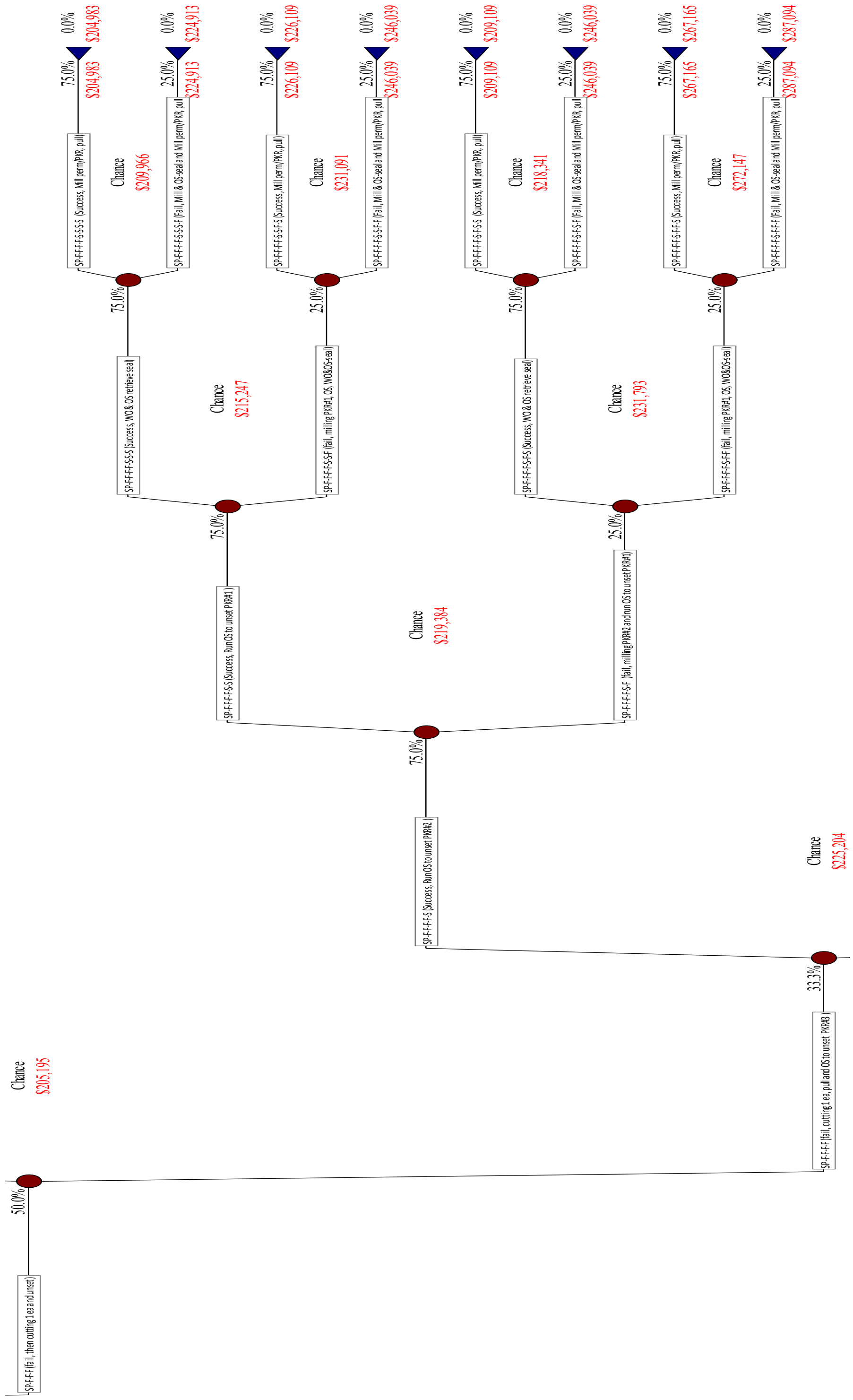

Figure 4.33d Decision tree for “model 4B”

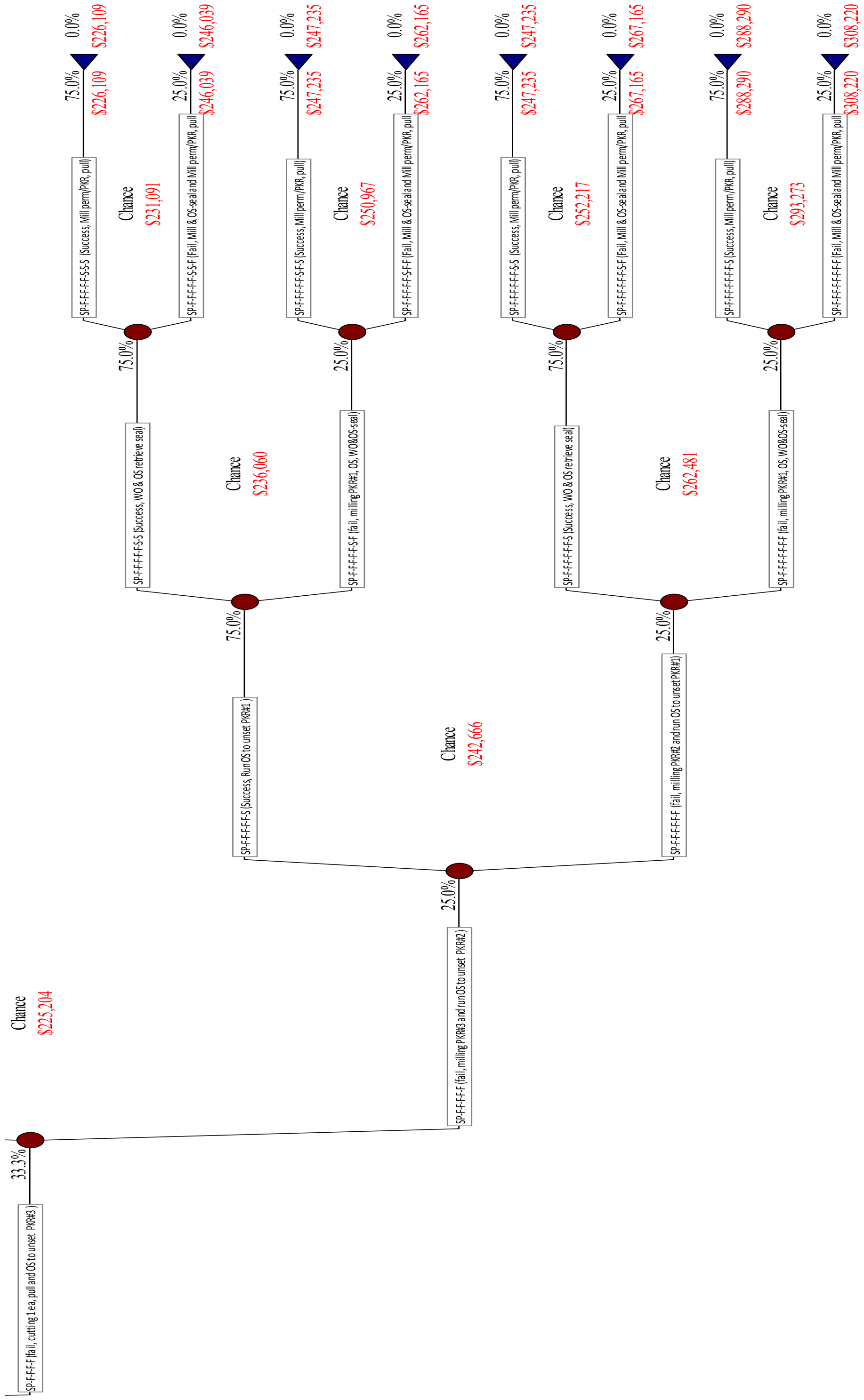

Figure 4.33e Decision tree for “model 4B”

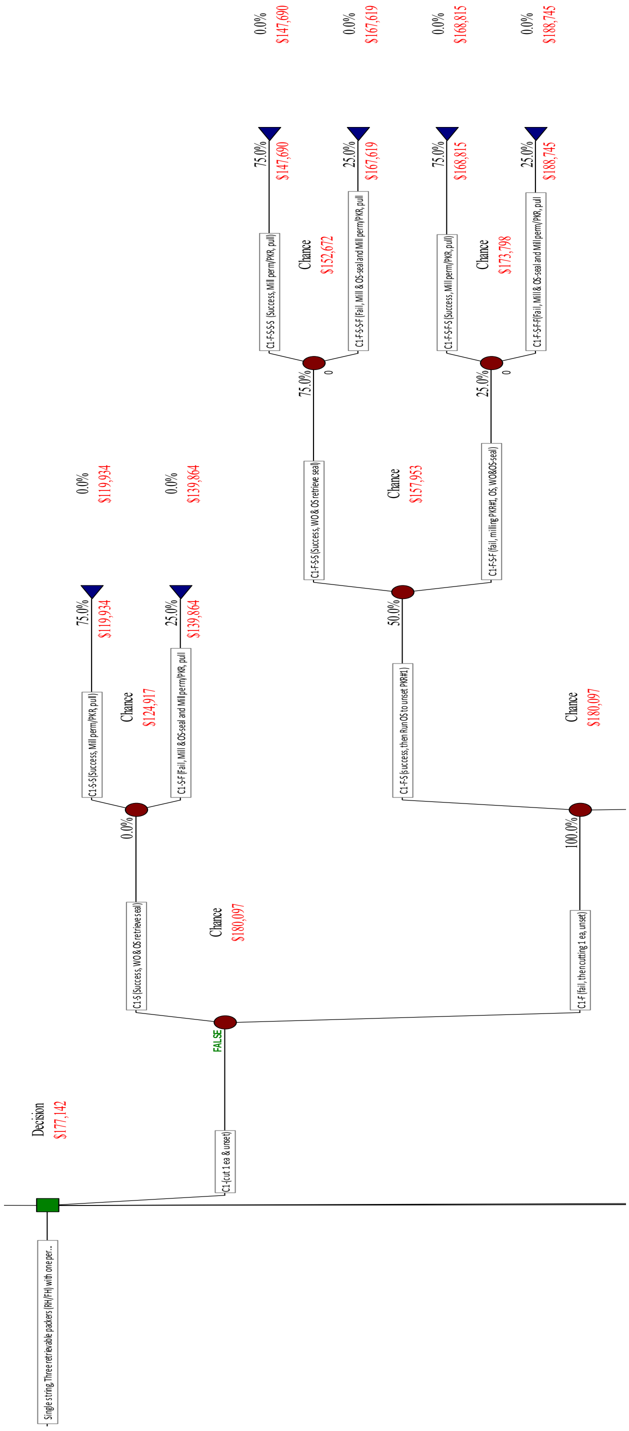

Figure 4.33f Decision tree for “model 4B”

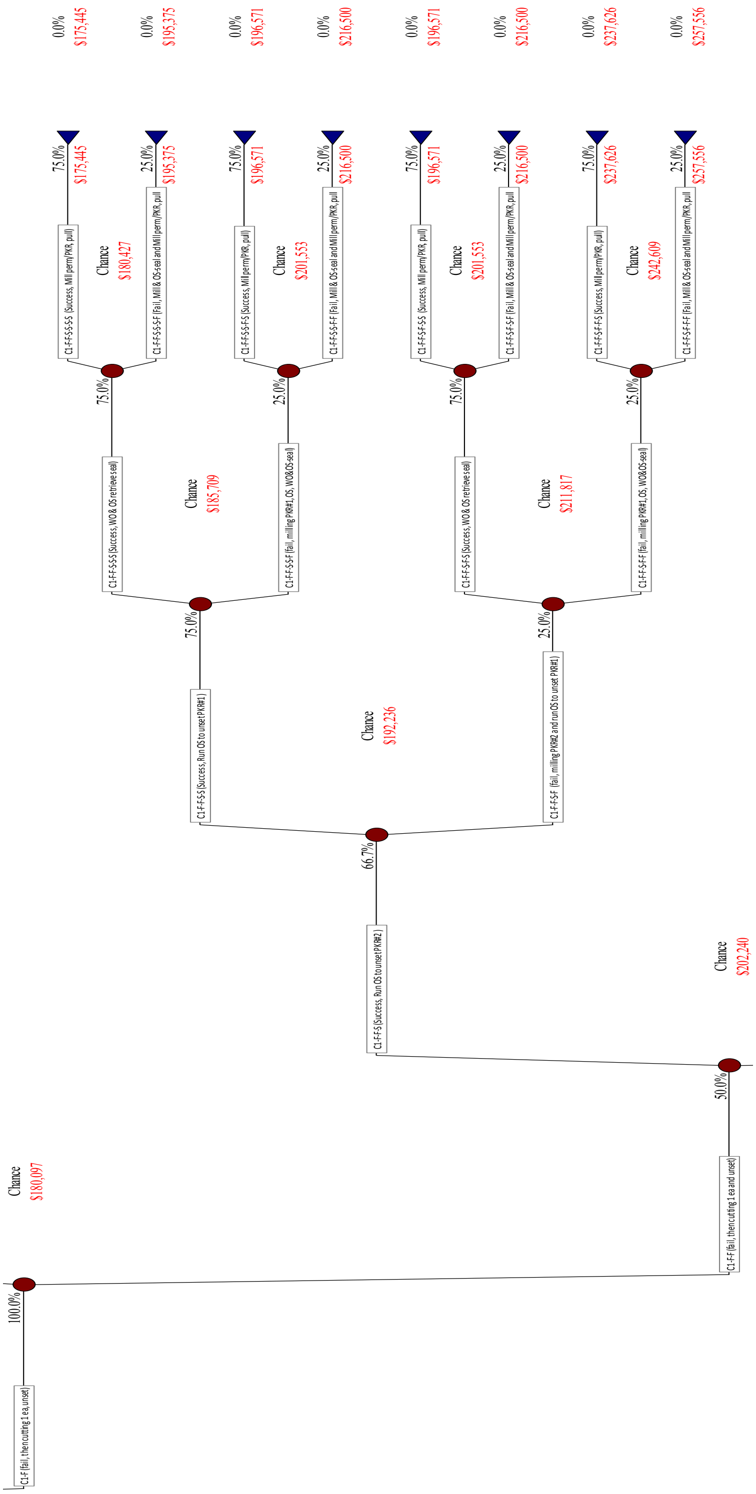

Figure 4.33g Decision tree for “model 4B”

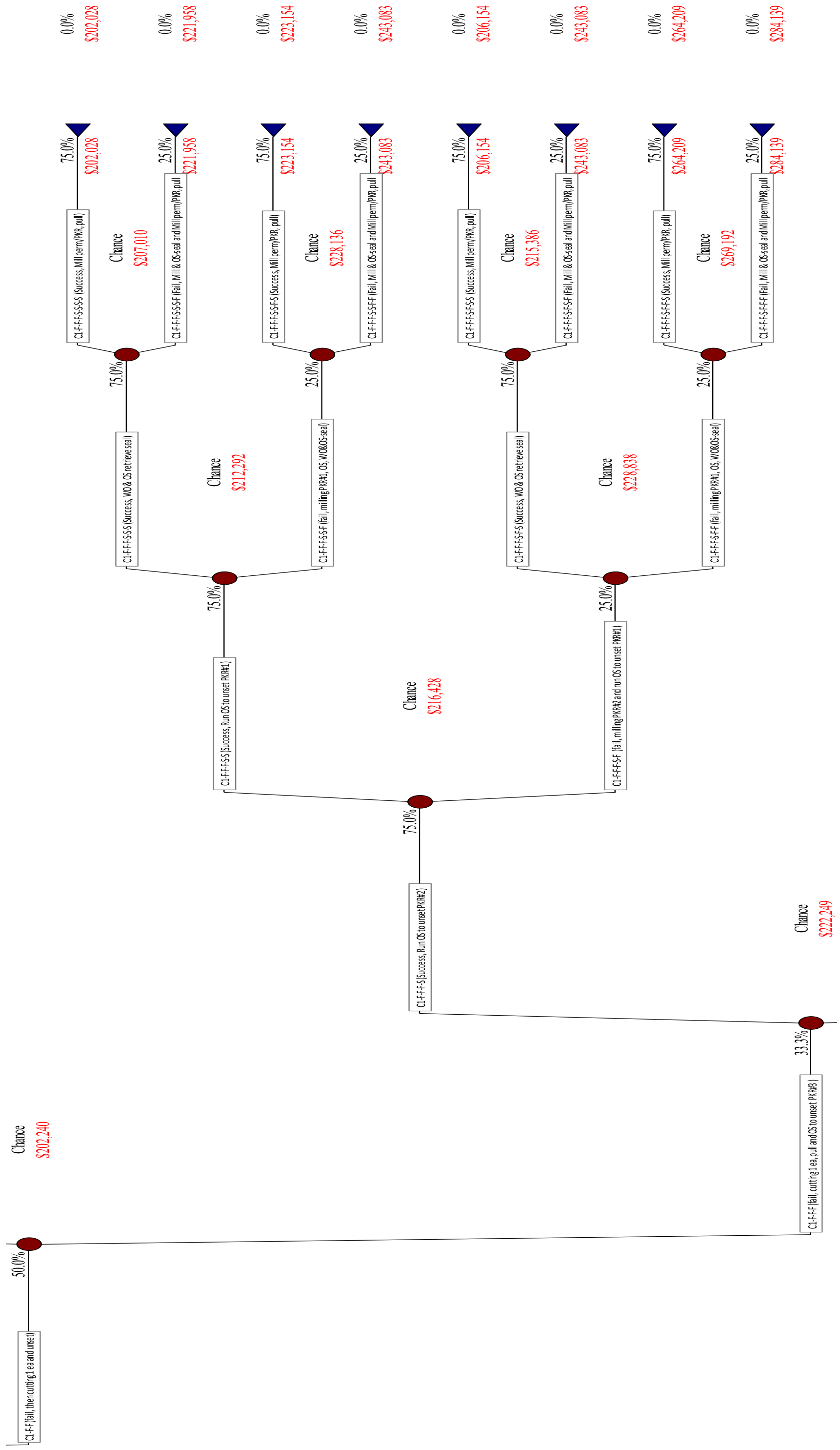

Figure 4.33h Decision tree for “model 4B”

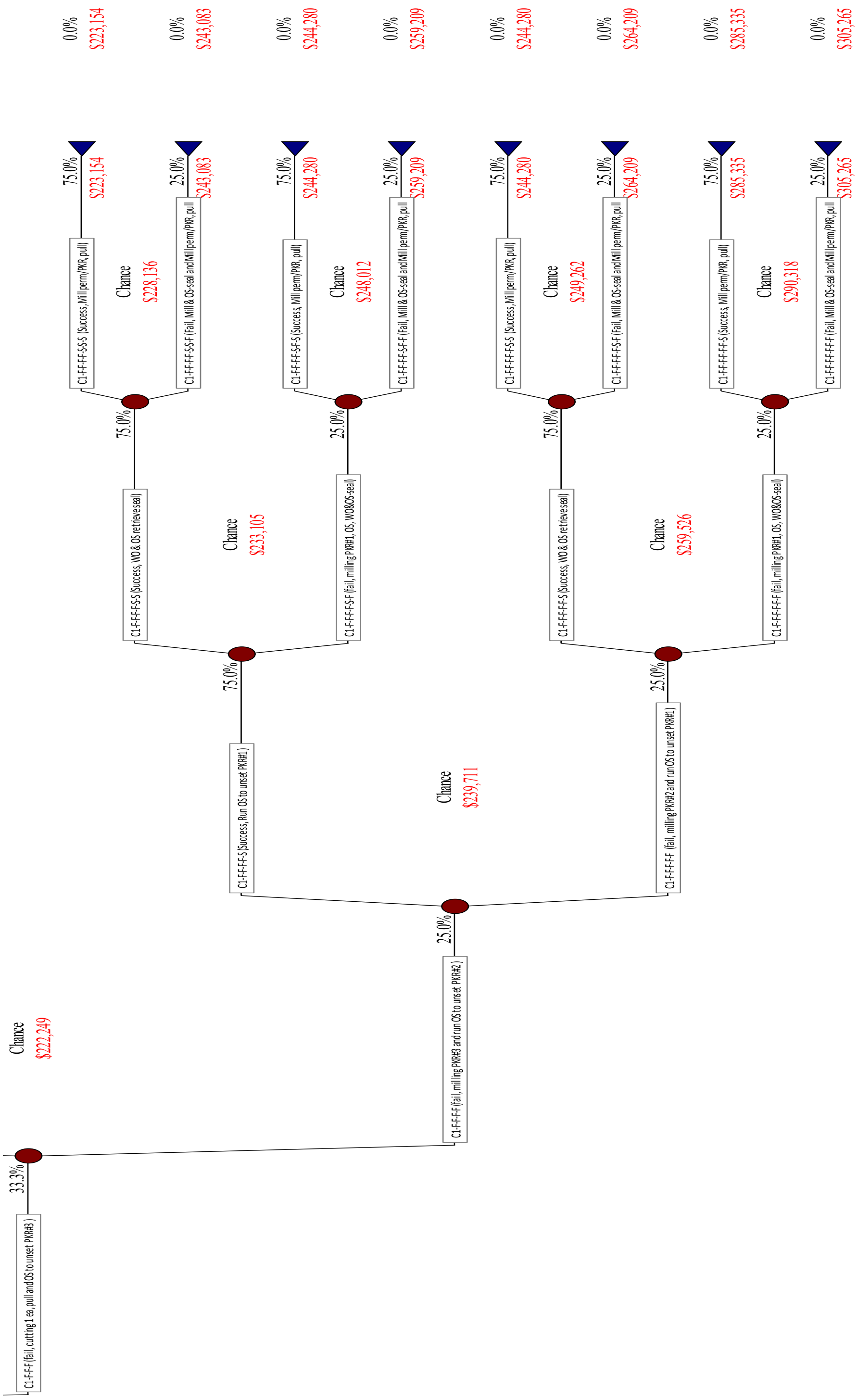

Figure 4.33i Decision tree for “model 4B”

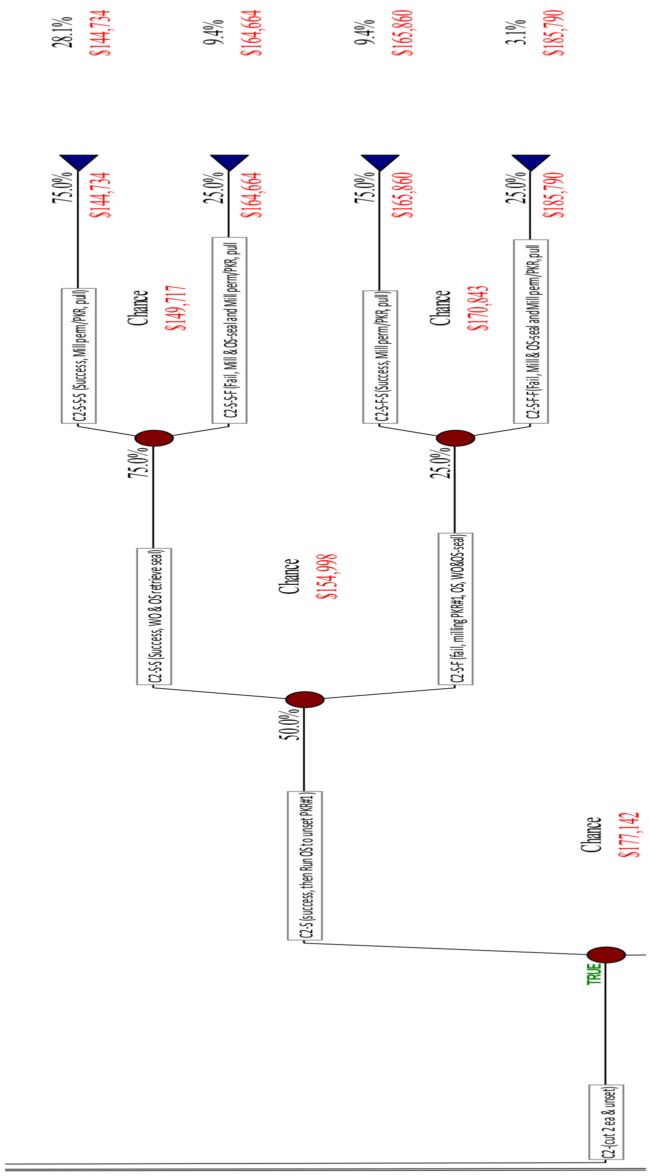

Figure 4.33j Decision tree for “model 4B”

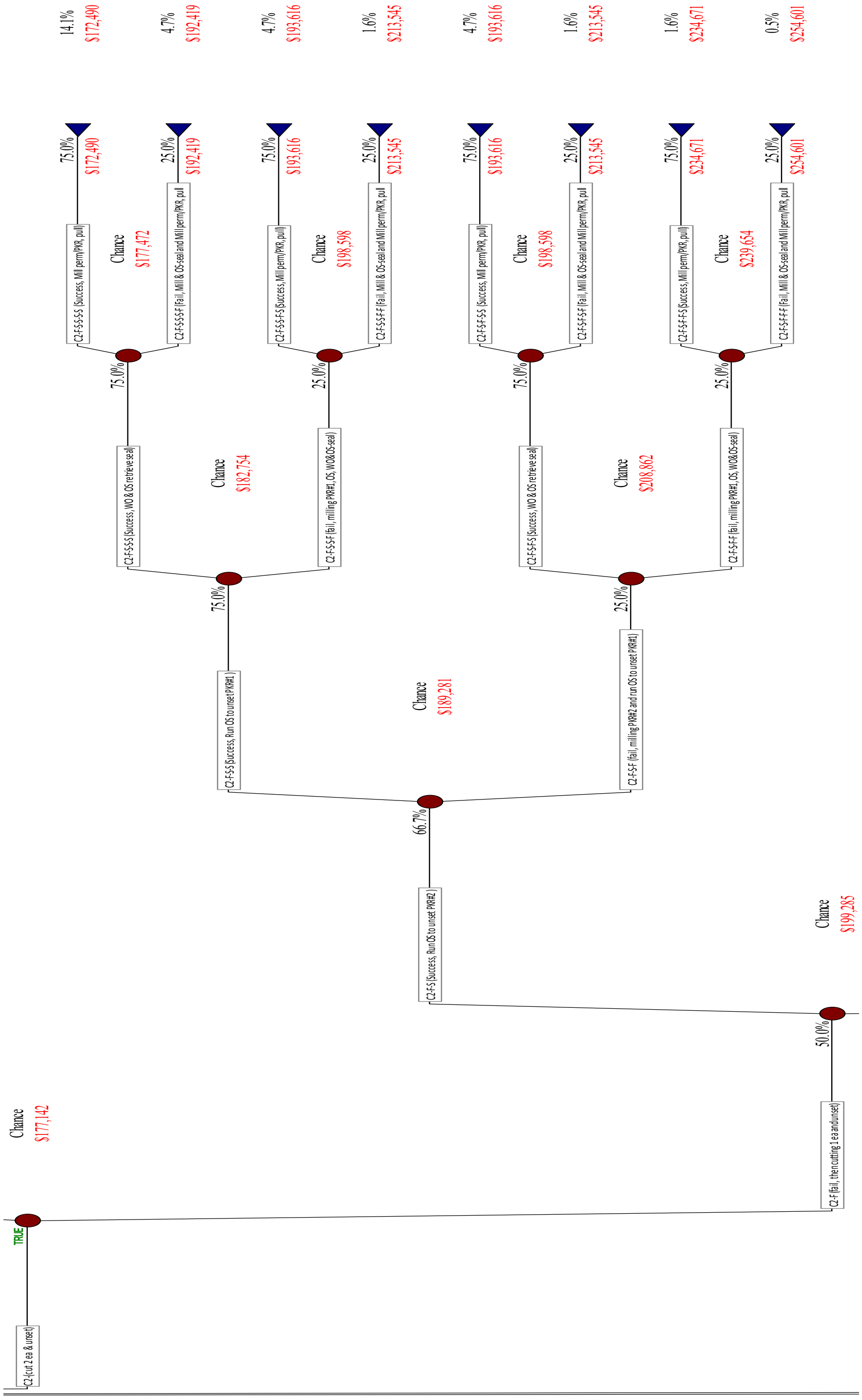

Figure 4.33k Decision tree for “model 4B”

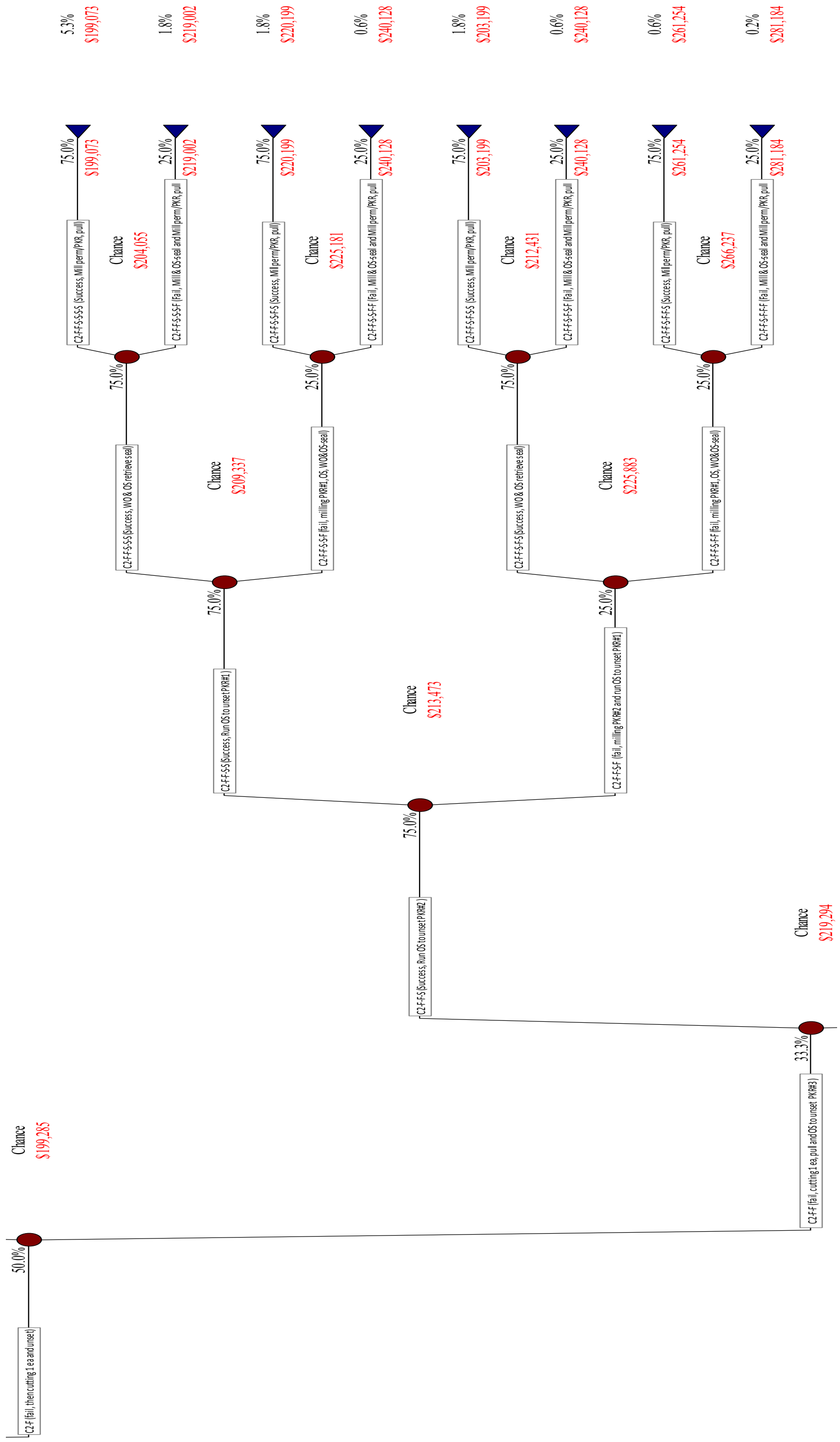

Figure 4.33l Decision tree for “model 4B”

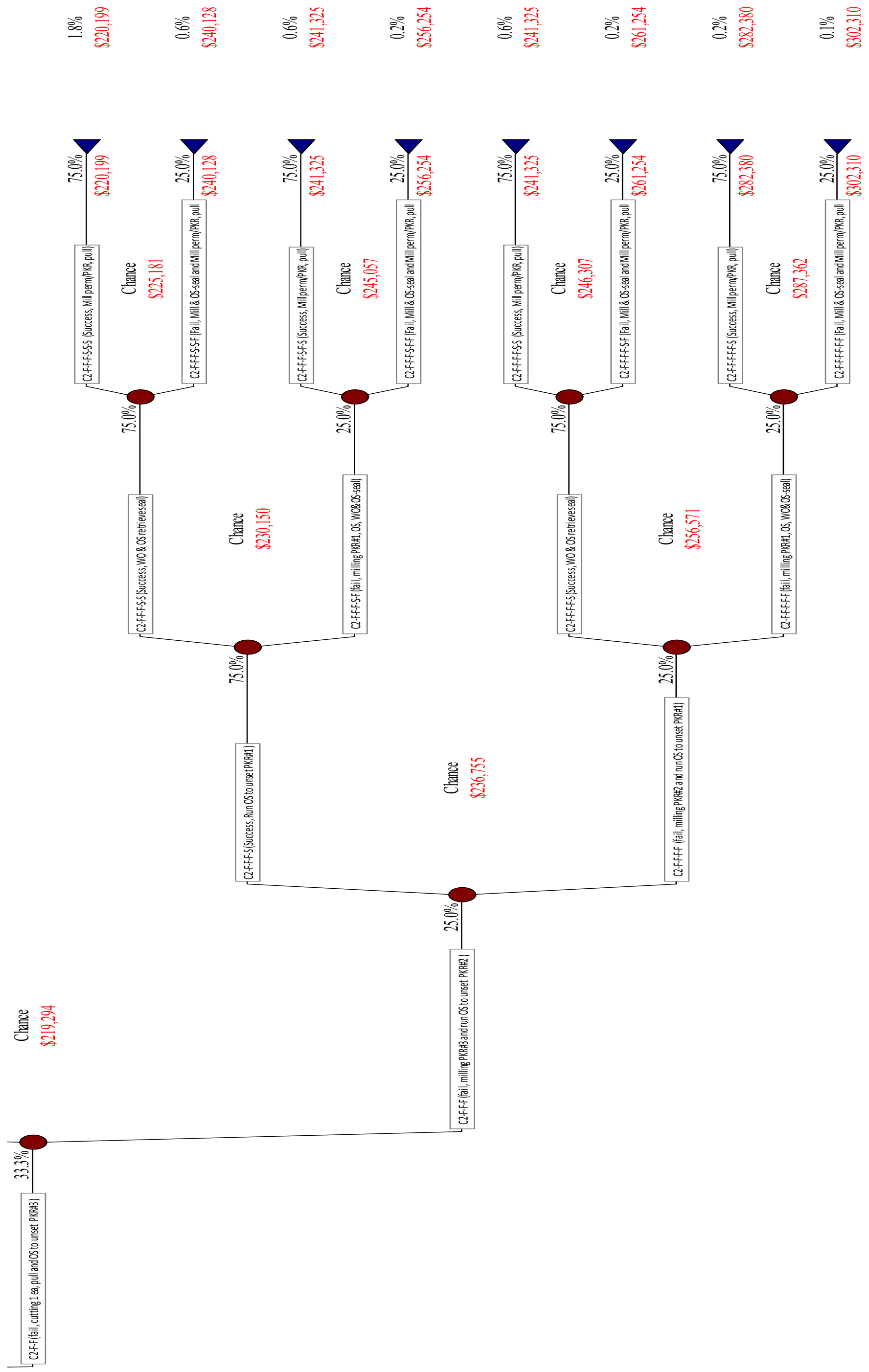

Figure 4.33m Decision tree for “model 4B”

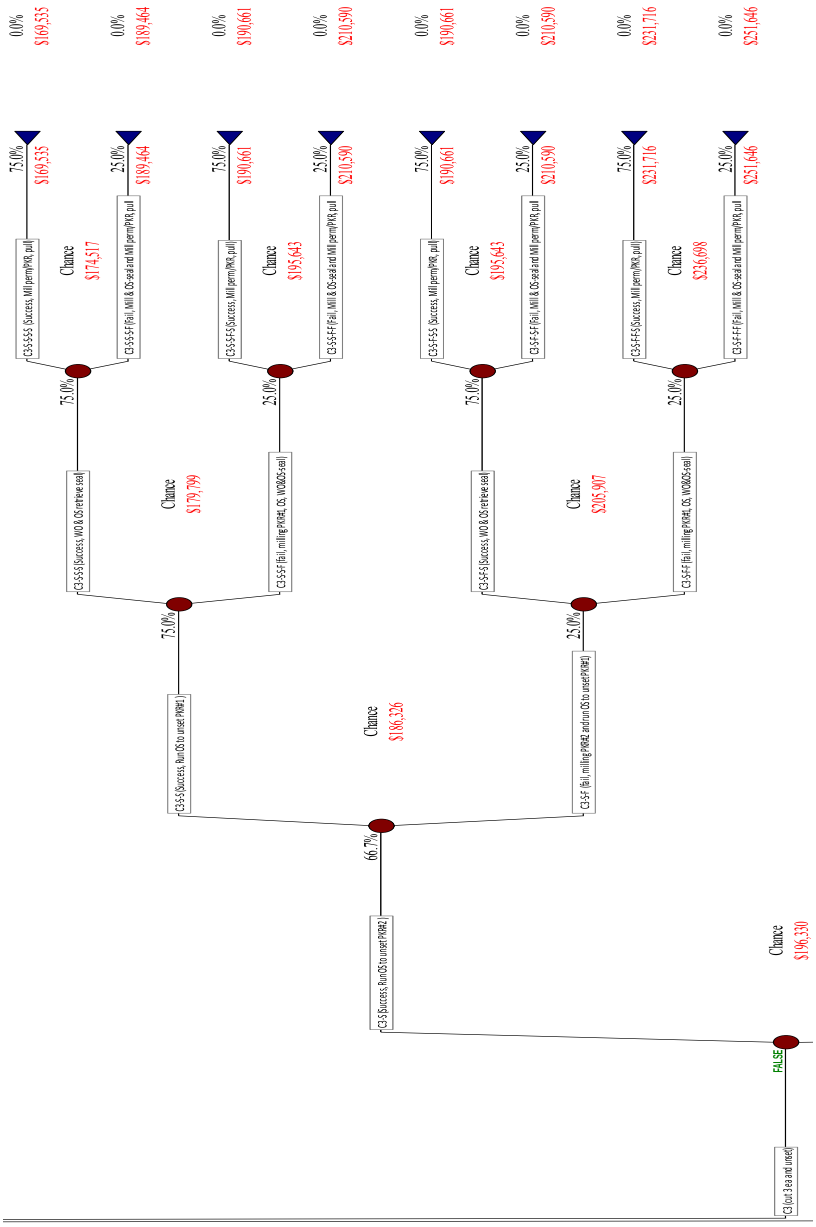

Figure 4.33n Decision tree for “model 4B”

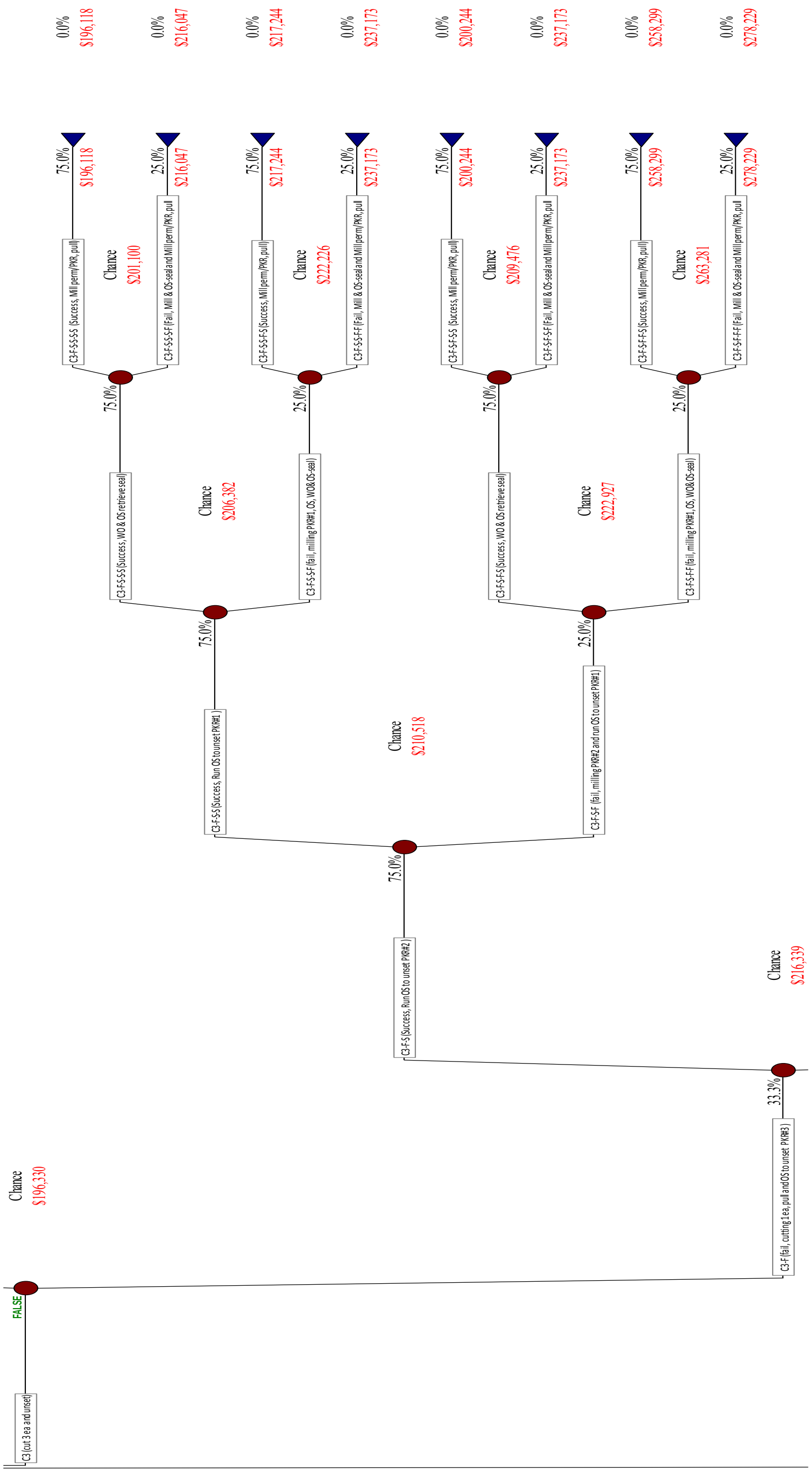

Figure 4.33o Decision tree for “model 4B”

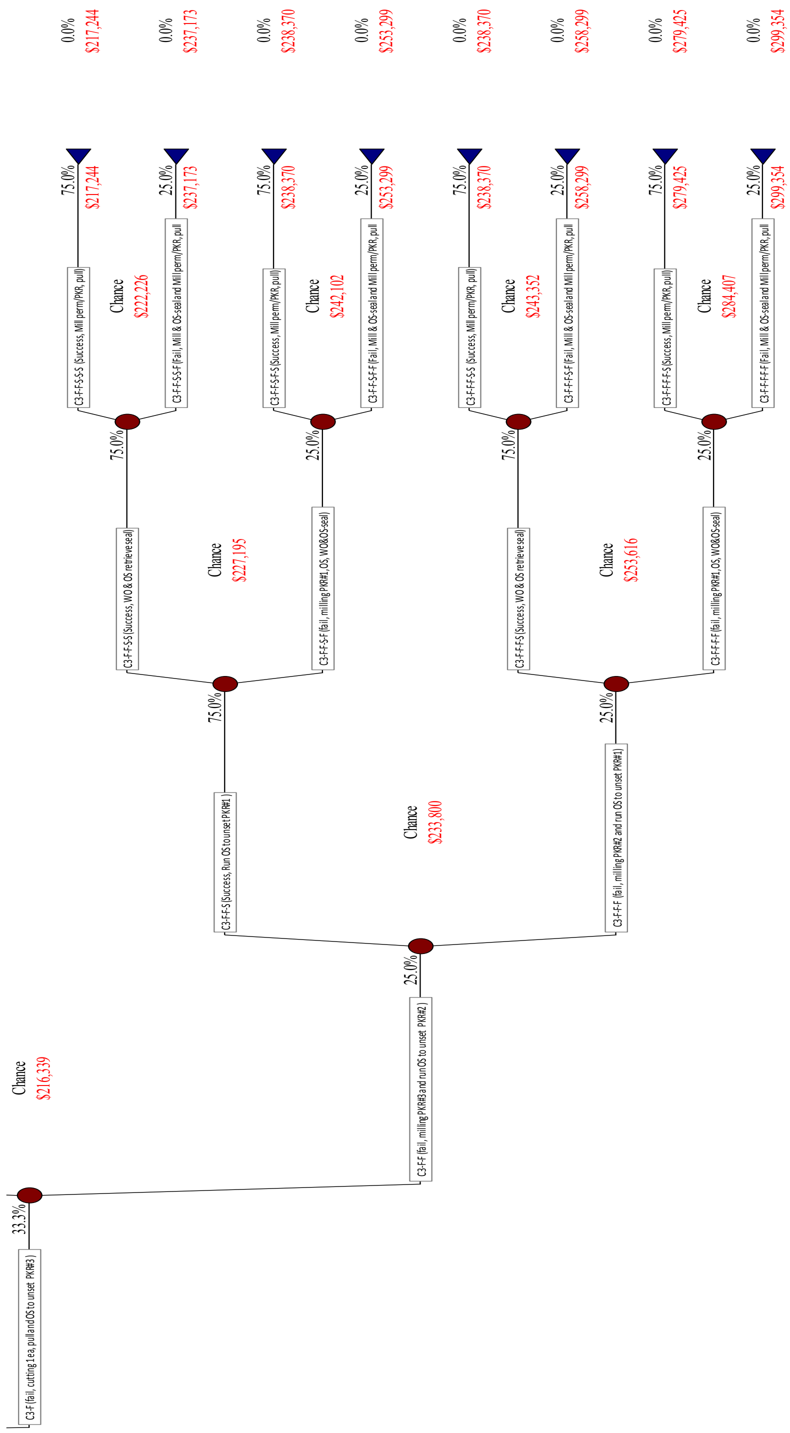

Figure 4.33p Decision tree for “model 4B”

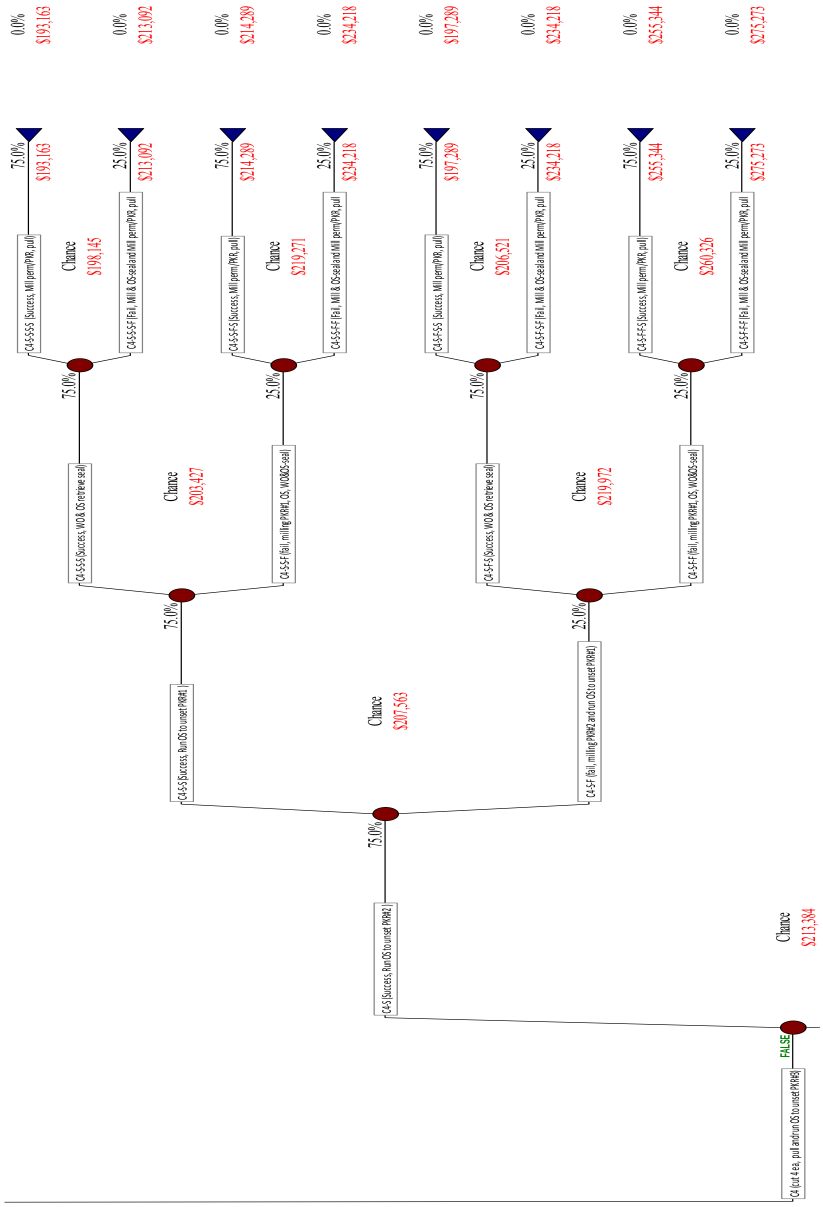

Figure 4.33q Decision tree for “model 4B”

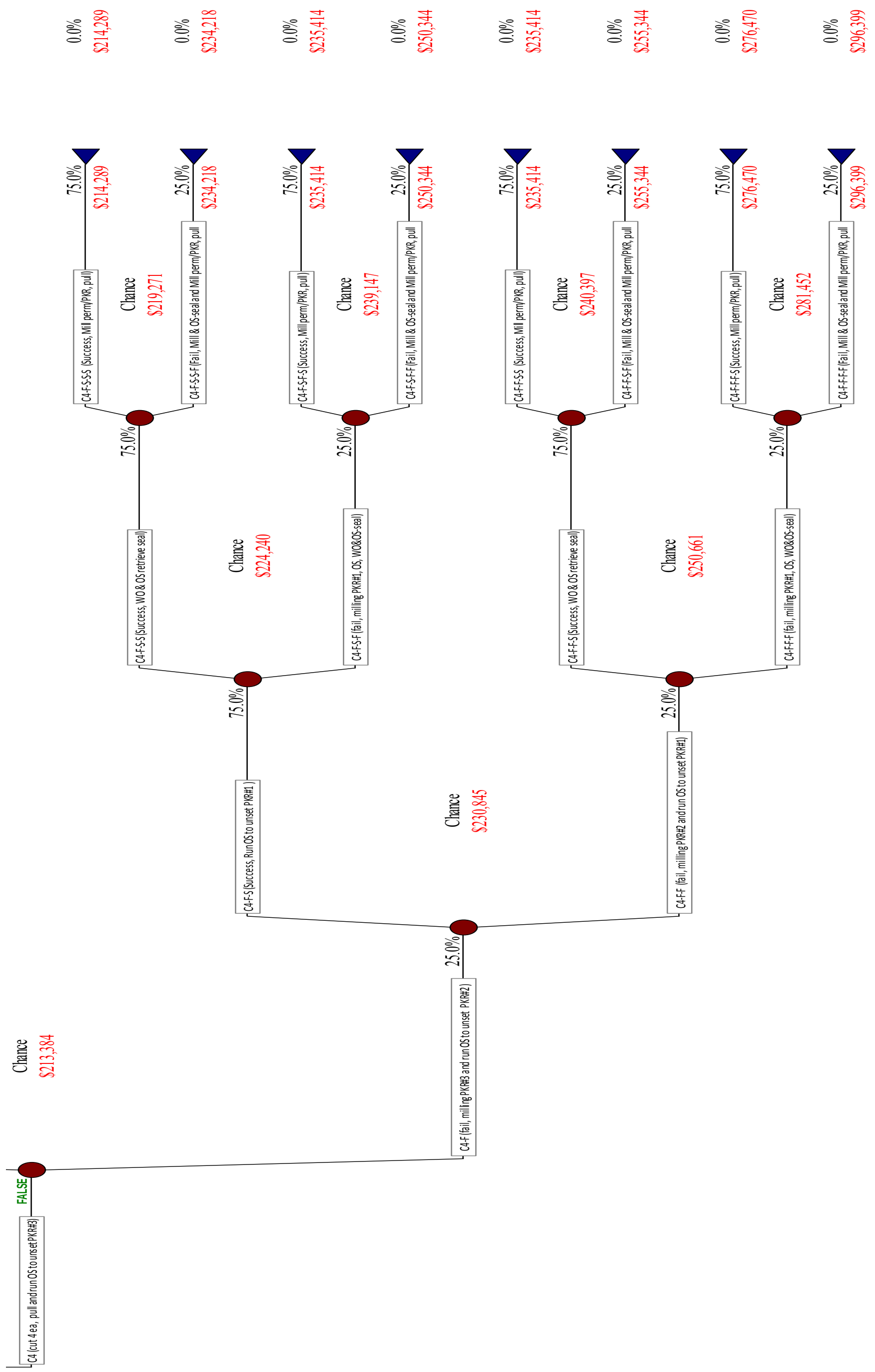

Figure 4.33r Decision tree for “model 4B”

The risk profile is a distribution function. It shows in a discrete density distribution which described the chance associated with all of possible outcome. It also demonstrates the uncertainty of decision using a frequency or cumulative frequency graph.

Figure 4.34 illustrates the probability chart; the height of the alternative node “C2” line at $144,734 is 28.10%, which is equal to the probability that the expected cost of alternative node “SP is $144,734.

Figure 4.35 illustrates the cumulative chart, the probability that the alternative node “C2” a value less than or equal to $144,734 is 100%.

Table 4.17 also illustrated the statistical summary of the risk profile, which provides a statistical summary report of the decision analysis.

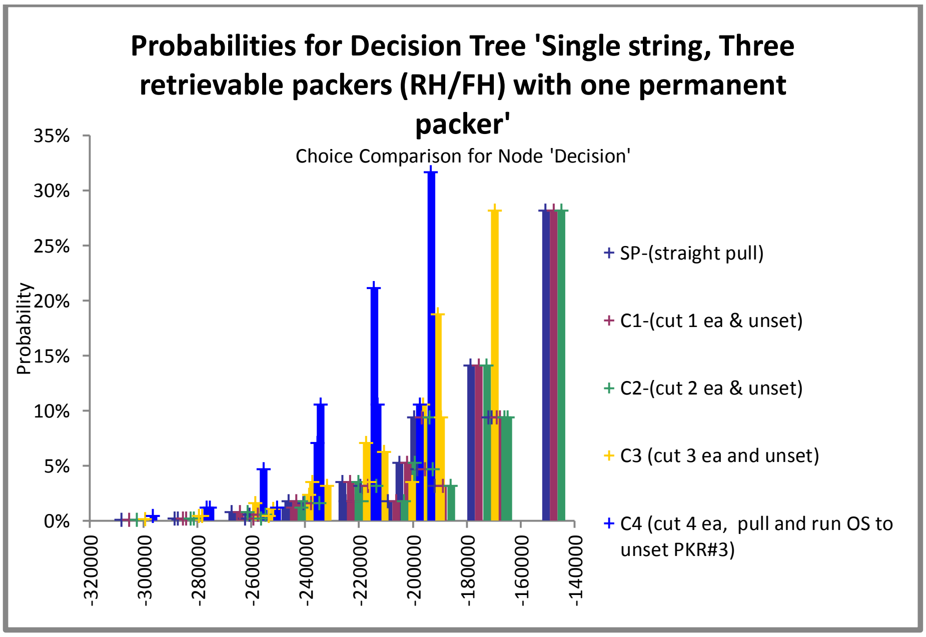

Figure 4.34 Probability decision for decision tree for “model 4B”

Table 4.17 Summary data of probability decision for decision tree “model 4B”

Expected cost	Alternative SP- (straight pull)		Alternative C1- (Cutting 1 cut and unset)		Alternative C2- (Cutting 2 cut and unset)		Alternative C3- (Cutting 3 cut and unset)		Alternative C4 (cutting 4 cut, pull and run OS to unset PKR#3)	
	Value	Prob	Value	Prob	Value	Prob	Value	Prob	Value	Prob.
#1	$308,220	0.10%	$305,265	0.10%	$302,310	0.10%	$299,354	0.10%	$296,399	0.40%
#2	$288,290	0.20%	$285,335	0.20%	$282,380	0.20%	$279,425	0.40%	$276,470	1.20%
#3	$287,094	0.20%	$284,139	0.20%	$281,184	0.20%	$278,229	0.40%	$275,273	1.20%
#4	$267,165	0.80%	$264,209	0.80%	$261,254	0.80%	$258,299	1.60%	$255,344	4.70%
#5	$262,165	0.20%	$259,209	0.20%	$256,254	0.20%	$253,299	0.40%	$250,344	1.20%
#6	$260,511	0.50%	$257,556	0.50%	$254,601	0.50%	$251,646	1.00%	$235,414	7.00%
#7	$247,235	1.20%	$244,280	1.20%	$241,325	1.20%	$238,370	2.30%	$234,218	10.50%
#8	$246,039	1.80%	$243,083	1.80%	$240,128	1.80%	$237,173	3.50%	$214,289	21.10%
#9	$240,581	1.60%	$237,626	1.60%	$234,671	1.60%	$231,716	3.10%	$213,092	10.50%
#10	$226,109	3.50%	$223,154	3.50%	$220,199	3.50%	$217,244	7.00%	$197,289	10.50%
#11	$224,913	1.80%	$221,958	1.80%	$219,002	1.80%	$216,047	3.50%	$193,163	31.60%
#12	$219,456	3.10%	$216,500	3.10%	$213,545	3.10%	$210,590	6.30%		
#13	$209,109	1.80%	$206,154	1.80%	$203,199	1.80%	$200,244	3.50%		
#14	$204,983	5.30%	$202,028	5.30%	$199,073	5.30%	$196,118	10.50%		
#15	$199,526	9.40%	$196,571	9.40%	$193,616	9.40%	$190,661	18.80%		
#16	$198,330	4.70%	$195,375	4.70%	$192,419	4.70%	$189,464	9.40%		
#17	$191,700	3.10%	$188,745	3.10%	$185,790	3.10%	$169,535	28.10%		
#18	$178,400	14.10%	$175,445	14.10%	$172,490	14.10%				
#19	$171,771	9.40%	$168,815	9.40%	$165,860	9.40%				
#20	$170,574	9.40%	$167,619	9.40%	$164,664	9.40%				
#21	$150,645	28.10%	$147,690	28.10%	$144,734	28.10%				

Result of constructing risk profile, alternative “SP” has twelve expected costs with its probability as summarize in Table 4.18.

Alternative “C1” has twenty one expected costs with its probability as summarize in Table 4.18.

Alternative “C2” has twenty one expected costs with its probability as summarize in Table 4.18.

Alternative “C3” has seventeen expected costs with its probability as summarize in Table 4.18.

Alternative “C4” has eleven expected costs with its probability as summarize in Table 4.18.

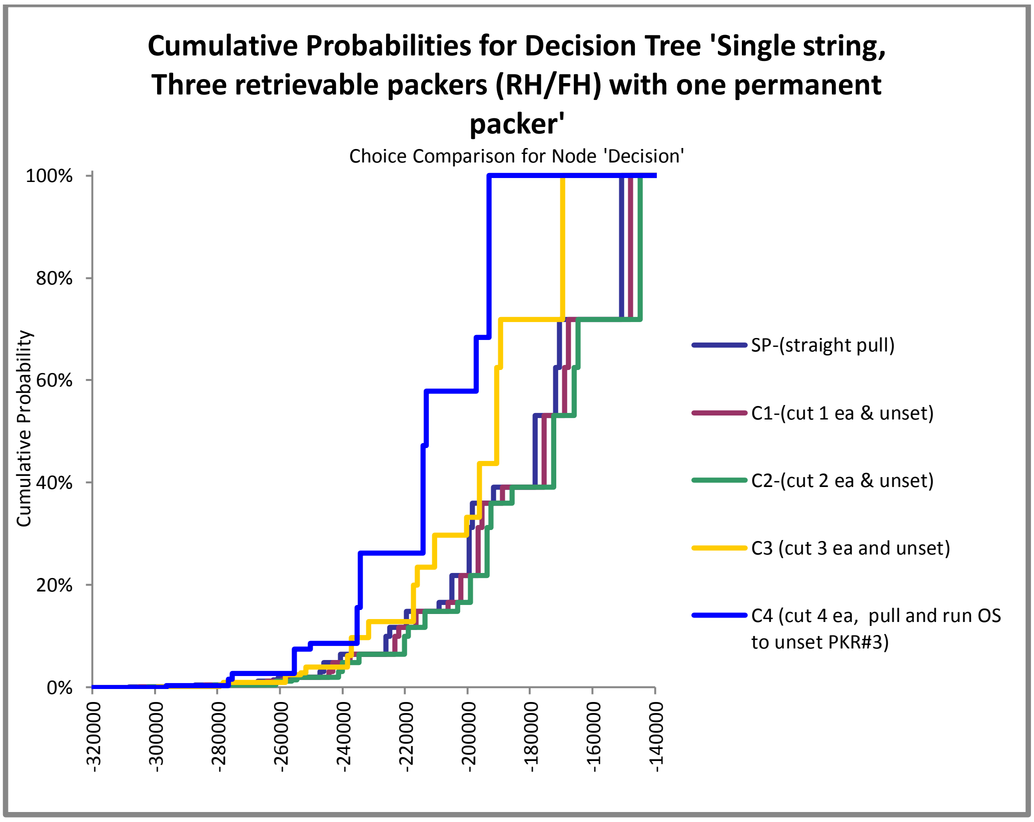

Figure 4.35 Cumulative probabilities for decision tree "model 4B"

Refer decision tree Figure4.33a-4.33r, at Alternative "SP" the expected cost of unsetting retrievable packers (PKR#3, 2, 1) and seal by straight pulling, is $183,052.

Where alternative "C1", the expected cost of cutting 1 cut above seal and unsetting retrievable packers (PKR #3, 2, 1) by straight pulling. After that, running BHA: overshot to retrieve seal, is $180,097.

Alternative "C2", the expected cost of cutting 2 cut, above seal, PKR#1, and unsetting retrievable packer (PKR#3, 2) by straight pulling. After that running BHA: overshot to unset PKR#1 and to retrieve seal, respectively, is $177,142.

Alternative "C3", the expected cost of cutting 3 cut, above seal, PKR#1, 2 and unsetting retrievable packer (PKR#3) by straight pulling. After that, running BHA: overshot to unset PKR#2, 1 and to retrieve seal, respectively, is $196,330.

In the last node, Alternative "C4, the expected cost of cutting 4 cut, above seal, PKR#1, 2, 3 and then pulling above part and RIH O-shot to retrieve each PKRs.is $213,384.

After calculating, the expected cost of decision alternative “C2”, is saving investment cost more than alternative “SP”, “C1”, “C3” and “C4”, so choosing “cutting 2 cut above seal, PKR#1, and unsetting retrievable packer (PKR#3, 2) by straight pulling. After that running BHA: overshot to unset PKR#1 and to retrieve seal, respectively” is most appropriate.

It can provide benefit $36,242 over alternative “C4” as shown in Figure 4.36a-4.36c, illustrated policy suggestion It presents only the optimum part of decision tree. It shows option was chosen alternative node by illustrating a reduced version of decision tree, with the optimum path highlighted and the expected value. The probabilities of each path are also displayed. The summary of statistical can be seen in Table 4.18.

Table 4.18 Statistical summary for decision tree “model 4B”

Statistics	Alternative SP-(straight pull)	Alternative C1-(cutting 1 cut & pull)	Alternative C2-(cutting 2 cut & pull)	Alternative C3-(Cut 3 ea and unset)	Alternative - C4 (cutting 4 cut, pull and run OS to unset PKR#4)
Mean	$183,052	$180,097	$177,142	$196,330	$213,384
Minimum	$308,220	$305,265	$302,310	$299,354	$296,399
Maximum	$150,645	$147,690	$144,734	$169,535	$193,163
Mode	$150,645	$147,690	$144,734	$169,535	$193,163
Std. Deviation	29322.46	29322.46	29322.46	24099.74	21301.92
Skewness	-0.85	-0.85	-0.85	-0.94	-1.1
Kurtosis	3.39	3.39	3.39	3.75	3.92

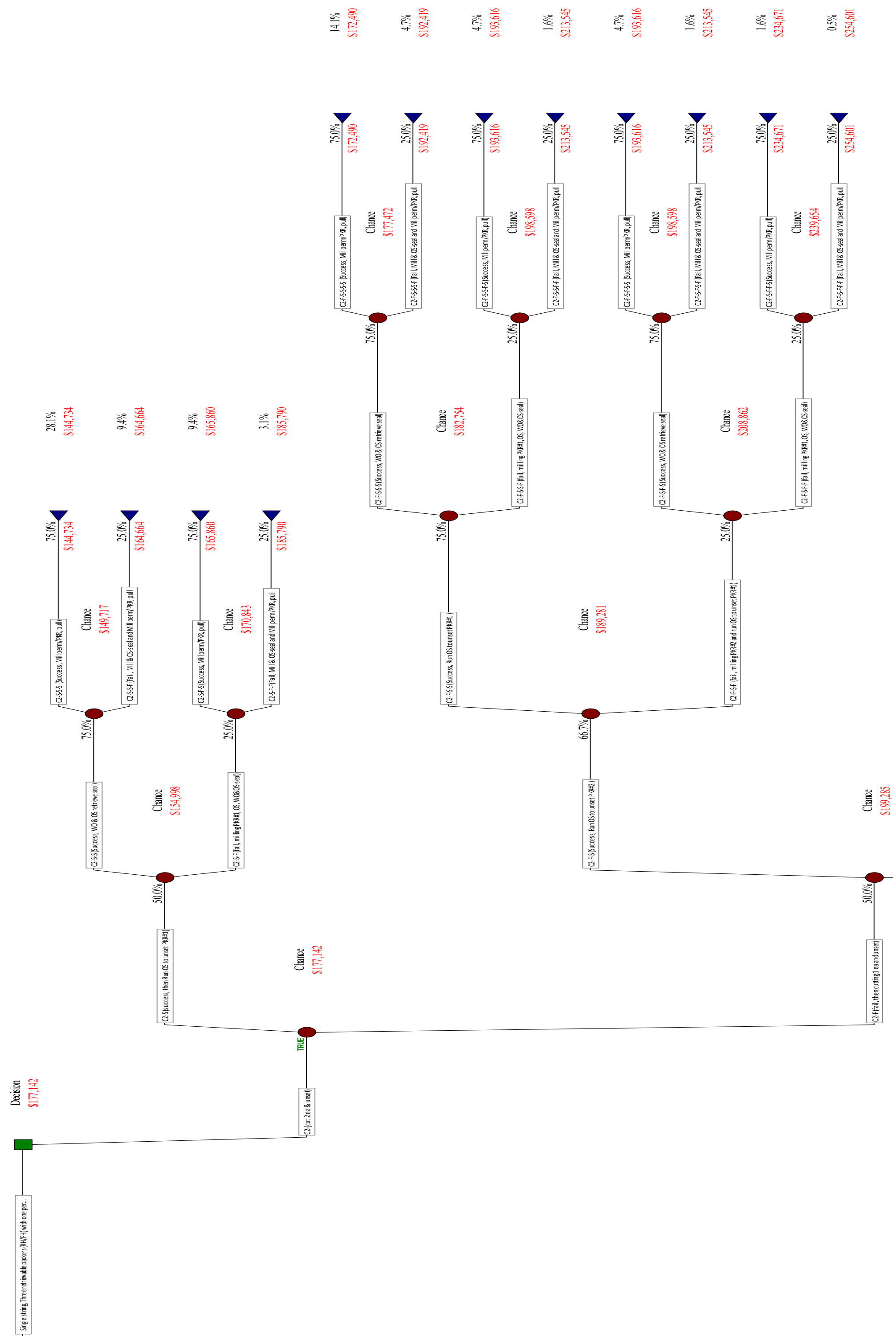

Figure 4.36a Optimum decisions tree suggestion “model 4B”

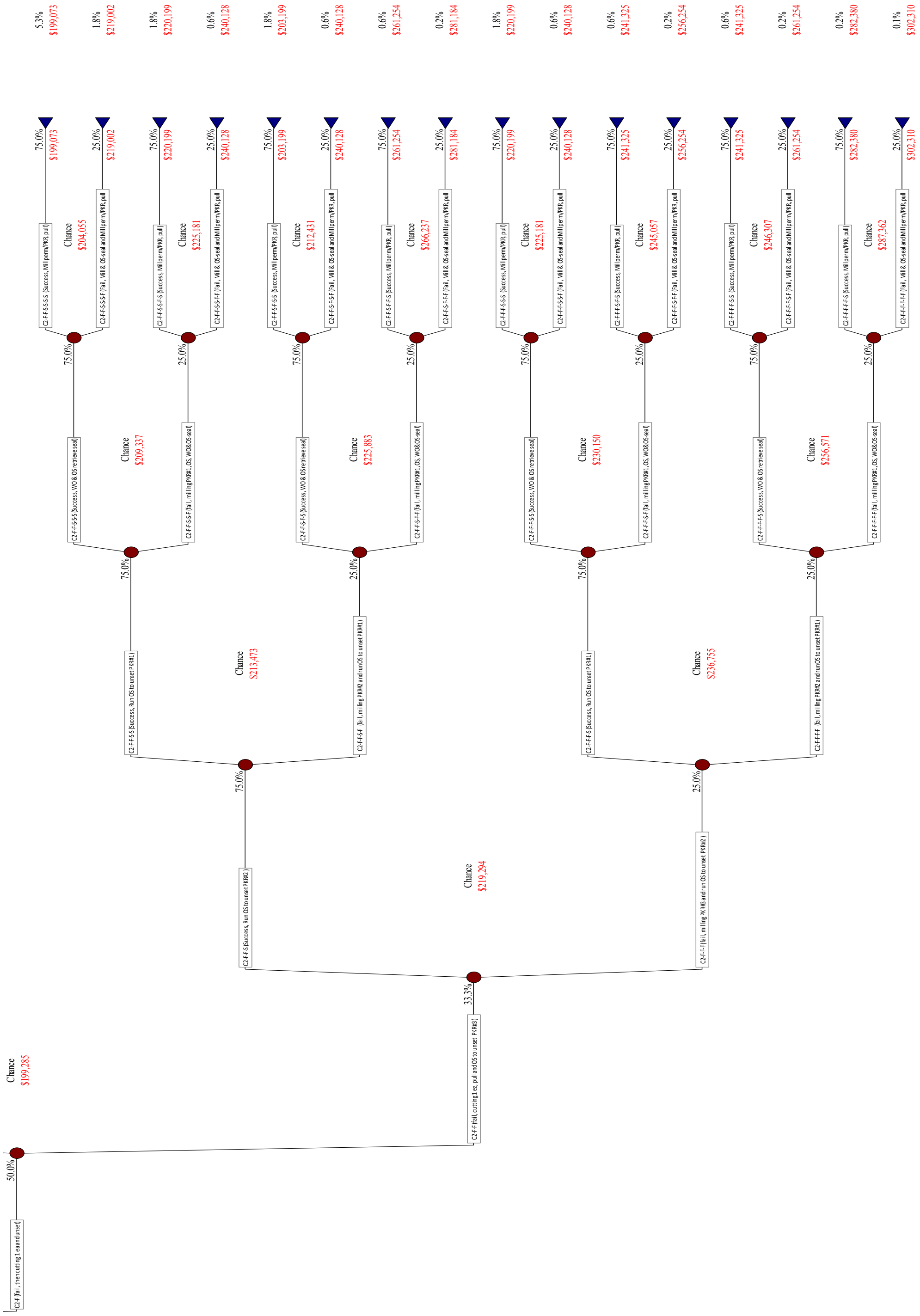

Figure 4.36b Optimum decisions tree suggestion "model 4B"

4.5 Result of decision tree analysis electrical submersible pump completion (Model 5)

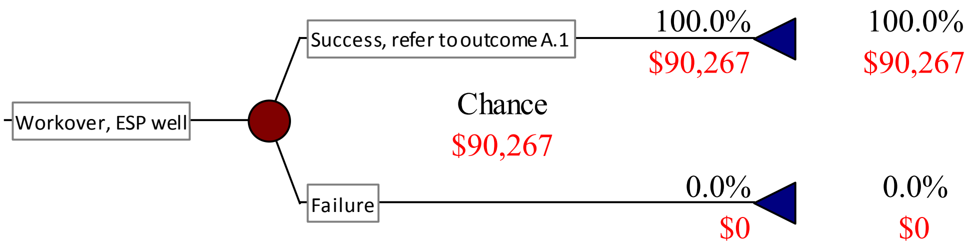

Figure 4.37 Decisions tree for "model 5"

To construct decision tree, it consists of decision node for making decision to find optimum operation cost of Electrical submersible pump completion, it represents by decision node (square),

there are two chance nodes (A, B) where chance node A, represent "successful "and chance node B, represent "unsuccessful" as illustrated in Figure 4.37.

A chance event is probabilistic information which is obtained from history data. Chance node A has probability of success 100 percentage, or successful 100 %. So, the decision tree always suggests pulling on rig, the result shall be successful.

4.6 Result of decision tree analysis rod pumping completion (Model 6)

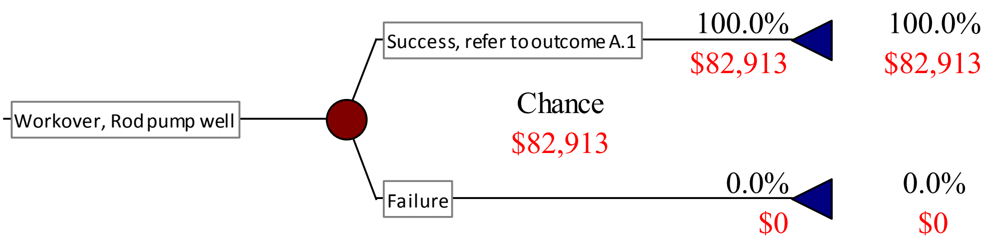

Figure 4.38 Decisions tree for "model 6"

To construct decision tree, it consists of decision node for making decision to find optimum operation cost of rod pump completion, it represents by decision node (square),

there are two chance nodes (A, B) where chance node A, represent “successful “and chance node B, represent ”unsuccessful” as illustrated in Figure 4.38

A chance event is probabilistic information which is obtained from history data as represent in the table 5.1. Chance node A has probability of success 100 percentage, or successful 100 %. So, the decision tree always suggests pulling on rig, the result shall be successful.

CHAPTER V

CONCLUSIONS AND RECOMMENDATION

5.1 Conclusions

In this chapter, to help evaluation and compare between each alternatives, it is divided analysis into 6 categories. Summary of decision alternatives in each well model can be seen in Table 6.1.

Table 5.1 Summary of decision alternatives in each well model

No	Zone	Type	Decision alternatives	Expected cost	Decision strategy	Details of decision strategy
1	Single zone completion	Model 1A	SP	$67,860	SP	Unsetting retrievable packer by straight pulling.
			C1	$88,572		
		Model 1B	SP	$73,951	SP	Unsetting retrievable packer by straight pulling.
			C1	$89,627		
2	Two zone completion	Model 2A	SP	$70,522	SP	Unsetting all retrievable packers (PKR#2, 1) by straight pulling.
			C1	$91,463		
			C2	$119,586		
		Model 2B	SP	$87,189	SP	Unsetting all retrievable packers (PKR#2, 1) by straight pulling.
			C1	$100,198		
			C2	$122,076		

No	Zone	Type	Decision alternatives	Expected cost	Decision strategy	Details of decision strategy
3	Three zone completion	Model 3A	SP	$95,924	SP	Unsetting all retrievable packers (PKR#3, 2, 1) by straight pulling.
			C1	$99,570		
			C2	$125,493		
			C3	$148,895		
		Model 3B	SP	$106,933	C1	Cutting 1 ea above PKR#1, and unsetting retrievable packer (PKR#3, 2) by straight pulling. After that, running BHA: overshot to unset PKR#1.
			C1	$93,942		
			C2	$134,646		
			C3	$152,933		
		Model 3C	SP	$160,927	C1	Cutting 1 ea above seal and unsetting retrievable packers (PKR #2, 1) by straight pulling. After that, running BHA: overshot to retrieve seal.
			C1	$157,972		
			C2	$171,553		
			C3	$185,292		
4	Four zone completion	Model 4A	SP	$82,521	SP	Unsetting retrievable packers PKR#4, 3, 2, 1 by straight pulling.
			C1	$117,172		
			C2	$139,806		
			C3	$154,419		
			C4	$177,624		
		Model 4B	SP	$183,052	C2	Cutting 2 ea above seal, PKR#1, and unsetting retrievable packer (PKR#3, 2) by straight pulling. After that running BHA: overshot to unset PKR#1 and to retrieve seal, respectively.
			C1	$180,097		
			C2	$177,142		
			C3	$196,330		
			C4	$213,384		
5	ESP completion	Model 5	SP	$90,267	SP	Straight pulling.
6	Rod pumping completion	Model 6	SP	$82,913	SP	Straight pulling.

5.1.1Single zone completion's conclusions

When comparing between the PHL/HS retrievable packer (model 1A), it can unset with lower investment cost than the RH/FH type (model 1B) same as philosophy of its packer. Both types has double grip mechanism for griping inner casing wall, while the RH/FH type has additional "hold-down buttons" which providing additional feature to grip inside the casing wall. For retrieving, both retrievable packer types are retrieved by upward pulling. Refer result in table 6.1 and mechanism, there is more chance of successful that the PHL/HS type can release easier than RH/FH type.

After evaluation by decision tree, we shall select decision alternative "SP" ; unsetting retrievable packer by straight pulling for both types of packer that provides lowest investment cost.

5.1.2Two zones completion's conclusions

Refer result from Table 6.1; the probability of workover two zones completion is indicated trend same as single zone. The result of decision trees also provided decision alternative "SP"; "unsetting packers by straight pulling on rig which provides saving cost more than other decision alternative both packer types.

5.1.3Three zones completion's conclusions

To perform workover, three retrievable packers- PHL/HS packer type (model 3A), the probability of workover two zones completion is indicated trend same as single zone and two zones. The result of decision tree also provided decision alternative "SP"; "unsetting packers by straight pulling on rig" that will save cost other decision alternative.

For three retrievable packers- RH/FH packer type (model 3B), the decision tree provides decision alternative "C1"; "cutting 1 cut, above PKR#1, and unsetting retrievable packer (PKR#3, 2) by straight pulling. After that, to run BHA: overshot to unset PKR#1", however, if we considers into sampling data, it was found that the evaluating was performed base on less sampling data than single packer. So, it may obtain error for the decision. The chance of successful may change, once there are more new data updates. Therefore, the writer would propose to keep continue monitoring chance of success for future decision.

For two retrievable packers - RH/FH packer type and one permanent packer (model 3C), the decision tree proposes to select decision alternative “C1”; “cutting above seal and unsetting retrievable packers (PKR #2, 1) by straight pulling. After that, to run BHA: overshot to retrieve seal”. If we considers into history data, it was found some sampling point has data same as perform workover model 3B. Thus, the current decision strategy would be proposed decision alternative “C1”same as decision tree result, however in the future, if we obtain new information or more data, the decision strategy may change.

5.1.4Four zones completion’s conclusions

The result of workover “four retrievable packer-PHL/HS type (model 4A)”, the expected cost of decision alternative “SP”, is saving investment cost more than other alternatives C1, C2, C3 and C4, so the optimum choice could be selected “unsetting all retrievable packer (PKR#4, 3, 2, 1) by straight pulling on rig”

The probability of workover three retrievable packers - RH/FH packer type and one permanent packer (model 4B) is quite low chance with decision alternative “SP” because the philosophy of this completion type is usually installed in deep well, it may has some produced sand above permanent packer. Some existing completion is also found leaking on the completion string.

So, selecting decision alternatives “C2”; “cutting 2 cut, above seal, PKR#1, and unsetting retrievable packer (PKR#3, 2) by straight pulling. After that running BHA: overshot to unset PKR#1 and to retrieve seal, respectively” is saving operation cost more than the other alternatives.

5.1.5Electrical submersible pump completion’s conclusions

It was found data which is collected from history data as represent in the table 6.1 that chance node A has probability of success 100 percentage, or in another word, perform successful 100 %. So, the decision tree always suggests pulling on rig, the result shall be successful. Normally, in this case, we might not need decision tree analysis.

5.1.6Rod pumping completion's conclusions

History data is collected as represent in the table 6.1 is also obtained chance node A has probability of success 100 percentage, or in another word, perform successful 100 %. Thus, the decision tree always suggests pulling on rig, the result shall be successful same as electrical submersible pump completion.

5.2 **Recommendations for further study**

Currently, the decision is made by experience of engineers in charge. The study is provided outline and demonstrated case studies for an example of decision making. Decision tree analysis is one of an effective tool, to help analyzing the project which having several uncertainties. In the case studies demonstrate how to use decision tree in workover operation that some wells are complicated. the problem can be defined and categorized from complex scenario to decision tree that can help to find expected cost easily. To fully utilizing, writer would recommend the decision makers; managers and engineers shall use a decision tool to help in their decision process.

There are more criteria such as well condition, corrosion, sand, reservoir characteristics that may affect for workover existing well completion. In case of, there are more sampling data, it would recommend to continue collecting data, so that, the decision will give accurate decision to decision maker.

In this study, writer uses the mean value form collected time. Thus, the result may be provided an error in some situation. In the future, the complementary tool such as Monte Carlo simulation may use to provide accurate of obtained probabilistic distribution such as any operational times. It may be used to combine all investment cost in a probabilistic distribution ranging from minimum to maximum with the most likely value which is obviously representing the highest probability. Finally, the simulation can be provided simulated cost that accurate than this model.

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APPENDICES

APPENDIX A

A Tables and histograms terms

Operational time rage; is the range of data set which use for create a frequency table in each histogram.

Histogram Minimum; is the minimum value set of histogram range. It starts the histogram range based on the minimum of the data graphed.

Histogram Maximum; is the maximum value set of histogram range end.

X-axis; is categorical data set of operational time

Y-axis; is the probability Density as the unit of measure reported on the Y-axis.

Frequency; is the actual number of observations in a operational time range.

Relative Frequency; is the probability of a value in the range of a operational time range occurring (observations in a range/total observations).

Density; is the relative frequency value divided by the width of the operational time range, insuring that Y-axis values stay constant as the number of range is changed.

Mean; refer to the arithmetic average. It is calculated from formula

$$\text{MEAN} = Y \quad 1/n \, \Sigma^{N}_{i=1} \, Xi$$

Standard deviation; is measure of spread or of a distribution. It represents how much variation or dispersion from the average

$$\sigma(r) = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - r)^2}. \quad , \quad r = \overline{x}.$$

Skewness; is a measure of symmetry. It is extent to which a probability distribution of a real-valued random variable "leans" to one side of the mean. The skewness value can be positive or negative, or even undefined.

Kurtosis; is a measure of peakedness. It measure tail thickness.

PKR; is reference a packer.

POOH; Pull out string of hole or trip out to remove the string from the wellbore.

R/U; Rigging up; refer the process of preparing ready for use.

R/D; Rigging down; refer the process of preparing ready for use.

RIH; Run in Hole; to connect pipe together and lower all string into the well.

M/U; Make up; to tighten threaded connections.

BHA; Bottom Hole Assembly**;** The lower part of the drill string consists of such as bit, bit sub a mud motor.

Wash over; a type of milling operation, which the outer of circular hollow mill swallow or mill into fish**.**

Fish; refer to any desirable objects in subsurface that obstruct well flowing**.**

O.S; Overshot (tool) for retrieving fish

APPENDIX B

B1 the histogram illustrates Probability density of each operational time in the appendix.

B1.1 Rigging up-operational time (days)

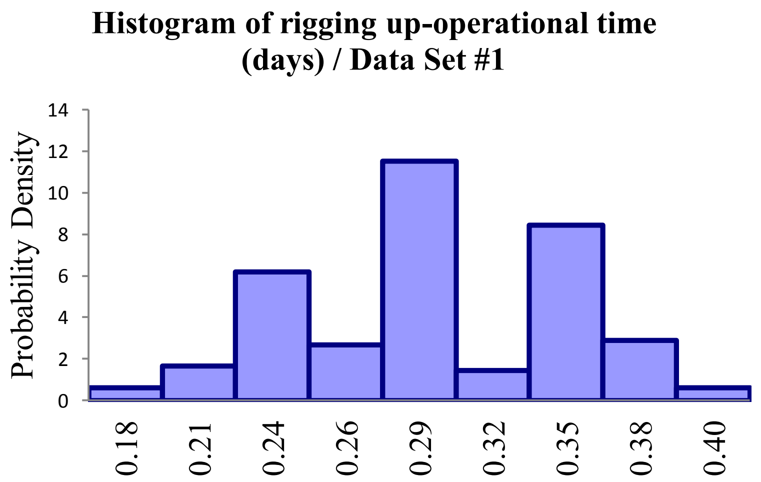

Figure B1.1Probability density and rigging up-operational midpoint time (days)

B1.2 Pulling up-operational time (days)

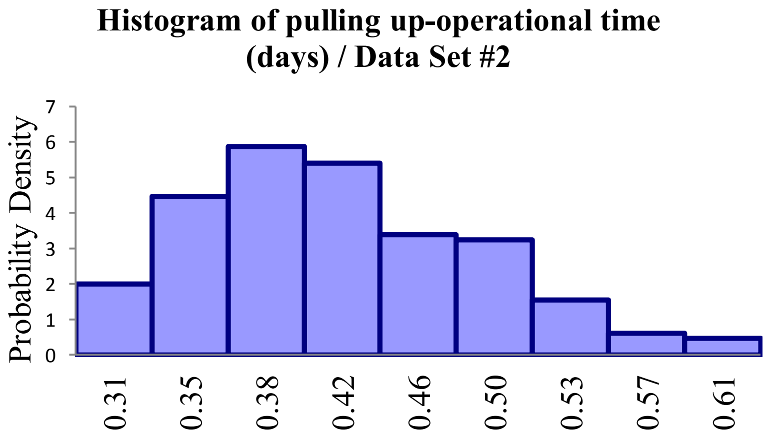

Figure B1.2 Probability density and pulling up-operational midpoint time (days)

B1.3 Cutting-operational time (days)

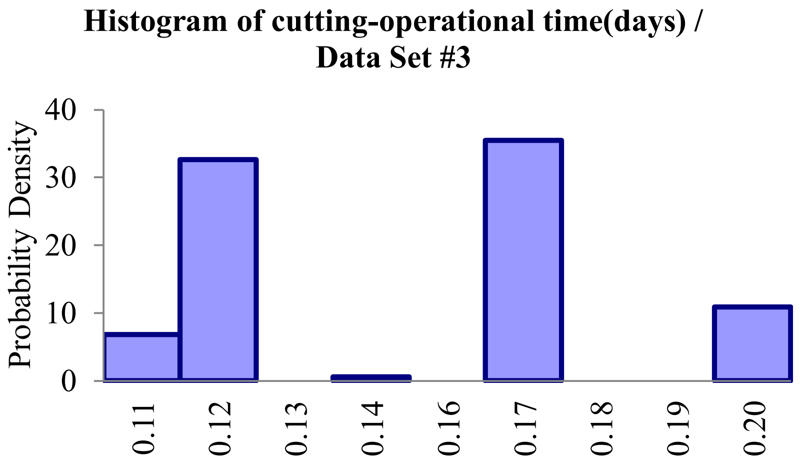

Figure B1.3 Probability density and cutting operational midpoint time (days)

B1.4 Attempt to unset-operational time (days)

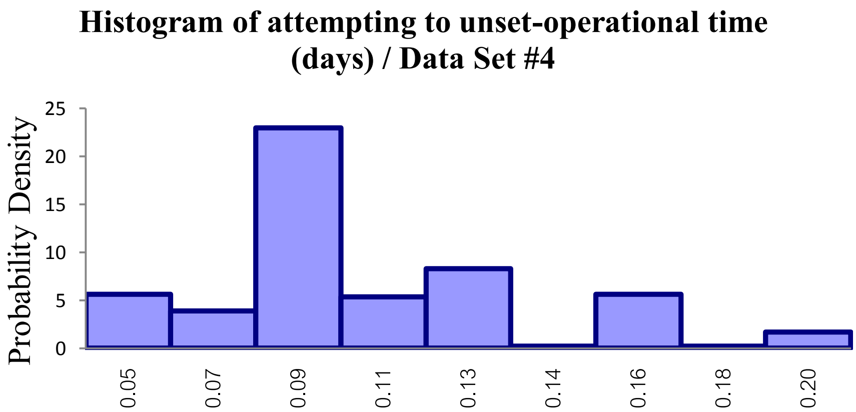

Figure B1.4 Probability density and attempting to unset operational midpoint time (days)

B1.5 BHA: washover-operational time (days)

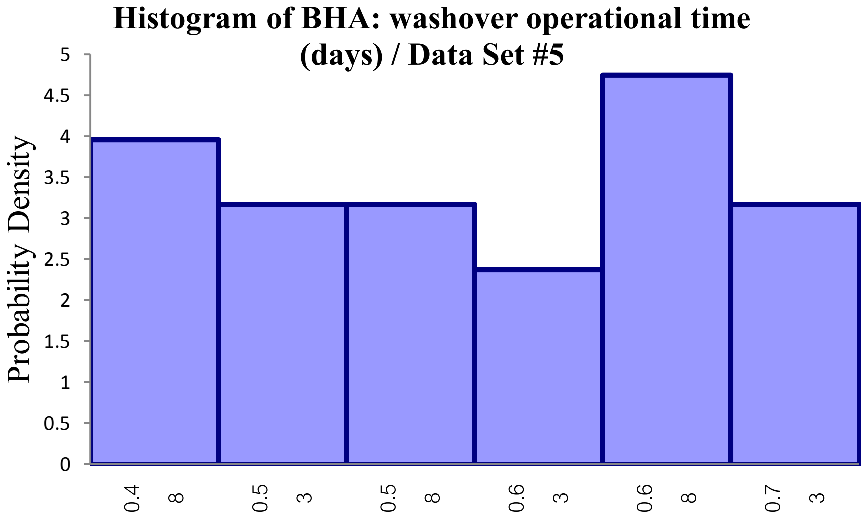

Figure B1.5 Probability density and BHA: washover operational midpoint time (days)

B1.6 BHA: Overshot-operational time (days)

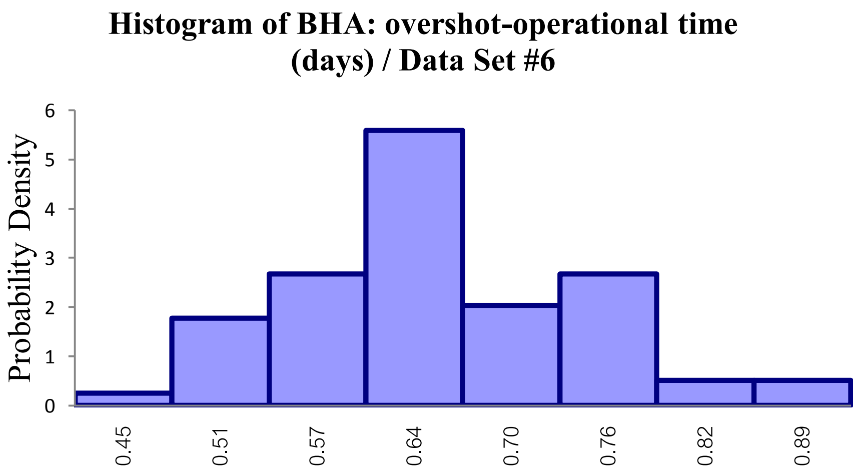

Figure B1.6 Probability density and BHA: overshot operational midpoint time (days)

B1.7 BHA: Spear-operational time (days)

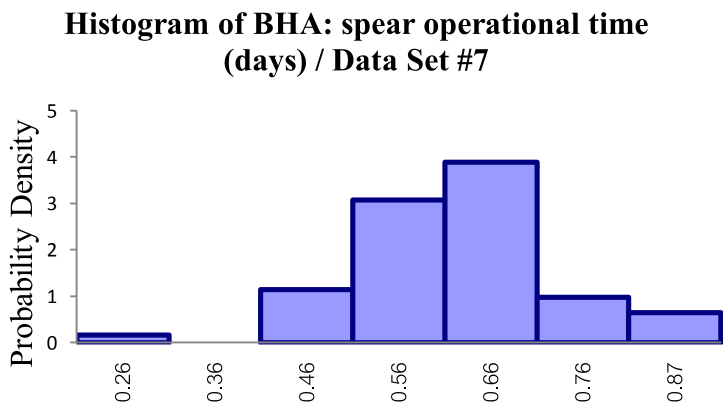

Figure B1.7 Probability density and BHA: spear operational midpoint time (days)

B1.8 BHA: Milling-operational time (days)

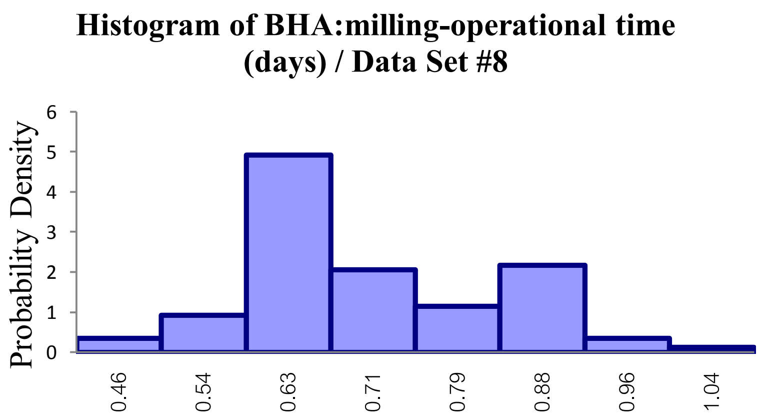

Figure B1.8 Probability density and milling -operational midpoint time (days)

B1.9 BHA: Running completion-operational time (days)

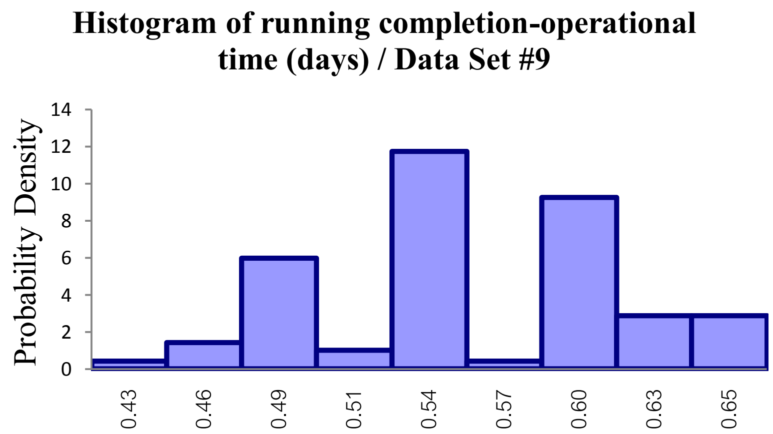

Figure B1.9 Probability density and running -operational midpoint time (days)

B1.10 BHA: Rigging down-operational time (days)

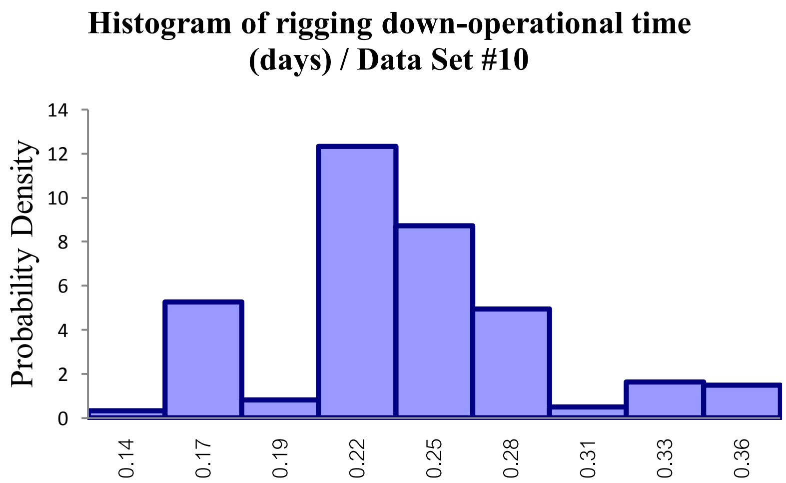

Figure B1.10 Probability density and rigging down -operational midpoint time (days)

B1.11 ESP Pulling up-operational time (days)

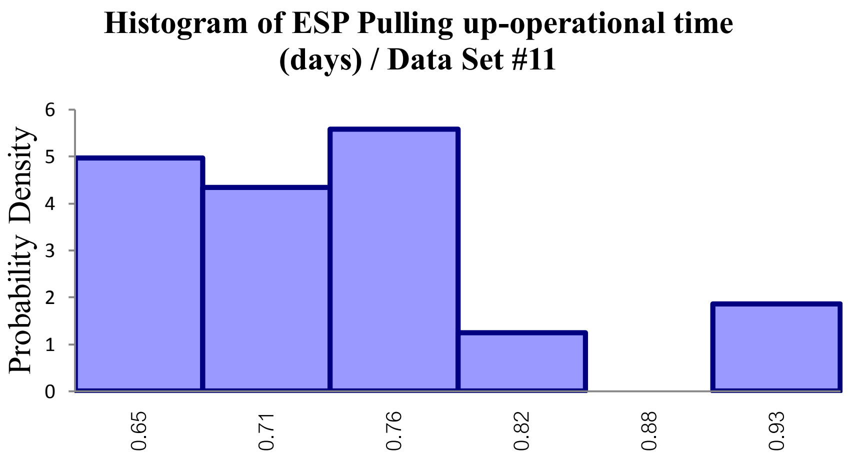

Figure B1.11 Probability density and ESP Pulling up -operational midpoint time (days)

B1.12 ESP Running up-operational time (days)

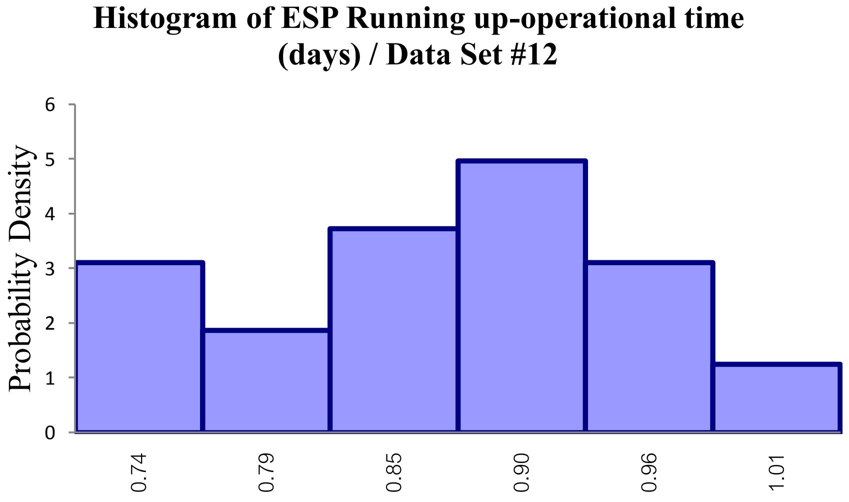

Figure B1.12 Probability density and ESP Running up -operational midpoint time (days)

B1.13 Rod pump, pulling up-operational time (days)

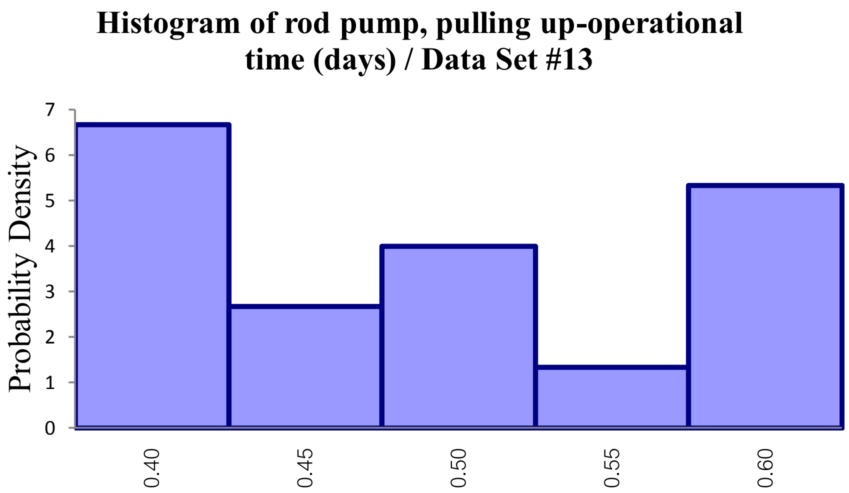

Figure B1.13 Probability density and rod pump pulling up -operational midpoint time (days)

B1.14 Rod pump Running up-operational time (days)

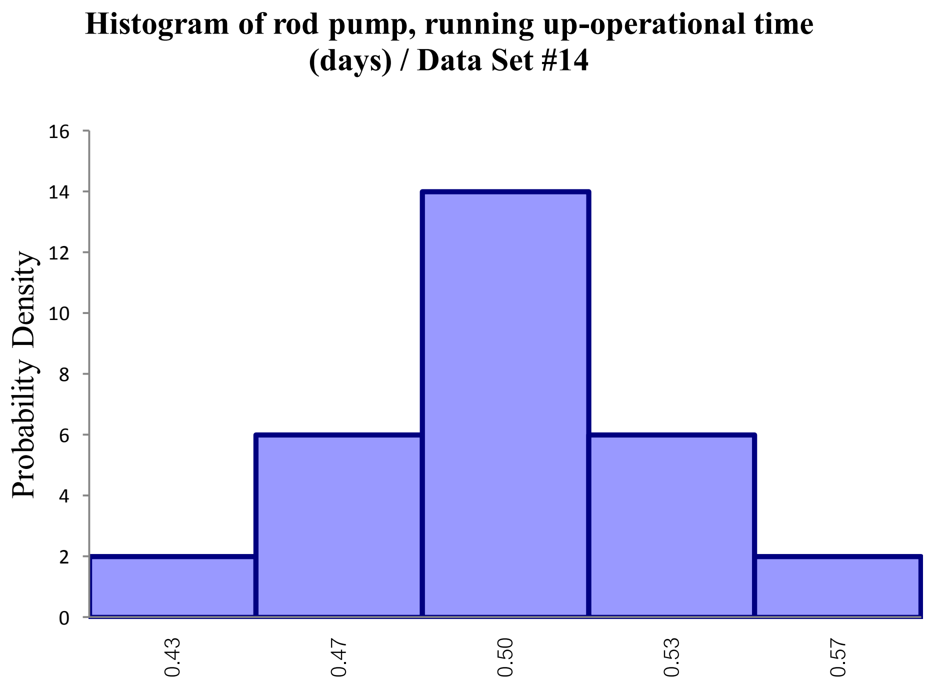

Figure B1.14 Probability density and Rod pump running up -operational midpoint time (days)

APPENDIX C

C1 An example of acreage decision tree for "four zones completions, four retrievable packers –PHL/HS packer type

Table C1 Operational details of outcome SP-F-F-F-F-F-F-S-F

Details of Outcome	Activity
SP	Straight pulling PKR 4,3,2,1
SP-F	Failure to retrieve
	then, do cutting 1 ea above PKR#1,
	then attempt to retrieve above part
SP-F-F	Failure, to retrieve PKR#1
	then, do cutting 1 ea above PKR#2
	then attempt to retrieve above part
SP-F-F-F	Failure, to retrieve
	then, do cutting 1 ea above PKR#3
	then attempt to retrieve above part
SP-F-F-F-F	Failure, to retrieve PKR#3
	then, do cutting 1 ea above PKR#4
	then pulling above part
	Then, RIH BHA: Overshot to retrieve PKR#4
SP-F-F-F-F-F	Failure, to retrieve
	Then, release BHA: Overshot
	Then, RIH BHA: Milling PKR#4
	Then, RIH BHA: Overshot to retrieve PKR#4
	Then, RIH BHA: Overshot to retrieve PKR#3

Details of Outcome	Activity
SP-F-F-F-F-F-F	Failure, to retrieve
	Then, release BHA: Overshot
	Then, RIH BHA: Milling PKR#3
	Then, RIH BHA: Overshot to retrieve PKR#3
	Then, RIH BHA: Overshot to retrieve PKR#2
SP-F-F-F-F-F-F-S	Success to retrieve
	Then, RIH BHA: Overshot to retrieve PKR#1
SP-F-F-F-F-F-F-S-F	Failure, to retrieve
	Then, release BHA: Overshot
	Then, RIH BHA: Milling PKR#1
	Then, RIH BHA: Overshot to retrieve PKR#1

APPENDIX D

D.1 Well construction

In this paper is also provided an overview of the well existing design and engineering which may be encountered in the onshore concession, in Thailand. The main models to show the existing completions assuming that the well is constructed in accordance with its intended design have been identified step procedure [25] such as below:

- Conductor casing
- Surface casing
- Intermediate casings
- Production casing
- Intermediate casing and drilling liners
- Intermediate casing and production liner
- Drilling liner and tie-back string.

Well Casing

Well casing consists of a series of tubular installed in the drilled hole. Installing well casing is an important part of the drilling and completion process. Operator must ensure that the well is secured with suitable integrity.

The well design and construction is necessary to ensure that the proper casing for each well is installed. The engineering design of casing should depend on the characteristics of reservoir, pressure survey data or expect pressure data and temperatures, including the diameter of the well or the pressures experienced throughout the well or nearby field area.

Typically, there are four main different types of well casing that are conductor casing, surface casing, intermediate casing and production string as can be seen in Figure D1.

Conductor Casing

Conductor casing is installed first, usually it is installed before rig move to location or prior the arrival of the drilling rig. For onshore well, the diameter size of conductor casing is usually designed for 16 to 20 inches and 20 to 50 feet long. It helps to prevent the top of the well from collapse and to help in the process of circulating the drilling fluid up during drilling top hole section. [25]

Surface Casing

Surface casing is the next stage of casing to be installed after conductor casing is being installed. The diameter has smaller than the conductor casing. In standard, the primary purpose of surface casing is to protect surface fresh water of the well from being contaminated by leaking of hydrocarbons or salt water from deeper underground and uses as a conduit for drilling fluid returning to the surface while drilling the next stage, and helps protect the drill hole from collapse during next stage drilling. [25], [26]

Typically, after surface casing is ran on place, the cement operation will be performed, respectively. So, the surface string becomes to support the wellhead and subsequent of casing strings. The thickness of the cement is very important to ensure that the well has integrity to protect freshwater contamination. The space between the outside of the surface casing and the drilled wellbore is called the annulus. In worldwide regulation, the depth of surface casing shoe has to cover the surface underground water level. [25], [26]

Intermediate Casing

Once the well has been drilled and set surface casing, the next stage of well construction is drilling to hydrocarbon zone or target zone. The casing of using in this section is called the intermediate casing. The primary purpose is used for the well control during drill into hydrocarbon section and isolated formations or well profile changes in order to minimize the risks along with subsurface formations that might be affect the well. In the some wells, an intermediate casing is run to separate hydrocarbon areas or problem zones. Moreover, it is usually used for isolating troublesome formations such as loss zone formation, high permeability including abnormal hydrocarbons or the high degree in build-up section of deviated wells.

In many cases, it has not evidence of an unusual underground formation; however intermediate casing is used in order to avoid the possibility of such a formation affecting the well. This intermediate casing is also required cement operation to place cement along the casing for added protection. Normally, it is required cement up from its shoe to the shoe of the surface string and in some cases all the way to surface. [25], [26]

<u>Production Casing</u>

In final stage of well construction, the production casing is installed in the last section. In exploration wells, it may have amount to only a short period to testing this casing, but for development wells, it need to repairs and recompletions. It is essential that the integrity of production casing is required throughout its life. The primary purpose of production string is isolate target zone in each intervals, prevent cross flow during starting flow to surface that it is beneficial to preventing blowouts and allowing the formation to be 'sealed' within the casing. Once, operator drilled a well to target depth. Normally, it also require logging to indicate target zone and mapping with sub surface target zone, after that the production casing will be run to target depth ,then perform cement job. The pressure test production casing must be done to ensure well integrity before handover to surface operation team. [25]

There are many options for cementation. In most of cases, the production string cement does not need to be brought completely to the surface; it requires only cement to achieve the required subsurface isolation zones. However, it depends on the geologic setting, well design, and wellbore conditions. Typically, the tail cement should be brought at least 500 ft above the highest formation in minimum case. [25]

<u>Liner</u>

Figure D2 shows liner completion. A liner is a string of tubular which is installed from desirable depth but does not reach all the way to surface. Normally, it is hung a short length of liner to overlap the previous casing. It is usually required cement placing over its entire length of previous casing in order to ensure it can make barrier. The benefit of liner string is to reduce tubular costs, to minimize the length of reduced diameter production tubing that affected flowing pressure loss and to meet rig ‘s tensional load limitations; however there are also potential disadvantages such as the risk of poor quality of cement across the liner and previous casing, caused to loss of well integrity. In many case, it was found that there is difficult to complete a well with good cementation due to smaller liner to hole and liner to production casing clearances. [25]

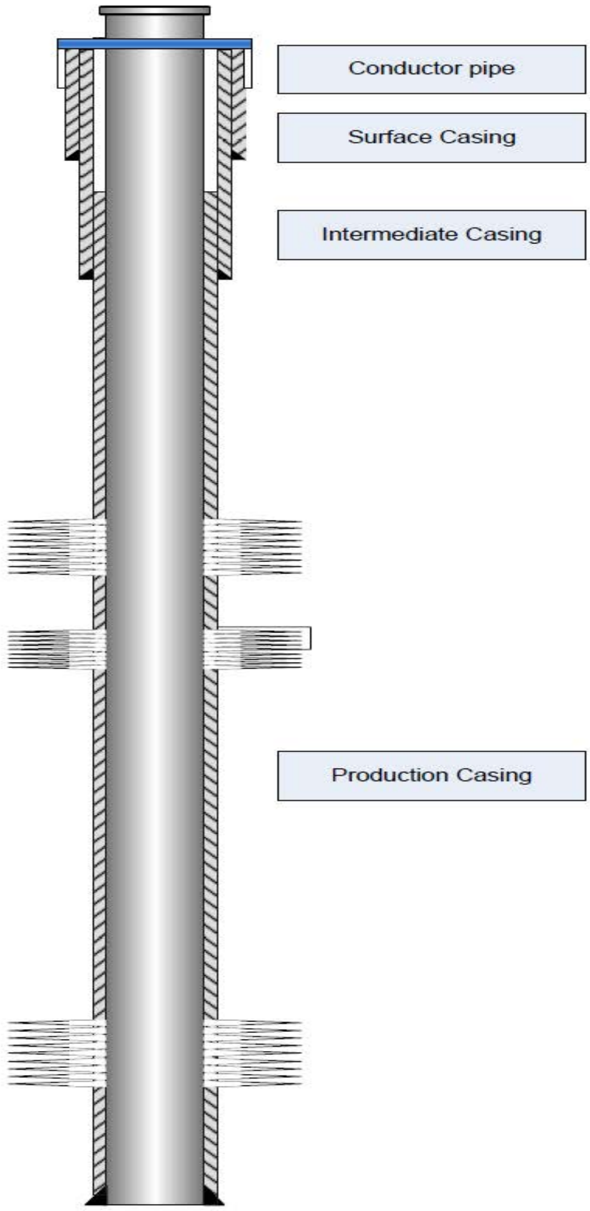

Figure D1Typical well construction schematic

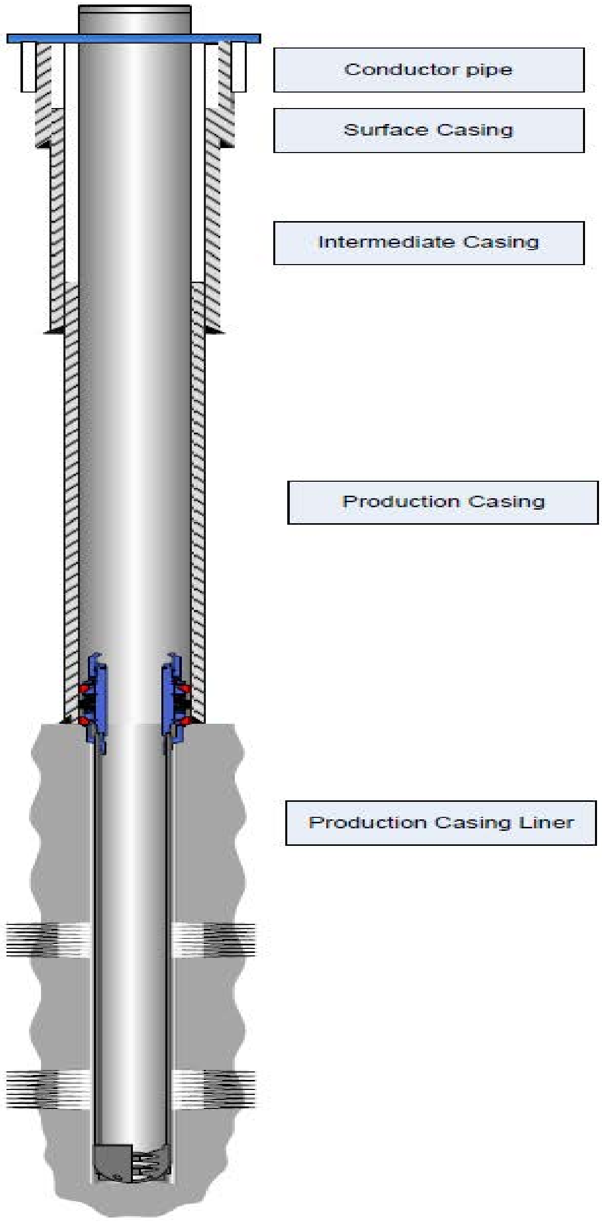

Figure D2 Typical well construction schematic with liner

D.2 Well workover operations

The term of workover operations; normally, it refer to well maintenance that mainly affect from equipment failures or remedial reservoir zone.

After operator prepares scope of work, identify service rig contractors for onshore workover operations, Thailand. Most of the major activities are consisted of activities such as below;

- To repair the existing completion string due to tubing leaked or changing to size of tubing
- To convert the existing well from conventional well to ESP well
- To convert the existing well from conventional well to rod pumping well
- To change out the existing un operated ESP pump well
- To shut off water sand by squeezing cement
- To clean sand that cover exiting perforation zone
- To drill the open hole section in order to access the other reservoir layer.
- To mill and clean the scale inside production tubing wall.
- To mill and clean the wax or high molecule weight crude oil inside production tubing wall.
- To repair well integrity problem e.g. casing leaked
- To repair rod stuck well
- To pull uneconomic completion from the lock in potential well able to flow with other methods e.g. changing dual completion to rod pumping completion.

D2.1 Workover program

The key aspect of several workover wells are the initial planning stage where most problem areas and most possible scenario can be identified as much as possible. This step should include a thorough review of the well problem, options in well workover method, geographic location, logistics, and remedial procedures, including an availability of the equipment, services company required and contingency plan. History of well reports either from its history data or similar workover operations, are the best sources of data available or should be closely considered for information on previous jobs, the problems encountered and solutions. New technologies should also be always researched to determine if it will help to improve on existing methods.

General activities step of well workover operation

The workover and recompleting an oil and/or gas well consists of several sequential activities. A list of these activities appears in sequential below,

1. Preparing the location and installing water supply and fluid handling equipment,
2. Setting up the workover rig and ancillary equipment and testing all equipment,
3. Perform kill the well by using workover fluid.
4. Pulling out existing completion
5. Performing the remedial activities that already identified from workover program, for example, performing sand cleanout, cement squeezing, and repair tubular and including any associate fishing jobs.
6. Performing recomplete the well as asset operator defines.

Pre-job analysis

Pre-jobs analysis should be considered critical areas before the job start as following items;

- The possibility of the well developing or depleting pressure during the workover operations.
- The effects produced when well fluids and treatment fluids are mixed in the reservoir and the well bore.
- Any operations which requires on over pull of the bottom hole assembly
- Any operation which requires set down weight on the bottom hole assembly
- Any operations where collapse or burst pressure may be generated
- Any special fishing tools that may be required.
- Lab analysis to confirm the flow rates and pressures necessary to achieve the objectives are attainable within the limitations of the workover unit, working string and the well.

- Torque and stress analysis to confirm that the objectives can be achieved within the safe operating limits of the workover equipment and associated tools
- Contingency planning

<u>Critical safety activities analysis</u>

To ensure safe operations, all hazardous activities associated with the operation need to have been identified and adequate controls and contingency measures put into place to manage the associated risks. Moreover, it is extremely important when planning any workover operations, everyone concerned is aware of the basic safety standards, such as hazardous zones, fire precautions, hydrogen sulfide and emergency response procedure plan.

<u>Well control</u>

Any aspects regarding well control issues shall be included in the well workover planning and equipment selection process. Consideration needs to be given to the well status such as well flowing or well dead and what consequently the required degree of well control competence and equipment requirements such as kill pump, mud tanks, lost circulation materials.

<u>Operation control and communications</u>

To ensure the Operation control and communications are carried in safe and efficient of each stage of the program. The following must be established;

- Well handover, it shall consist of work permit requirements and simultaneous operations.
- Responsibility of personal in workover unit system during execution job.
- Lines of communication; Line of command and communications between inside and outside workover unit should be cleared.
- Actions in case of emergency.

<u>Hazards and safety</u>

To ensure all safe working area, all details shall be discussed during planning phase, on the job meeting and post meeting. Some Specific items such as personal protective equipment, confine space shall be included in the hazards and safety meeting.

D2.2 Fishing operation

Fishing is the process to removal equipment or tools or objects that has become stuck or lost in the wellbore. The fish, or lost object, is classified as completion equipment, wireline tools that have stuck in well, tubular (drill pipe, drill collars, tubing, casing) or miscellaneous (bit cones, small tools, wire line, chain, junk).

Jar operation

Jarring is the process of transmitting energy that is stored in a fishing string as stretch into kinetic energy. This process is started from the releasing of the stress in mechanical force when a preset over pull value is reached. When the detent is released, the jar trips and delivers the energy to the fish.

Usually, jarring technique is a useful technique for freeing stuck pipe or freeing object in the well. The jar 's body allow fluid circulation through the internal Wire line tools such as a free point tool or string shot is also able to pass through them. Nowadays, jar has available in a wide range of sizes, So that, to select the internal diameter of the jar is equal to or greater than the internal diameter of the fish is essential.

The impact of a hydraulic jar is determined by weight that being run above the jar and by the amount of over pull force applied prior to the tripping of the jar.

Overshot operation

The most common fishing tools in workover operation are overshot operation that it uses for retrieving a packer. Most of fishing is done with standard overshot however need to ensure that the slips in overshot are correct size for fishing identify job.

Spear operation

Spear operation is designed to latch in an internal polish bore of the fish. The body of spear has built to withstand severe jarring operation. When the jar latch into internal fish's bore, it causing the grapple to be pushed upward, then spear function is activated by this mechanism.

In additional, it has circulation device that allow circulation from string through the fish. In case of, the fish cannot retrieve after extreme jarring; it has function to release by mechanical.

D2.3 Milling operation

It is common that milling operation is in a part of workover operation such as milling out of packer when packer cannot release by its original method. The limitation of workover unit regarding capacity to carry out is necessary to consider.

Working string rotation is usually provided by rotary table or in case of highly deviated well; down hole motor can help to provide rotation to reach desired Revolutions per minute.

The development in downhole motor has been improving its performance and reliability in decade year. The well parameter such is temperature, pressure are took into account to find suitable motor. In addition, to reduce internal casing wear in case of use rotary turn the string is also an advantage of using downhole motor over rotary system. However, in case of the well has large well casing diameter, the operating flow rate from motor may limit, so that the rotary system which provide unlimited flow rate can select to use.

The types of milling used have many types in the worldwide market. To mill a packer is a process to mill slips and rubber. The rotary shoe is most common tool to be used with wash over pipe that is designed for milling both permanent packer and retrievable packer. Short tooth or ocean wave type is usually used in medium and hard packer. The milled particle transport velocity can be determined by using Stoke‘s law. Generally, when unconsolidated types encountered, the efficiency fluid velocity will designed to between 120-150 feet per min. Viscous gel can be sequent pumped in order to increase effectively carry out.

In highly deviated wells, gravity will act at an angle to fluid velocity, resulting in a setting out of fill particles on the low side of the hole, while, the completion string is also laid in the low side position, so, it‘s difficult that only high viscosity with turbulence flow rate can lift particle to surface. Hence, to move string up and down while rotation would help to increase clean out efficiency. For in this paper provides most case that selected to use for illustrate economic models.

- Other milling tools

Many milling tools are fabricated for specific exiting fish. Usually mills are manufactured from a solid piece of AISI 4140 heat-treated steel , and some milling tool are fabricated by welding the blades and stabilizer pads on to a simple tubular body.

Junk mills are designed to mill such as unshaped fish, bit cones, reamer blades, or any other junk which may obstruct the casing, while flat bottom mills are designed to allow spot its flat facing on irregular surfaces which may obstruct the casing.

Although these tools are quite simple in appearance, It is usually attach with boot basket to catch small metal which being milled. Normally, these tools are designed to withstand hard spudding, hard weights, and fast rotation. Factors that affect milling rates and the design milling tools are depend on the type of fish, composition, the stability of the fish, and its hardness.

Vitae

Potchara Promwikorn received a Bachelor of Engineering in Chemical Engineering from the Faculty of Engineering, Prince of Songkhla University in 2001. After graduating, he has been working in Oil and Gas Company, in Thailand.

During working period, he has been starting to study in his studies in the Master of Petroleum Engineering program at the Department of Mining and Petroleum Engineering, Faculty of Engineering, Chulalongkorn University in 2010.