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Modeling and Simulation of Oil Drilling Activities

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Abstract

The oil demand keeps growing worldwide [1]. The oil price keeps changing as the low prices are powering the trend couple of months back but then it raised. The price is relative as it depends on many factors. The Exploration and Production of oil companies to remain competitive in the oil market they need to minimize their production costs. Definitely, the production of oil is a challenging job in terms of production environment and cost but as long as the production methods are being continuously enhanced it won't be a much expensive process. It shows that even though the price of the oil can swing wildly the growth of demand is surprisingly stable. When just considering the growth in consumption, it is clear that oil remains important at least for next few decades. Although we also need to search for renewable energy source but for time being we simply need everything that we have. So, it concludes oil. Drilling is the primary tool for extracting oil from the subsurface rocks [2]. There are many experiments and studies are done for improvement of drilling technology which will lower the drilling costs and increase the rate of success in finding the oil.

Building the drilling rig and running the drilling process is a challenging and costly job which requires plenty of manpower, money and time. So, optimized practices with highly qualified personnel are mandatory. Before establishing any rig well-planned estimation for rig construction and running practices is important to have a streamlined job without any delay and confusion. Although simulation technique may differ depending upon the size and complexity of the process. But the well-designed simulation program for drilling gives almost an accurate result. So, simulating the whole activities allows driller virtually run drilling activities under different conditions to see how it works. On top of this, the goal of the simulation technique is to ensure that the process will remain safe under stressful or abnormal condition. Hence, the modeling and simulation of the oil drilling activities simplifies the drilling task and helps to estimates the cost, time, and manpower. This also helps to plan all the pre and post production activities so the drilling process can run smoothly without any hindrance.

The main objective of this thesis is to model and simulate oil drilling activities as Discrete Event Systems (DES). To achieve the goal first, the literature study on the oil drilling activities is done to gather all the necessary information, components, manpower etc. related to oil drilling activities. Second, the mathematical model of the oil drilling activities is represented in Petri Net model by using Platform Independent Petri Net Editor 2 (PIPE2). The simulation of overall oil drilling activities can be visualized in Petri Net environment itself. Third, the Petri Net model is simulated with General-purpose Petri Net Simulator (GPenSIM) to simulate the drilling activities of each component in more details. Finally, the simulation results are analyzed and drawn a conclusion for better drilling activities. Hence, the modeling and simulation of oil drilling activities facilitate the driller to drill better gaining maximum throughput in finding oil with minimum utilization of time and money.

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1. INTRODUCTION

The world's energy demand is continuously growing so drilling technology has seen great advances over the past two decades [3]. In fact, the world would almost stop without oil [4]. It won't be difficult to realize why oil is so important. The transportation such as the bus couldn't move, cars, airplanes are grounded, tractors on the farm will rust etc. So, oil production is a very challenging job but at the same time very essential for human lives and industry.

So, modeling and simulation have become essential for oil companies to use as a decision-making tool and production planning tool [5]. It is well known that oil companies spend lots of money to explore and produce oil. There is a huge loss of money, manpower and time if drilling a dry well. It will be a great loss for the company. So before starting any drilling task many companies prefer standard computerized program for modeling and simulation to simplify the process and to overcome the risk of losing money.

1.1 Motivation and goals

Usually, the main challenge of the drilling is to plan for long drilling wells [17]. The horizontal sections long wells are challenging to drill as they impose mechanical and hydraulic constraints. There is a need for the proper and well-managed plan before starting a drilling job. In the planning phase, the qualified drilling engineers must provide better solution to reach a target depth and the route to reach there.

If there is well-planned procedure before starting the rest of the drilling process will be smooth without any complication. So there seems a need of a good simulating tool which can show the excellent drilling results so it will be easier to plan and help to reduce the complication that can encounter later during the execution of the task in the field. If the well-planned scenario includes all the possible situations then it is easier to take the precaution before. So in crux, if there is some accurate modeling simulating tool for drilling it greatly helps for any drilling operation in terms of time, money and manpower. This motivates there is a need for better-simulating tools for oil drilling activities which can help to plan better to achieve the goal quickly.

The drilling process is a very complex system involving the number of activities, components and personnel with various duties. To include all the drilling activities in this paper is not possible in this short time frame. So among them, this paper is based on one of the major and challenging tasks among those various activities.

The simulation tool that is introduced in this paper simulates the overall drilling activates like adding new components, tripping in, drilling hole, tripping out, collecting components, cementing, casing etc. and calculate the time taken for each component and later overall time taken for the execution of whole process. There are a section target and final target value set in the process. The process will first check for the section target depth value. So, unless and until the section target depth is meet the drilling process is repeated in the same loop to reach the section target value. Once the section target is achieved it checks for final target. So the process repeats until reaching the final value. First, the mathematical model of the activities is prepared in Petri Net using PIPE2. The overall drilling activities can be tract running the simulation from Petri Net itself. Second, the model is implemented using GPenSIM, it shows the drilling activities in more details. It will provide the estimation of drilling time of each component and overall activities. This simulation also displays the time taken to perform each unit activity during the execution process. Thus, this study helps to plan wisely for the field of oil drilling activities which will minimize the cost, time and manpower greatly.

The main purpose of this modeling and simulating tool is to reduce the risk of guessing and to estimate how long it will take to get the oil.

1.2 Organization of the Thesis

The thesis is organized in the following way,

- Chapter 2 presents the literature study of oil drilling activities of this study
- Chapter 3 describes the fundamental background of this study
- Chapter 4 provides the design and methodology used in this study
- Chapter 5 provides the strategy used in the implementation of this study
- Chapter 6 discuss running test and discussion of the results of this study
- Chapter 7 summarize with discussion and conclusion drawn from this study

2. DRILLING OVERVIEW

This chapter begins with a short introduction of oil drilling followed with the rig components. This study discusses rig components to gain the knowledge about the rig components working principle in short and to familiarize with all the drilling activities.

2.1 Introduction to Drilling

Oil drilling is an art and science of drilling a hole in the ground to the desired depth as fast as possible without accidents in search of oil [6], [7]. The drilling rig composes of many pieces of equipment, machinery and system. The main purpose of the rig is to drill a hole in the ground. The hole it drills can be deep hundreds of meters depending upon the target depth of the hole [8]. There are different rigs that work on land and sea both. The term offshore is the oilfield term for sea rig. In most of the cases, the land rig seems to be easier because one can drive to reach them. Instead offshore rigs are complicated as they reside many miles from land and generally requires a boat or the helicopter to reach them.

The most distinctive parts of the drilling rig are big and strong assembly tower called mast or derrick. They are strong because they have to support many tons weight of drilling tools. The drill floor is the core work area of the rig. It generally has a strong base and it is raised above the ground. The rig is huge but the hole it drills is not very huge normally less than a foot in diameter when it reaches the final depth.

Describing drilling process in simple term, the process of drilling hole is accomplished with connecting the bit and drill string [34]. The more drill pipes are added when bit progresses. The bit work is to drill a hole and at the same time, it makes to circulate the mud to take out the drilled particles. The drill string have to withdraw out when it is necessary to change the worn bit. It is mandatory to rotate the bit to continue drilling further along with putting weight on the bit. Simultaneously, the drilled formation has to be removed away from the bottom to make a way for the bit to contact with clean surface.

2.2 Rig components

The drilling rig components build a complete drilling rig system. It is important to know the function of each rig component which makes easy to understand the complete drilling system. Therefore this chapter explains each rig components in more details. Ultimately, the rig components are the part of drilling rig system. The main purpose of the drilling rig is to enable drilling the hole. Making a hole requires a number of qualified manpower and advanced equipment to work with. The rig components can be categorized mainly into four systems.

- Power System
- Hoisting system
- Rotating systems
- Drilling fluid circulating system

2.2.1 Power system

The rig needs a power system to run hosting, circulating, hydraulics, electrical system and rotating mechanism to make a hole [8]. Early days most of the rigs are powered by steam engines and mechanical transmission system. When powerful and portable diesel and gas engines became available mechanical engine began replacing steam rigs. In the 1970s and 80s, electric generators run by diesel engines start to replace the mechanical rig. Currently, electrical or diesel-electric rigs leading the drilling scene. These modern drilling rigs use electric transmission as it allows the driller to apply power more smoothly [9].

Most of the rigs are operated in remote locations where there is no power supply system generating electrical power to operate rig components is needed [8] [9]. The electrical power generators are run by diesel powered internal combustion engine. Then the electricity is supplied to drawworks, rotary table, hydraulic power units and mud pumps via electric motors connected to it. The rig may have up to 4 prime movers depending upon the rig size and capacity which can supply more than 3000 horsepower (hp).

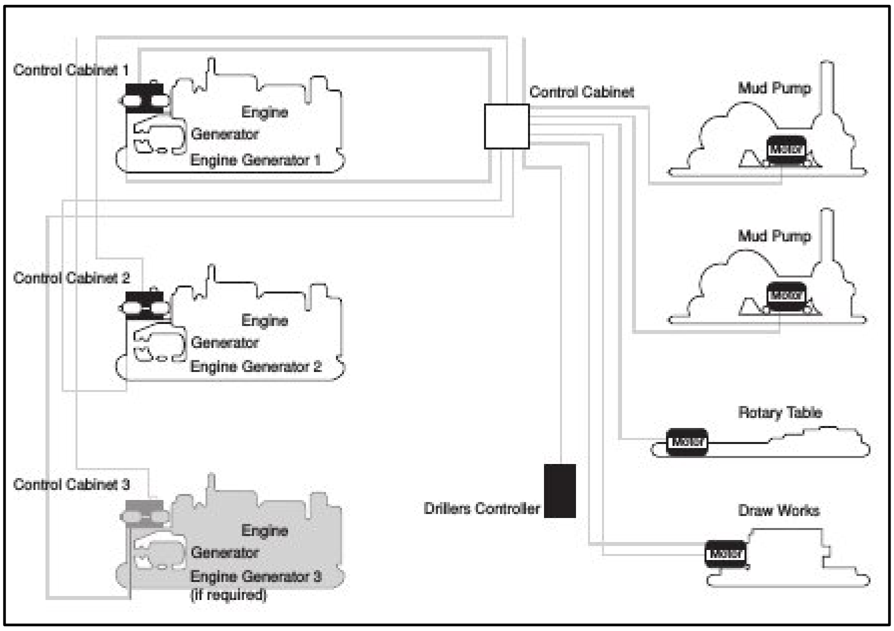


Figure 2-1: Drilling power system [9]

2.2.2 Hoisting system

The hoisting system is used to raise equipment out from well and lower the equipment into the well. In actual, it is a system to raise and lower the drill string and casing into and out from the well [10]. The standard hoisting system consists of drawworks or hoisting element, a mast or derrick, the traveling block, the crown block and the wire rope drilling line.

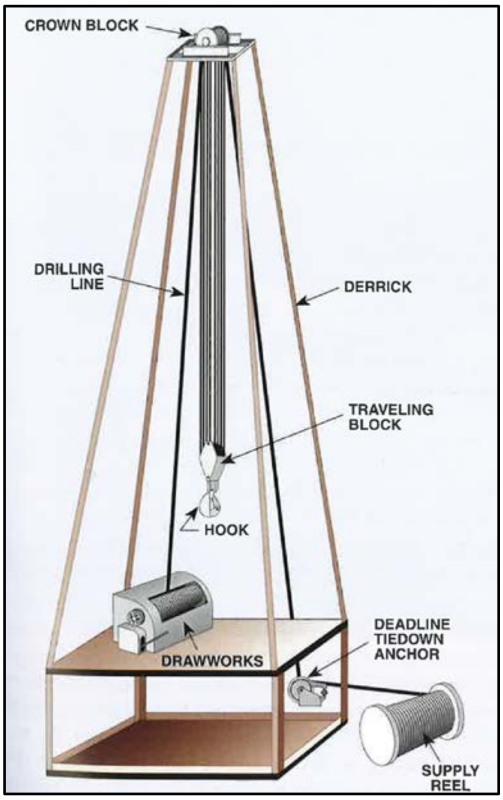


Figure 2-2: Drilling hoisting system showing the main parts [8]

Drawworks

The drawworks is a bit complicated mechanical system which comprises of large revolving drum around where a wire rope or the drilling line is rolled [10]. It has clutch, chain-and-gear drives where the driller can change the speed and direction during drilling [8]. The main brake allows the driller to slow down or to stop the drum.

Crown Blocks, Traveling and Drilling Line

The drilling line is made from very strong wire rope. It is normally 7/8 to 2 inches in diameter and is made of steel wires [8]. The line starts from the large reel called the supply reel. From the supply reel, the line goes to the deadline anchor. Then it runs to the top of the derrick of large pulleys. This large set of pulleys called a crown block. In the oil field, the pulleys are termed as sheaves.

The drilling line is looped several times between the crown block and traveling block. The heavier the loads on the traveling block it is important more line is reeved between the crown block and traveling block. When the last line is strung in the crown block sheaves then the end of the line goes to the drawworks drum. Driller by operating the drum also makes several wraps of line around the drum.

The line that runs from the drawworks to the crown block is called fastline. Fastline means it moves if the driller raises or lowers the traveling block in the derrick. The end part which runs from crown block to deadline anchor is called deadline because it does not move.

Masts and Derricks

Masts and Derricks are structurally very tall towers which support the blocks and drilling tools [8]. The derrick provides sufficient height so the driller can raise the drillstring and crew members can break and make it up. Also, the mast is the portable derrick where the crew members can raise and lower as a unit. These days using masts for rigs are popular because the rig can be made up and down much faster than in standard derricks.

2.2.3 Rotating systems

The rotating equipment rotates the drill string and eventually bottom hole assembly and drilling bit components. The rigs can rotate the bit mainly in two different ways.

First method, rig with a rotary table drive drilling.

Second method, rig with the top-drive drilling. These both systems are described in detail below.

There is also a method called downhole motor but this is used in a special situation only. Hence mostly we have two major methods.

In our study, we have classified drilling system with conventional rotary table and top drive system. With this comparison, it helps to identify the system with the best performance.

2.2.4 Drilling fluid circulating system

The circulating system helps to circulate the drilling fluid down from drill string and up to the annulus [13]. During circulation, it carries the drill cuttings from around the bit to the ground surface. The important task of drilling fluid is first, helping to clean the hole from cuttings made by the bit and second, applying the sufficient hydrostatic pressure which prevents fluid from entering the borehole.

Drilling fluid or mud is a mixture of water, a weighting material, clay and chemicals. At first, the mud is mixed and conditioned in the mud tanks and it is circulated to the downhole by pumps. Mud Pumps starts circulation of mudflow through the standpipe, kelly hose, swivel, kelly and to the drill string. At the bottom, mud passes through the bit nozzles and comes to the annulus carrying with cuttings to the surface. On the surface, the mud directed to the mud return line from the annulus. Before the mud enters the mud tanks the drilled cutting are removed from the drilling mud by the equipment such as junk catcher and shale shakers. When the mud cutting is removed it is re-circulated to the bottom of the hole and again to the surface with mud cutting. During the process, the properties of mud are also checked continuously to make sure that the properties of the mud are well maintained. If no chemicals are added to mud to bring properties back that is required to fulfill the functions of the fluid.

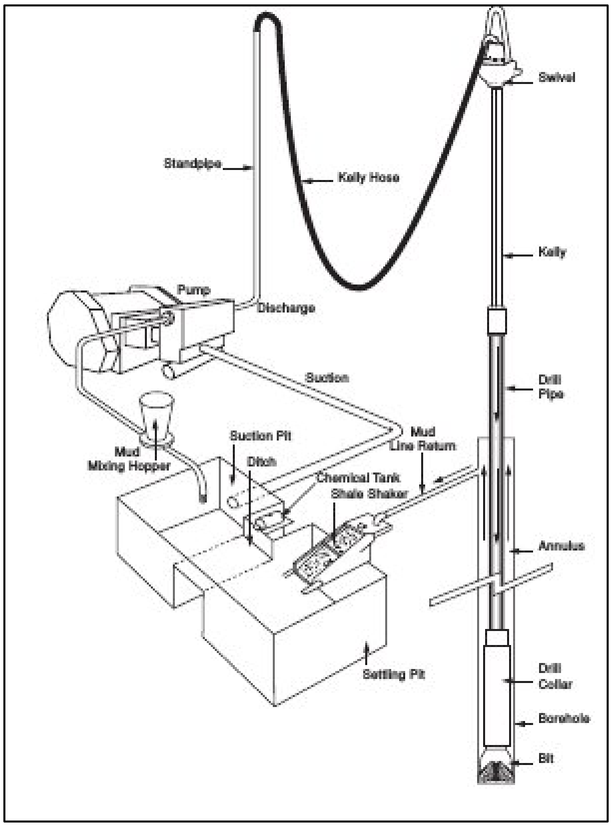


Figure 2-3: Drilling fluid circulating system [13]

2.3 Rotary table drive drilling

Generally, the land rigs use rotary table system in order to rotate the drill string and bit. The rotary table has five main parts. 1. Turntable rotary table 2. Master bushing 3. Kelly Drive Bushing 4. Kelly and 5. Swivel [8].

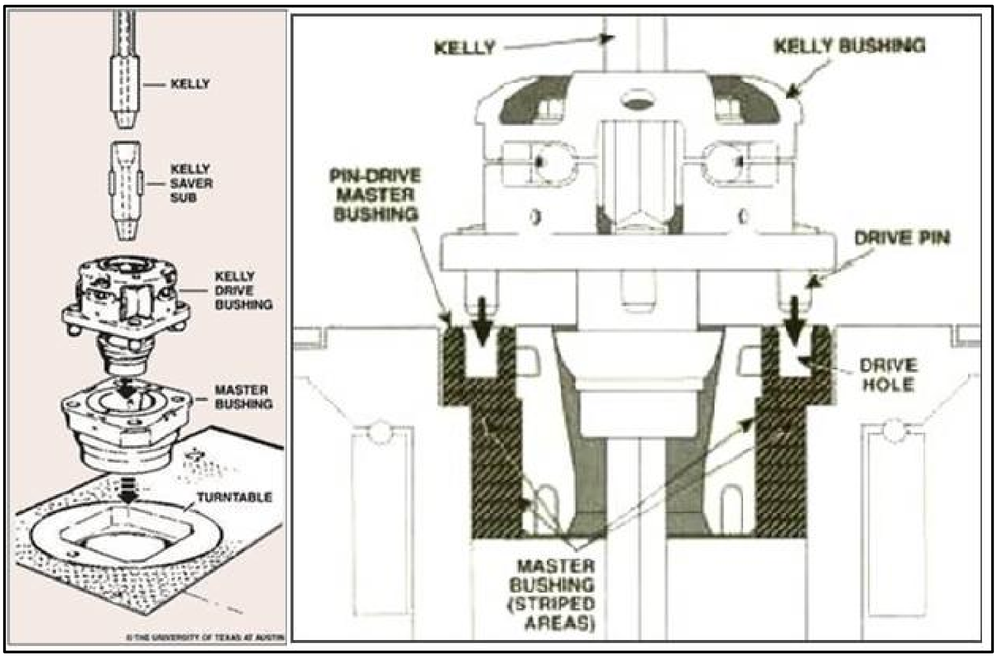


Figure 2-4: Rotary table system showing the main parts [11]

Turntable Rotary Table

The turntable is round in shape and resides in the middle of a stationary heavy-duty rectangular steel case housing. In addition to this, the case also holds gears, bearings and other components which helps turntable to rotate. So, this arrangement is producing turning motion to the drill pipe and the connected bit.

Master Bushing

A bushing is a fitting that goes inside a machine. In the same way, rotary table mater bushing fits inside the turntable table. Here the turntable helps to rotate the master bushing. The master bushing has an opening from where crew member passes the pipe to the hole.

When the driller stops rotation, using hoisting system to lift the pipe and bit from the bottom of the hole. Then it is necessary for the crew members to suspend the pipe. To hold the pipe, there set a pipe gripping elements called slips. These slips grip the pipe and keep suspended off the bottom.

Kelly Drive Bushing

Kelly Drive Bushing fits into the master bushing and provides rotation to the special length of pipe known as kelly. The kelly drive bushing has strong steel pins on the bottom here fits the master bushing four drive holes. This arrangement makes rotation to kelly drive bushing when master drive rotates.

Kelly

Kelly has a special length of pipe and its structure is not round like a conventional pipe. kelly have a rectangular or hexagonal cross-section because the flat side makes the kelly to be rotated easily. The kelly flat sides connect with a square or hexagonal opening in kelly drive bushing. That is why when the driller inserts kelly in matching four or six-sided opening in the kelly drive bushing activates the rotary table. The activation helps kelly drive bushing rotates the Kelly. Finally, the kelly helps to rotate the string and the attached bit in it as the crew members make up the drill string in the kelly.

Swivel

A heavy-duty bail but quite bigger fits in a big hook at the bottom of the traveling block. The hook suspends the swivel and attached to drill string. The crew members attach the top of the kelly to the swivel. The stem rotates with the kelly and kelly helps to rotate the drill string and bit. Simultaneously, drilling mud runs through the stem into the kelly and to the drill string.

2.4 Top drive drilling

Many land rigs use the kelly and rotary table system to rotate the drill string and the bit. But still, many choose a different system. Top drive system eliminates the use of kelly, kelly drive bushing and the master bushing instead it has power swivel which rotates the drill string and bit. It has a regular swivel which is hanged with a large hook and there is also a pathway for drilling mud to reach to the drill pipe. Driller operates the top drive from a control console as usually it is equipped with a heavy-duty electric motor. Moreover, some huge top drive has two motors. Especially offshore drilling rigs use the top drive on their rigs.

Top drive has a threaded drive shaft. The drive shaft is fixed into the top of the drill string. So, when top drive motor started, it rotates the drill string and the bit. The system does not need kelly, kelly drive bushing and master bushing but it still needs the rotary table with master bushing and a place to suspend the slips when the bit is not drilling. Here the use of the rotary table is only for crew members to place slips on rigs.

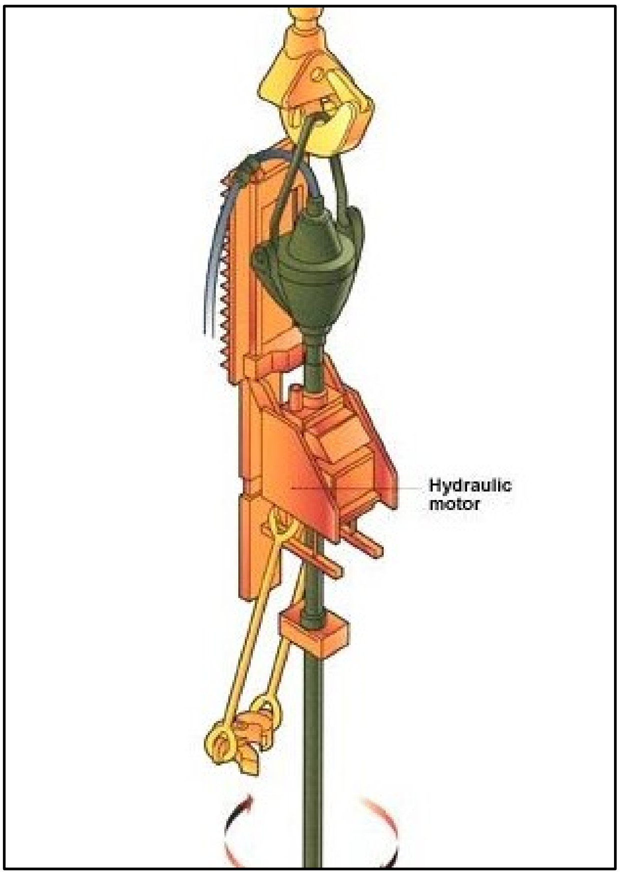


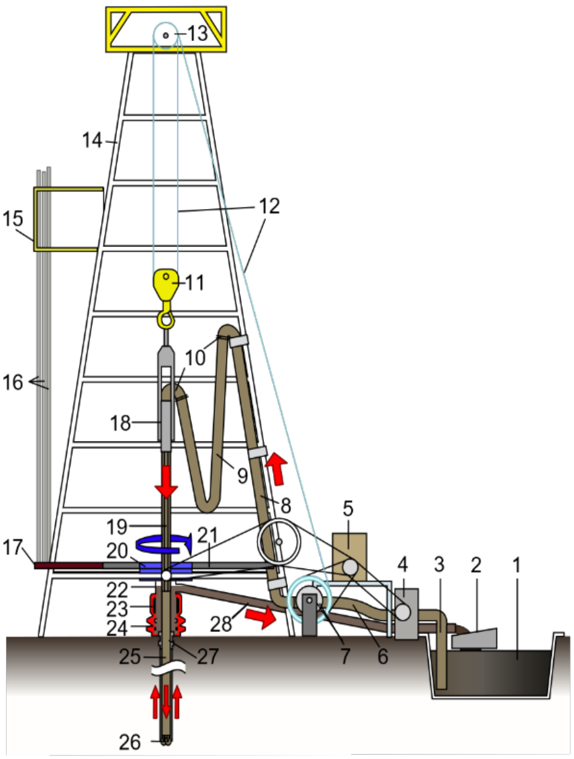
Figure 2-5: Top drive drilling system [12]

2.5 Drill String

Drill String consists of drill pipes, heavy weight drill pipe and special heavy walled pipes called drill collars [8]. Drill collars are like a drill pipe but made of metal tubes through which the driller pumps the drilling fluid. Drill collars are heavier than drill pipes because they are used in the bottom of the string to put weight on bit. The required bit weight varies depending on the types of formation it is drilling, trajectory of the well, mechanical calculation made for that well and type of drilling bit. However, 30,000 pounds (13.61 metric ton) is a good example of required bit weight.

2.6 Drilling rig system

The drilling rig comprises of list of rig devices shown below figure with the list of components name in the right side. All the components have its own importance.



Legend:

1. Mud tank
2. Shale Shakers
3. Suction line (mud pump)
4. Mud pump
5. Motor or power source
6. Vibrating hose
7. Drawworks (winch)
8. Standpipe
9. Kelly hose
10. Goose-neck
11. Traveling block
12. Drill line
13. Crown block
14. Derrick
15. Monkey board
16. Stand (of drill pipe)
17. Pipe rack (floor)
18. Swivel (or top drive in orange)
19. Kelly drive
20. Rotary table
21. Drill floor
22. Bell nipple
23. Blowout preventer (BOP) Annular
24. Blowout preventer (BOPs) pipe ram & shear ram
25. Drill string
26. Drill bit
27. Casing head
28. Flow line

Figure 2-6: Oil drilling rig taken from [14] and is licensed under Creative commons [15]

The first thing to consider during installation of the drilling rig is to decide the best position for the installation of the drilling equipment. Usually, it resides vertically above the point of maximum thickness with the geological layer suspected of comprising hydrocarbons [16]. The driller makes hole ranging from 20 to 50 cm in diameter. This hole goes down to the depth between 2000 and 4000 meters. In some exceptions, some well exceed 6000 meters some even deeper exceeded to 11000 meters as well.

Derrick is used to introduce drill strings vertically down to the hole. The mud pump is connected to the rotating device. The top drive or rotary table helps to rotate the drill string. The drill strings are made of metallic tubes screwed end to end. The top drive has a powerful inbuilt motor to obtain the required torque to drill the rock. The top drive is suspended with the traveling block which raises up or lowered down with the hoisting system [17]. The drill string generates a rotating movement to the drilling tool called the drill bit (26). To remove the cutting away from the bit, there is a special fluid called drilling mud is pumped from drill string to the drill bit. The drilling mud pushes away the cutting and carries back to the surface. The cutting then flows via the annulus. The annulus is the space between drill string outer wall and wall of the hole. The drilling rig works like and huge electric hand drill where derrick is the body, the drill string is the drive and drilling tool is the drill bit.

The drill bit rotates, through the drill pipes the designed mud is injected [16]. The mud engineer prepares and controls the mud. This mud cools the drill bit and also consolidates the sides of the borehole. Moreover, it equilibrates the pressure avoiding overflowing of formations (oil, gas and water) from the layer being drilled. In turn, the mud cleans the bottom of the well. The mud comes back to surface along the pipes so it carries the rock fragments to the surface. Then geologist studies these cuttings to determine the characteristics of the rocks and to identify ultimately the presence of hydrocarbons.

The drilling crew takes the measurements down the hole called loggings when drilled a few hundred of meters by lowering electronic tools in the well to measure the physical parameter. The measures validate or make specific hypotheses to put forward about the rocks and fluids. After drilling of a section is completed, tubes called casing are run and cemented. It isolates the various layers encountered. When hydrocarbons are found and if the pressure is enough to come up to the surface naturally then a driller performs a flow check. Then oil comes to the surface in several hours or several days through a calibrated hole. The quantity recovered can be measured with the changes in pressure at the bottom of the well. In this way, the knowledge is gained for the probable field. If the field seems promising, the team drills a second well.

The driller taking measurement down the hole called loggings. The measurement is taken when normally drilled a few hundred of meter down and taken with lowering electronic tools in the well to measure the physical parameter. The measures validate or make specific hypotheses to put forward about the rocks and fluids. The responsible person for this analysis of the results related to various loggings is the log engineer. Now, the tubes called casing are cemented into the ground. It isolates the various layers encountered. When hydrocarbons are found and if the pressure is enough to come up to the surface naturally then a driller performs a flow check. Then oil comes to the surface in several hours or several days through a calibrated hole.

3. BACKGROUND

3.1 Modeling

Modeling is the procedure for constructing a model. In other words, it is a representation of the system of interest, construction and working principle [18]. A model can be the kind of representation of the system but it is much simpler than the system it represents. One of the purposes of creating a model is to predict any effects if any changes in the system are made. In one way, a model should be a close approximation of the real system with all the silent features. In another way, it should not be so complex so that it will be difficult to understand the model and experiment on it. A model is called a good model when it looks realism with the real system and at the same time, it should be simple enough to understand. One of the important issues in modeling is model validity. The model validation techniques comprise simulating the model with known input and comparing the model output with the real system output.

3.2 Simulation

Simulation of a system can be defined as the operation of a model, which is a representation of the actual system [19]. The system is simulated where it is impossible, too costly, or it is not feasible to implement a process or actions using the actual system. The function or the process of the model studies and with the information the required behavior of the actual system is concluded.

The system is simulated meaning, it is tried to duplicate the characteristics of the actual system. Before making any business decision first analyzing with creating a mathematical simulation model of the actual system is being very popular these days [20]. Hence simulation is being one of the commonly used modeling techniques for making a decision. It is being very popular because it is flexible, it can handle huge and complex system, it can answer what-if question, allows studying the system without interfering with the actual system.

In other words, simulation is a tool to evaluate the performance of the system with a different configuration of interest over a very long period of time which to evaluate in a real system is practically impossible.

Below is the block diagram of the schematic of the simulation study [18]. The real system under study is simulated and evaluate the system. If any alteration is made in the real system, the simulation study is remodified and evaluate again. In this way, the process repeats until and unless the appropriate result is obtained.

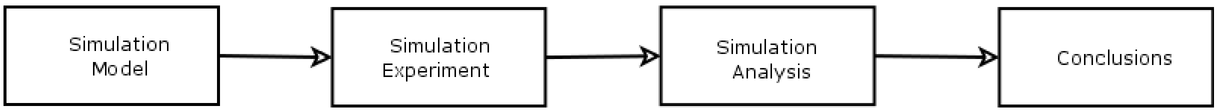


Figure 3-1: Block diagram of simulation study

Simulation Model

The simulation modeling first task is to identify the problem. Once the problem is identified clearly the problem is formulated. The real system data is collected and processed. Then the model is developed along with validation. Once the model is ready, the same model is documented for future so it can be reused with minor modification.

Simulation Experiment

Once the model is ready the next step is the simulation experiment. For this purpose, the appropriate experiment design needs to decide wisely and the experiment condition is defined to set up and run the experiment.

Simulation Analysis

When the simulation experiment is completed. The next step task is to present the simulation results with some interpretation in accordance with the system. Hence with the result analysis, it is easy to recommend further action.

3.2.1 Benefits of Simulation modeling

The modeling and simulation are one of the widely and frequently used operation in the research area. These are the things that are possible because of simulation and modeling analysis [18]:

1. There is a better understanding of the system by developing the mathematical model of the system. One can view the system operation in long run with details.
2. The system feasibility study can be easily performed.
3. The modeling system can run for long periods or even expand the time when there is a need to observe the complex phenomenon in detail.
4. All the effects of the system can be studied by altering the system model which can be done without disturbing the real system.
5. It is easier to identify bottlenecks in the flow model.
6. It makes easier to develop and construct a robust system which ultimately minimizes the system development time.

3.3 Simulation Models

There are different simulation models classified according to their characteristics. They are

3.3.1 Static or Dynamic

A model is static if that represents the system at a particular time. In other words, the model is static if it is not described as a factor of time [21]. Monte Carlo simulation is one of the best types of static simulation where random numbers are used to solve the stochastic problems where time plays no role [22].

3.3.2 Deterministic or Stochastic

A deterministic model has no variable model parameters; therefore, it contains no random variables [22]. Hence, it is obvious that when a deterministic model is run with same input it always calculates the same output. A deterministic model is also equally important but in most of the cases have random or unpredictable values in their components, in this case, there is a need for a stochastic model. One of the powerful features of simulation is its ability to model random values. Therefore, stochastic simulation has one or more random variables to define the system which is being studied. It is an important point to recall that the output data of stochastic simulation are random itself.

3.3.3 Continuous or Discrete

Continuous simulation the system state that changes continuously with time. For example, in a flight of an airplane, the variable of velocity and position changes continuously with respect to time [22]. In contrast, the system whose state is discrete and changes only at the particular point of time and remains in the same state for some time is called discrete simulation. For example, the number of customers in the bank. The number of the customer is a discrete integer and there are changes in customers when somebody enters the bank and get his work done from the counter.

3.4 Discrete Event Simulation

In this study, drilling simulation is based on the Discrete Event Systems (DES) paradigm. Basically, in discrete event system, there are two basic notations that are state and event. The drilling activities are represented in term of state and event. For analyzing the model, numerical method is given the first priority to calculate the timing of each activity during the process. The simulation model is numerically solved and run the simulation to display the results to the end-users. The simulation results are displayed first theoretically and later graphically in forms of graphs for better observation. Therefore, the observation results can be analyzed which detect bottlenecks of the system. Finally, correct methods can be concluded to improve the system performance.

3.5 Petri Nets

Petri nets are widely used tools for discrete systems modeling [23]. Although there are many tools available for simulation of discrete event systems, Petri net is popular. Some of the available tools like automata, stateflow etc. As Petri net is a graphical representation and well-defined semantics of the model it is possible to use for formal analysis of the models. In addition, the mathematics used in the simulation for designing Petri net models is also very simple as it requires knowledge of matrix addition and multiplication only.

Petri Nets is a graphical and mathematical modeling tool which is applicable to many systems [25]. It is a promising tool for studying information processing system which is characterized as being distributed, parallel, nondeterministic, stochastic, concurrent or asynchronous. As Petri nets is a graphical representation tool it can be used in visual communication aid which is similar to flowcharts, networks and block diagram. To simulate dynamic and concurrent activities token are used. As it is used as a mathematical tool so it is easy to set up equations like algebraic equations and other mathematical models to represent the system behavior.

A Petri Net consists of directed arcs which connect places and transitions. The places may or may not hold the tokens. The marking of the net is defined as the assignment of tokens in its places. Below shows the simple example of Petri net contacting all the components.

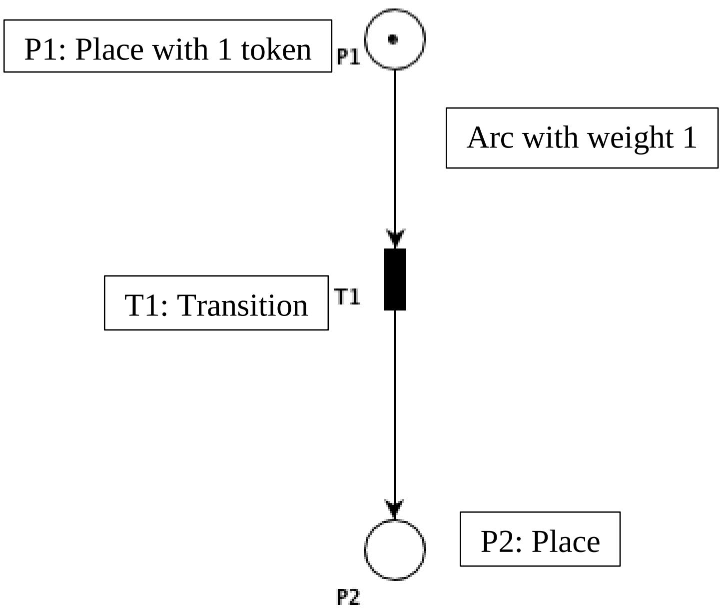


Figure 3-2: Simple Petri Net Model

Places have the infinite capacity of tokens in default but here in the figure above the place P1 with token 1 and P2 having no token before firing. The arcs will have weight 1 by default if not assigned any value. If it has capacity other than 1 then it is marked on the arc. The transition has no capacity and does not store any token as well. The arc can only connect to places to transition and transition to places. With the rule, there is no connection between two places and two transitions.

The transition gets enabled when the number of tokens in the input places is equal to or greater than the weight of the arc that going from places to transition. The enabled transition can fire any time and when the transition has fired the token in input places move to the output places in accordance with the weight of the arc and the capacities of place. This results in setting new marking in the net.

The table below shows, some of the interpretations of Input Places, Transition and Output Places.

Input Places	Transition	Output Places
Preconditions	Event	Postconditions
Input data	computation step	Output data
Input signals	Signal processor	Output signals
Resources needed	Task or job	Resources released
Conditions	Clause in logic	Conclusion(s)
Buffers	Processor	Buffers

Table 3-1: Interpretations of Input Places, Transition and Output Places presented in [25]

The formal definition [25] of Petri nets,

Petri Net is a bipartite weighted graph represented by a 5- tuple **PN = (P, T, F, W, M_O).**
Where,
P is the finite set of places. P = {p1, p2, p3,…, p_n}
T is the finite set of transitions. T = {t1, t2, t3, …, t_m}

F $\subseteq (P \times T) \cup (T \times P)$ is the set of arcs from places to transition and from transition to places in graph.

W: is the weight function on the arcs, W: F → {1, 2, 3, . . .}

M_O: is the initial marking. M_O: P→ {1, 2, 3, . . .}

N = (P, T, F, W): It is the Petri net structure without any initial marking and is represented by N.
Hence, (N, M_O): It is a Petri net with an initial marking.

Petri Nets with Inhibitor Arc

The Petri nets with inhibitor arc are very powerful as it can model any discrete event systems. In the Petri net model, an inhibitor arc is graphically represented as an arc ending with a small circle in the transition instead of an arrowhead like a regular arc [27]. The transition can fire if and only if there is no token in the place of inhibitor arc. The inhibitor arc run from place to transition only and represented by circle headed arc. When the inhibitor arc drawn from place to transition has defined n weight means that the transition cannot fire if the corresponding inhibitor place contains at least as many tokens as the weight value defined in the arc.

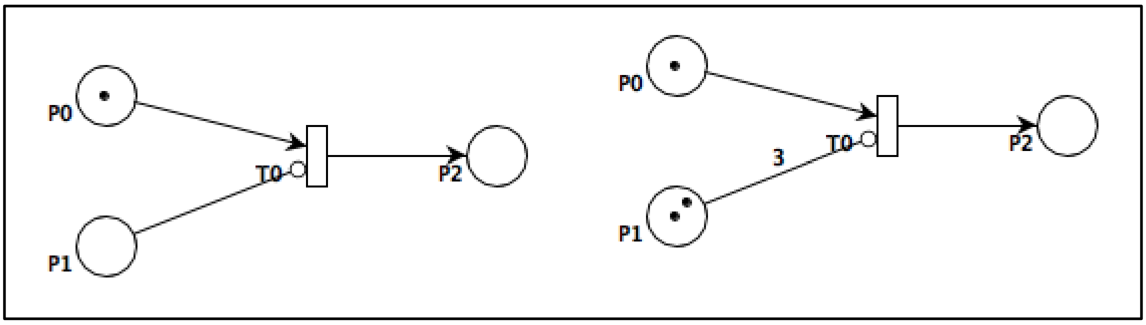


Figure 3-3: Petri Net Model showing Inhibitor Arc

In the first model,

The transition is enabled if there is no token in place p1.

The transition is not enabled if there is any token in place p1.

In the second model,

The transition is enabled if satisfying the condition that, if tokens in p1 should be less than 3 i.e. p1<3 else the transition is disabled.

3.6 GPenSIM

"General-purpose Petri Net Simulator (GpenSIM) is a Petri net language for modeling and simulation of discrete event systems on MATLAB platform" [24, p.1].

GPenSIM is developed by Reggie Davidrajuh [24]. The Petri net model can be developed and simulated with GPenSIM. These days, GPenSIM is being popular around the world as it supports many Petri nets extension and also provides collections of functions for performance analysis which makes the simulation task much simpler and easier.

The architecture of GPenSIM consists of modules in the form of files. The modeling of discrete event systems with GPenSIM has its own structure. In the beginning, there should be a clear separation of static and dynamic details. The definition of a Petri net graph is a static detail so it is defined in Petri net Definition File (PDF). There can be a single PDF file or if the model is divided into sub-modules then each module has a single PDF file. So there will be multiple PDF files available for this case. In contrast, the Main Simulation File (MSF) has dynamic information of the Petri net. In addition to this, there can be also Transition Definition Files (TDFs) i.e. pre-processor and post-processor. There can be a common pre and common post or can have multiple files.

It is easy to access and exchange global parameter values in different files through a packet called 'global_info'. The parameters are added in 'global_info'when the values are accessing from different files. This packet is available in all files and the files can read the values and also update if necessary.

The main operating files of GPenSIM are Main Simulation File (MSF) and Petri Net Definition files (PDFs).

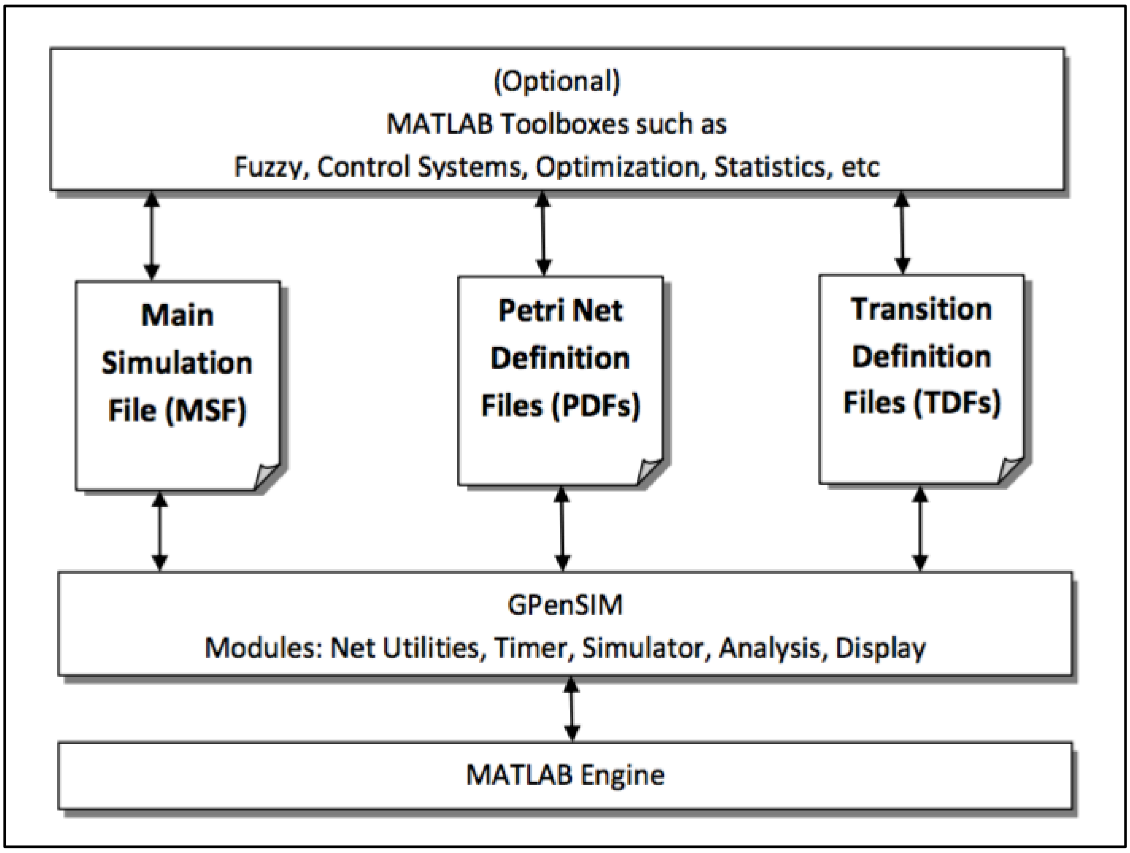


Figure 3-4: Architecture of GPenSIM presented in [24]

Main Simulation File (MSF)

Main Simulation File by the name itself it says that it is the main file which runs directly from MATLAB platform. It includes dynamic information of the model such as initial token in places, firing times and transitions. All the required PDFs files are defined in this file.

Petri Net Definition Files (PDFs)

Petri Net Definition Files it includes the static information of the model. The model has multiple PDFs files if the model is subdivided into multiple modules. The places, arcs, transitions including the whole Petri net information is encoded in this file.

Transition Definition Files (TDFs)

Beside MSF and PDFs files there can be a number of pre-processors and post-processors. The pre-processors are run before firing the transition to check if there are any additional condition set to fire this transition. All the pre-processors can be written in a common pre-processors file as 'COMMON_PRE' or it can be separated according to the transition with the naming convention transition name followed by '_pre'.

Post-processors execute after firing of the transition. This file has a condition or actions coded that need to carry out after firing the transition completed. Likewise, post-processors can be written in a common file with naming convention 'COMMON_POST' or in a separate file with a transition name followed by '_post'.

4. DESIGN AND METHODOLOGY

The method and design are based on all the knowledge gained from the theoretical or literature study for the oil drilling activities. In this system design, the system is represented in forms of a block diagram. There are many activities involved in this process and all those activities are represented with as much detail as possible to include for master level thesis. There are mainly two different methods of drilling, drilling with the rotary table system and drilling with the top drive system. The paper presents a design of both drilling methods so it is easier to analyze between two different systems in terms of setup or in terms of performance.

4.1 Design of overall oil drilling activities

The drilling program begins with adding new components to the drill string as illustrated in Figure 4-1 below. The new components consist of drill pipe and other supporting components to make a complete drill string. Here in this design, two drill pipes constitute one complete drill string. Actually, one drill pipe equivalent to nine meters in practice (typical example) but here for simplicity chosen 1 drill pipe of 10 m long. So, one complete drill string is 20 m long. After adding new components to drill string the drill pipe is tripping in. The tripping in activity continues unless and until it reached to the bottom of the hole. If the pipe is not sufficient to hit the bottom another round of suitable drill component is added. When it is confirmed that it hit the bottom of the hole then the drilling gets started. The drilling hole continues unless it reached the section target depth. Here initially, the section target depth is set to be 80 m (example). So, checking the section target depth runs in parallel like drill little further and checking the section target value. Once the section target value is obtained. The drill string is pulled out of the hole. Then the drill components are collected. It is confirmed, if all the drill string is out or not? If it found that still, all the drill string is not out of the well, the pulling operation goes forward and trip out drill string from the hole and start collecting. When it is confirmed that all the drill string is out of the well, then operation of running casing starts and then cementing follows. Once the cementing to that particular section is finished it checks for final target depth. Here the final target depth set in this design is first is 80 m, second is 200m and 800 m and so on. For instance, suppose in this case the target depth is 80 m. It will check if it reached 80 m or not. If 80 m drill is not completed the process repeats with adding new components. In this way, the whole drilling process repeated from the beginning and again check for final target depth. This time if it is confirmed, that the final target depth is achieved the drill program marked as finished for this particular rig. In this way, a complete drilling process executes.

In this paper, it is shown that drilling with the depth target of 80, 200 and 800 m. But this system can run with any target depth value according to our requirement.

The simulation of the drilling activities also calculates the time taken for each activity and finally the total time taken for overall activities. Each components timing can be compared and overall timing to study the system performance. This simulation process identifies the bottleneck of the system which ultimately helps to improve the system performance greatly.

This is the high level design of oil drilling activities and it has several simplifications presented in this study to make the system simpler.

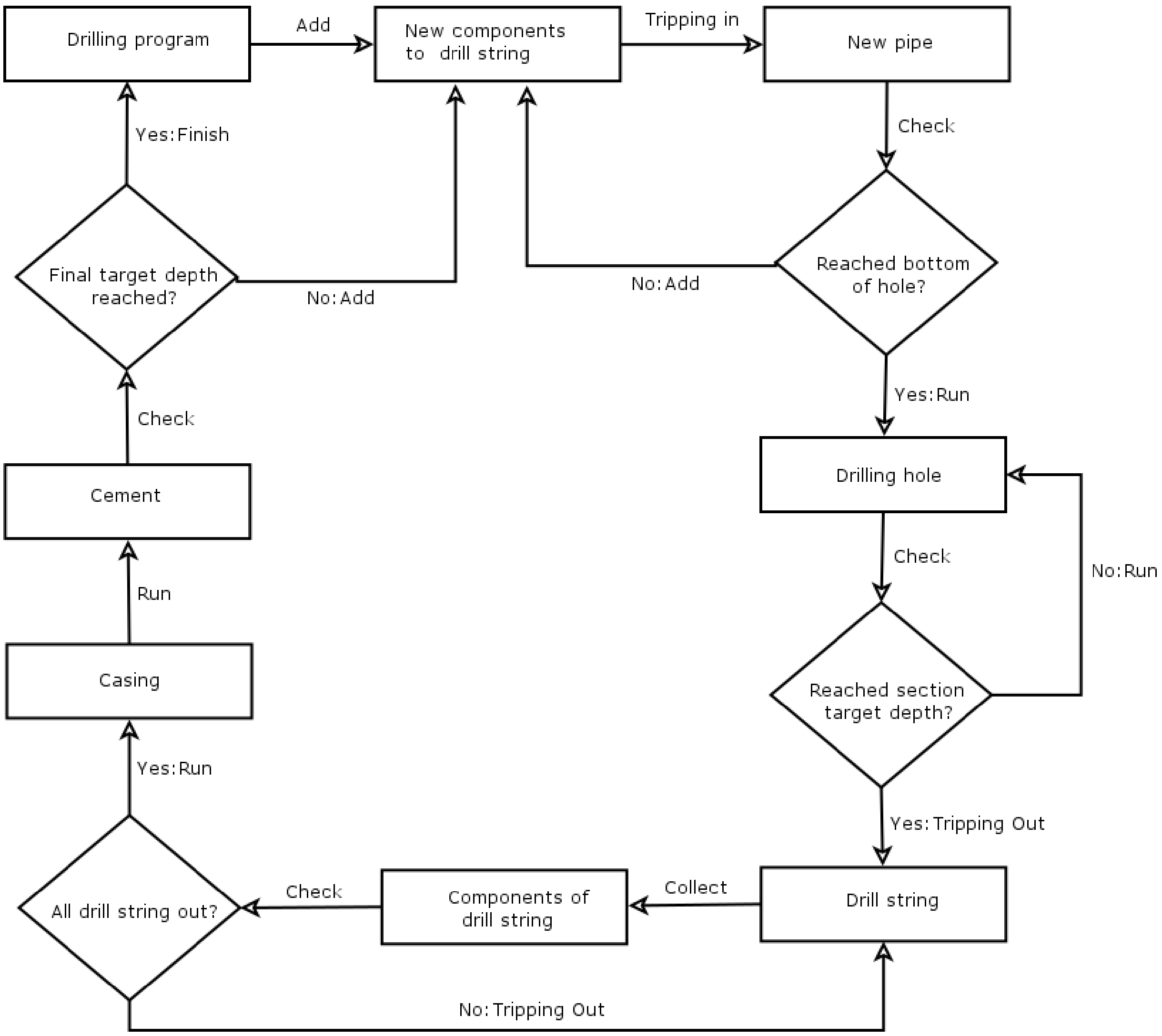


Figure 4-1: Design of overall oil drilling activities

The design shown above in Figure 4-1 is an overall package of whole drilling activities so breaking down each component for more details.

4.2 Design of adding new components to drill string

The design of adding new components to drill string is described with both methods of drilling technique i.e. top drive system and rotary table system. The following design with detail activities helps to identify the similarities and differences of adding new components to drill string in both drilling methods.

4.2.1 Design of adding new components to drill string with the top drive system

The design of adding new components with the top drive is illustrated in Figure 4-2 below. The design shows the adding new components in detail.

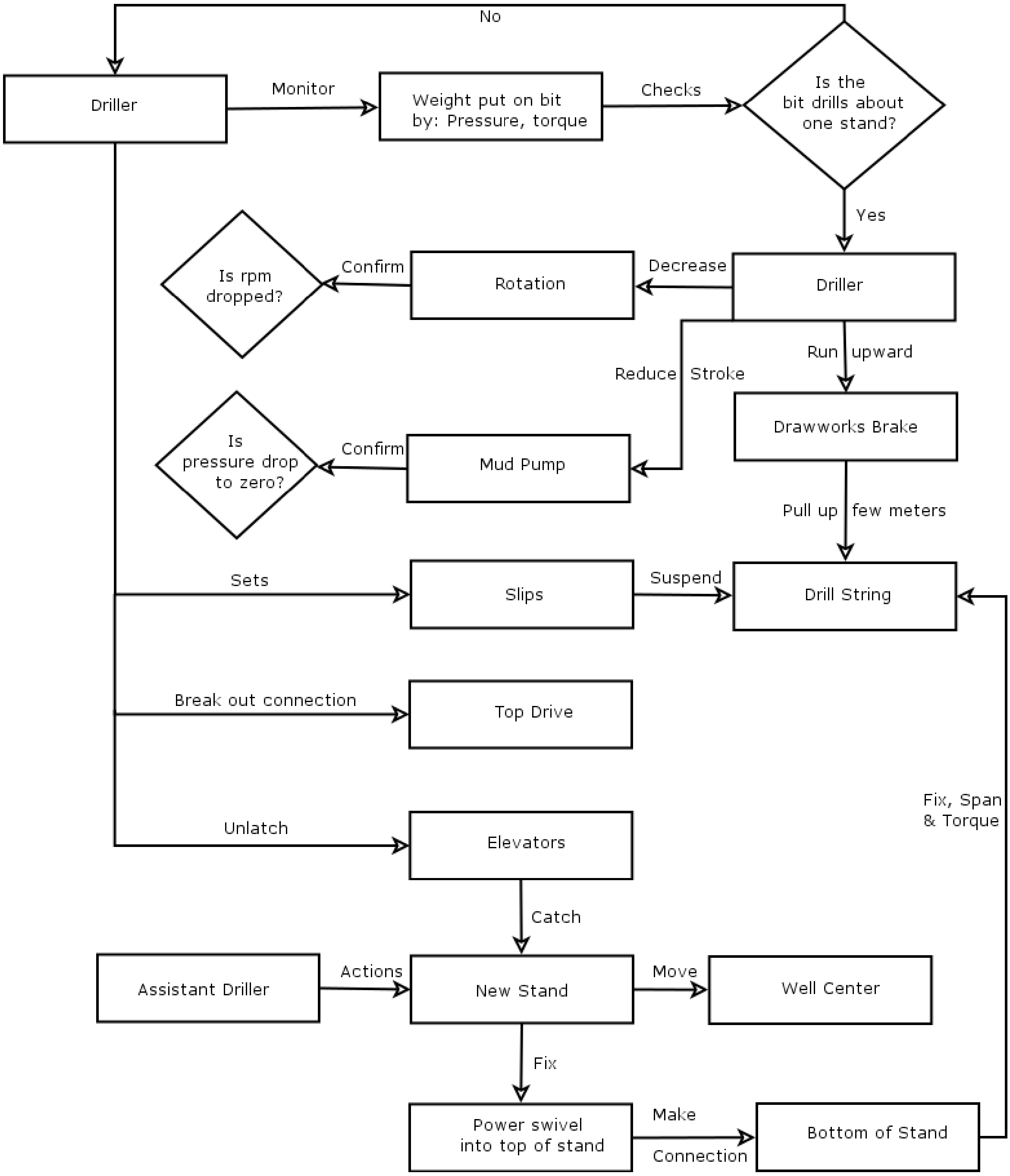


Figure 4-2: Design of adding new components with the top drive system

To activate the process to add new components, the driller identifies the weight put on a bit by monitoring depth increase, pressure and torque reading. With this reading, it identifies whether the bit drills about one stand. In this design, 20 m is set to the value of one stand. When driller confirms it's time to add new components then he decreased the rotation and in the same time reduce stroke of the mud pump. He confirms the decrease in rotation looking at the value of rpm by reading the value if it is dropped or not. Similarly, he confirms the mud pump reduction with the pressure value if it dropped to zero or not.

Once the driller confirms the reduction of mud pump stroke and decrease the rotation he runs drawworks brake upward which pulls up drill string few meters from the ground then it is suspended with slips in order to prevent it fallen into the well. Then driller breaks out the connection with the bottom of the top drive and unlatches the elevators and the block is lifted up to the top of the derrick (link down) and the elevator catch the new stand which is already set in well center in standby position by the assistant driller. The new stand top is fixed into the power swivel and bottom of the stand is made a connection with a drill string which is suspended with slips. The stand is fixed with span and torque to the drill string. In this way, new stand or drill string is fixed to expand the hole depth.

4.2.2 Design of adding new component to drill string with rotary table system

The design methodology of adding components to drill string with the rotary table system is illustrated in Figure 4-3 below. The rig with rotary table system differs slightly from the top drive system. For both the systems, the steps until identifying if it is necessary to add the components or not, is same. The only difference is how the new components are fixed. It’s because there is little different regarding the structure of this systems.

The drill string is pulled few meters up and the crew member’s sets slip to suspend the drill string. The crew members unscrew the kelly as the drill string is already supported with slips in the rotary table. Then swivel and kelly are swing and moved over the mousehole. The mousehole is a place where the pipe is fixed and place for further arrangement. Now, the drill pipe of mousehole is screwed in kelly and move towards the well center. The assistant driller (drilling crew) fixes the pipe to the top of the drill string with applying span and torque. Now, the drill pipe is added to the drill string. The pipe is moved and fixed to the length equal to one stand. In this design two drill pipes are equal to one drill stand.

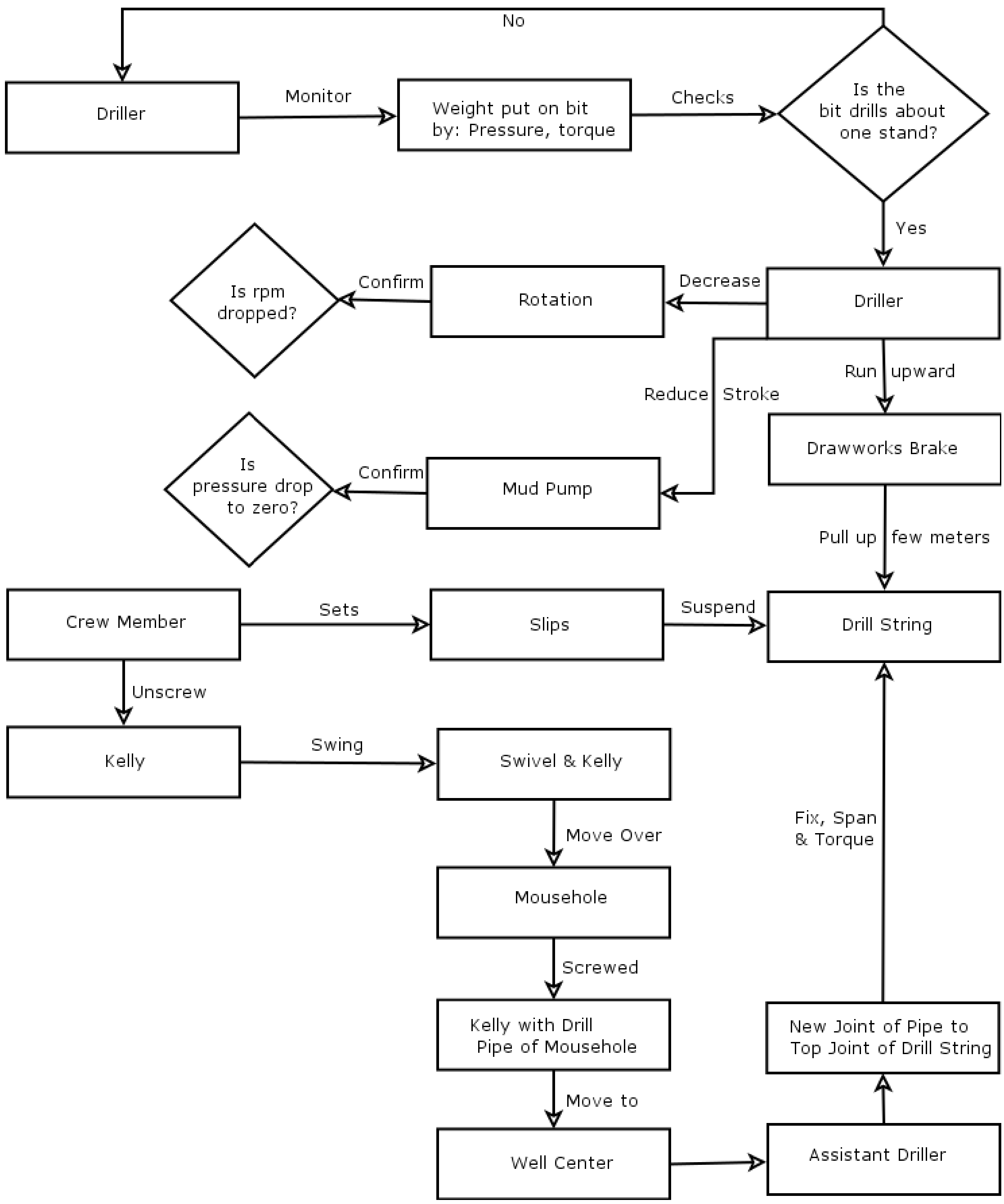


Figure 4-3: Design of adding new components with rotary table system

4.3 Design of tripping in new pipe with top drive/rotary table system

This is the design methodology of tripping in a new pipe with the top drive and rotary table system both. Here, the driller release drawworks brake which lowers drill string. In the same time driller support moving down the drill string by releasing the slips of the drill string. This task of releasing slips is performed by a crew member in the rotary system and the rest of the job is same in both the system.

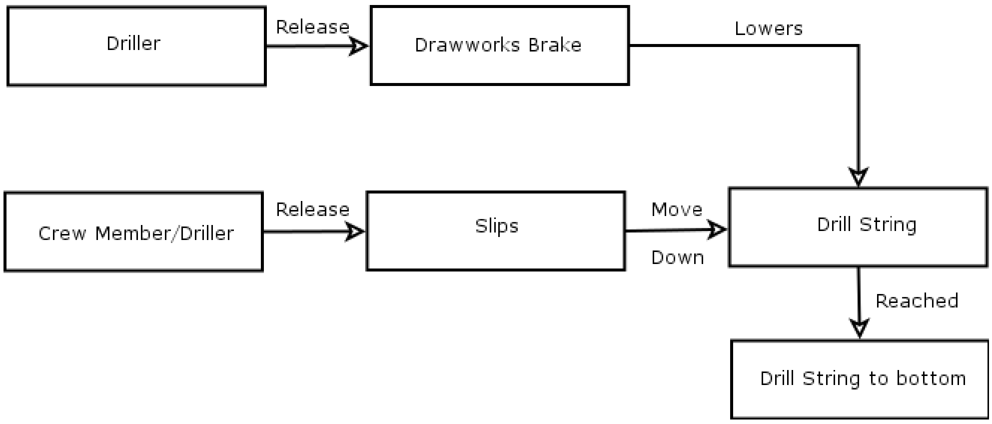


Figure 4-4: Design of tripping in new pipe with top drive/rotary table system

4.4 Design of drilling hole

The design model of drilling hole is described here with both drilling technique i.e. top drive system and rotary table system. The following drilling hole design with detail activities helps to identify and analyze the similarities and differences of drilling hole in both drilling methods.

4.4.1 Design of drilling hole with top drive system

This is the design methodology of drilling hole with the top drive system. The driller confirms whether the drilling is progressing by checking if the drill string and bit rotated or not? If the rotation is not started the driller starts the motor of top drive to actuate the rotation of drill string and a bit. When it is confirmed that the rotation is established driller start the mud pump and check the flowback check from the well to ensure there is mud circulation. The mud circulation is mandatory to throw out all the cutting from the well while drilling. In the same time driller also checks the weight put by the components to ensure the drilling is established or not. When the drilling is established the weight gets reduced. The reduction of weight ensures that the drilling is established. Then, the driller releases the drawworks brake to lower drill string and a bit. When all above mentioned condition are satisfied, together with the drill string and bit start making a hole in the ground.

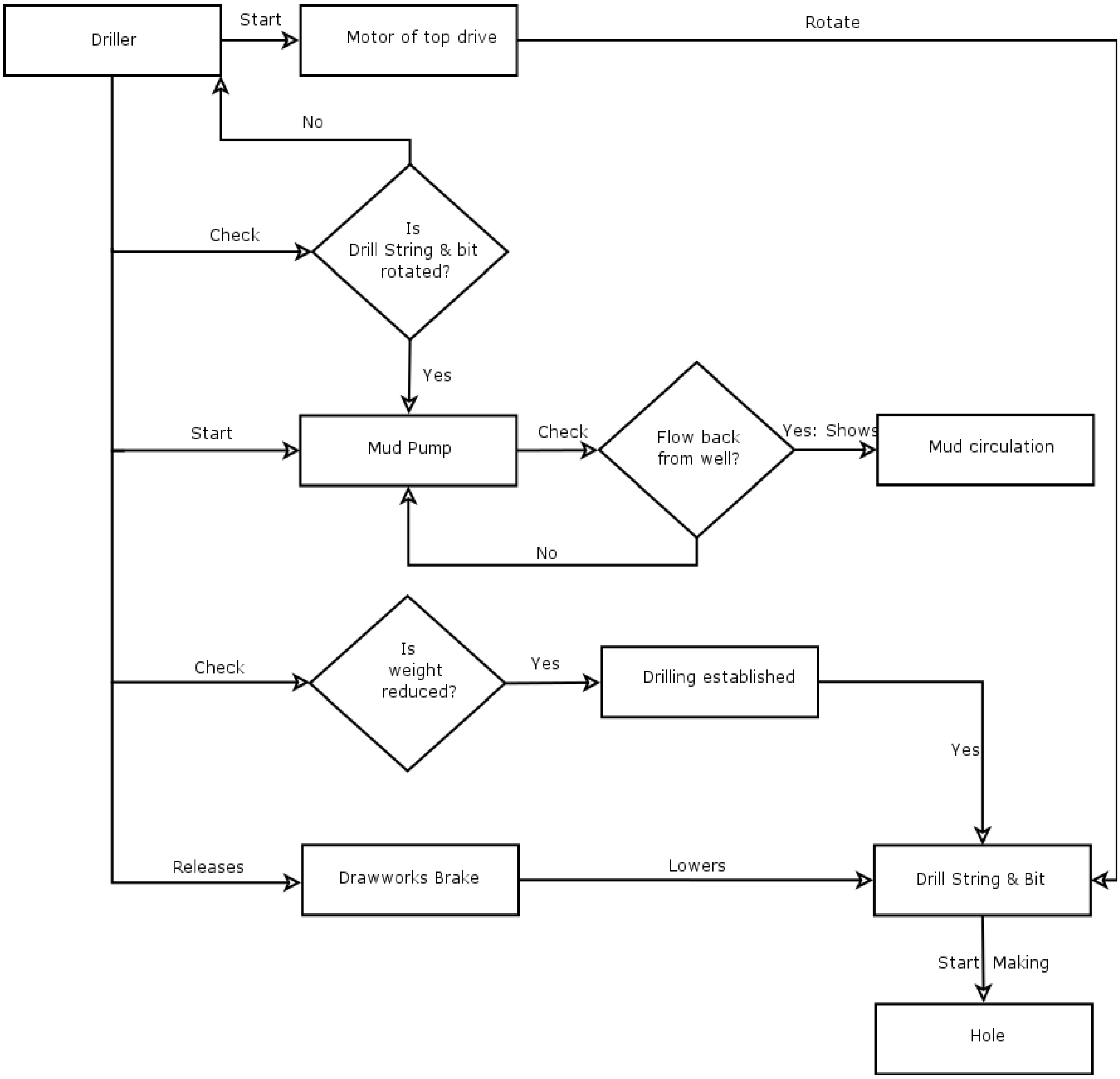


Figure 4-5: Design of drilling hole with top drive system

4.4.2 Design of drilling hole with rotary table system

This is the design methodology of drilling hole with the rotary system. The driller checks the drill string and bit is rotated or not? If it is not rotated driller releases drawworks brake which lowers kelly drive bushing and it engages master bushing. This action helps to initiate rotation in rotary table and simultaneously driller also send the signal to operate rotary table. This both action keeps rotating the rotary table.

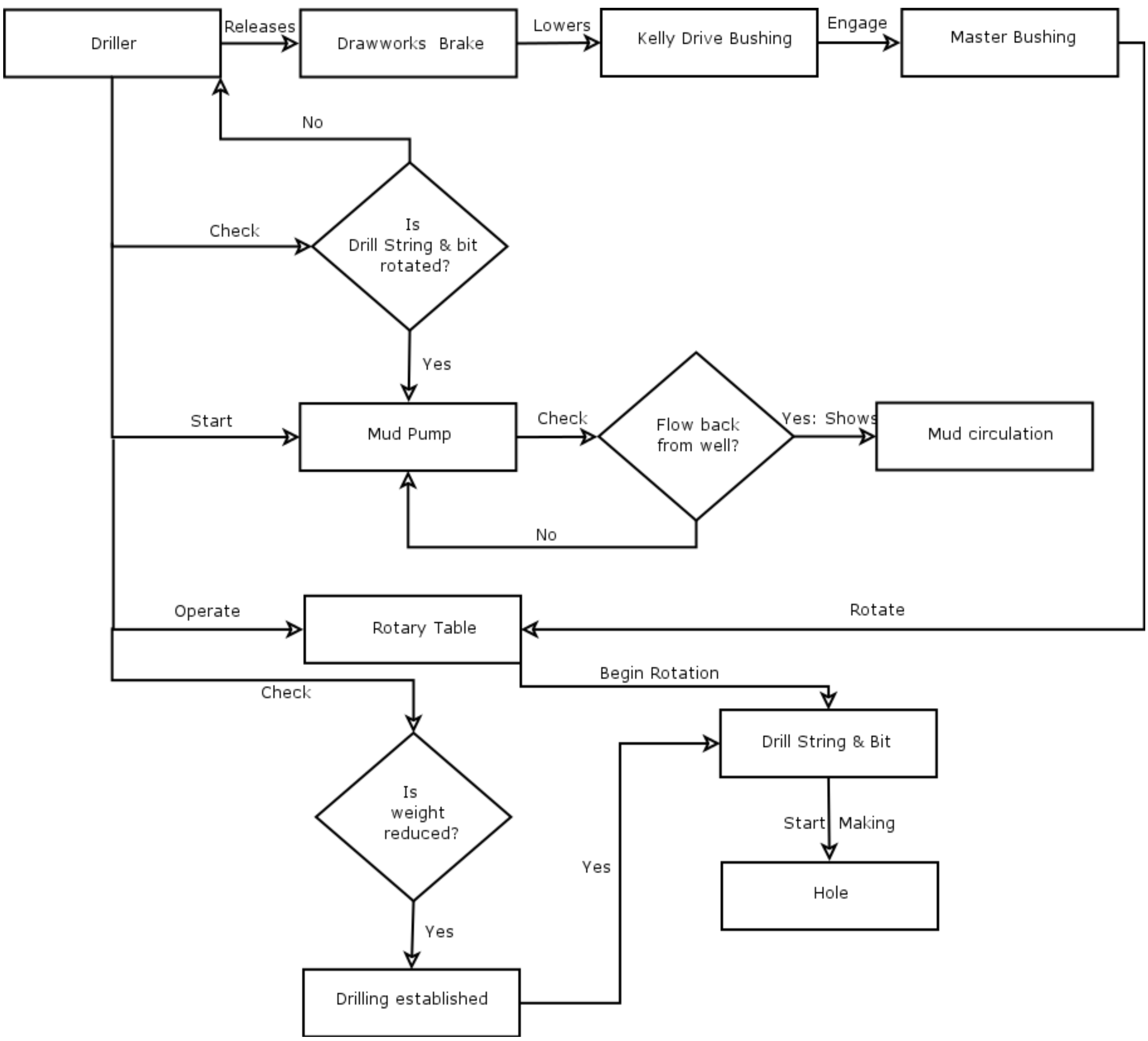


Figure 4-6: Design of drilling hole with rotary table system

At first, the driller confirmed drill string and the bit are rotated. Then he starts the mud pump and performs flow back check from well to confirm the mud circulation. When the mud pump and rotary table have started, it helps to begin the rotation of drill string and a bit. In the meantime, driller checks the weight put by the drill string and bit is reduced or not, to ensure the drilling has been established. The reduction of weight ensures the drilling is established so drill string and bit start making a hole. The process continues until and unless the section target value is met.

4.5 Design of tripping out drill string with top drive/rotary table system

This is the design methodology of tripping out of drill string when the section target is met. In this design, the section target is set to be 40 m depth. Once the section target is obtained the drill string is tripped out for further activities of the process.

Driller release the drawworks brake to raise the drill string. The raised drill string is suspended in the well with sips which are set by a crew member or the driller. When the tripping out is carried out by top drive system it's the driller who does this job otherwise in the rotary table system it's the crew member who performs this job. In this way, the drill string is ready in the well for collecting of drill components.

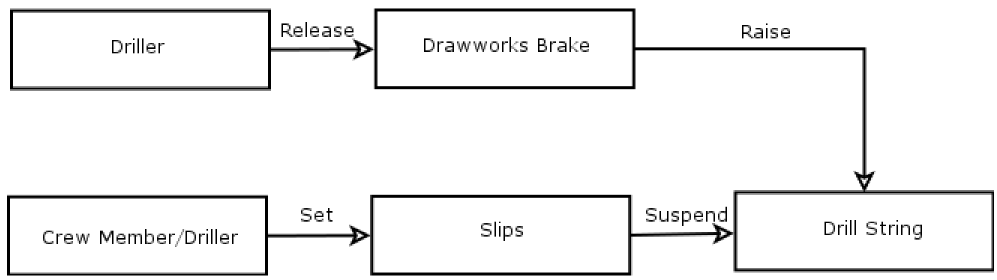


Figure 4-7: Design of tripping out with top drive/rotary table system

4.6 Design of collecting drill components

The design model of collecting drill components is described here with both drilling technique i.e. top drive system and rotary table system. The following design of collecting drill components with detail activities helps to identify and analyze the similarities and differences of collecting drill components in both drilling methods.

4.6.1 Design of collecting drill components with top drive system

This is the design methodology of collection of drill components with the top drive system. Before starting collection, the driller already sets slips to suspend the drill string in the well. Otherwise, the drill string will fall into the well if it is not supported with slips. The driller stops mud pump and rotation both. The driller breakout the connection with the top drive and started getting ready for collection.

The arrangement of setup to start collecting components starts with unlatching of the elevator which gets lowered with releasing the drawworks brake. When the elevator is lowered it latches the pipe from the drill string which is suspended in the well by slips. Derrickman unlatches the elevator and guides the pipe to move into the fingerboard. In the meantime, crew members help to break out the connection of pipe from the drill string to move into fingerboard. Breaking connection of pipe and arranging into fingerboard repeats unless and until all the drill pipe is moved to the fingerboard.

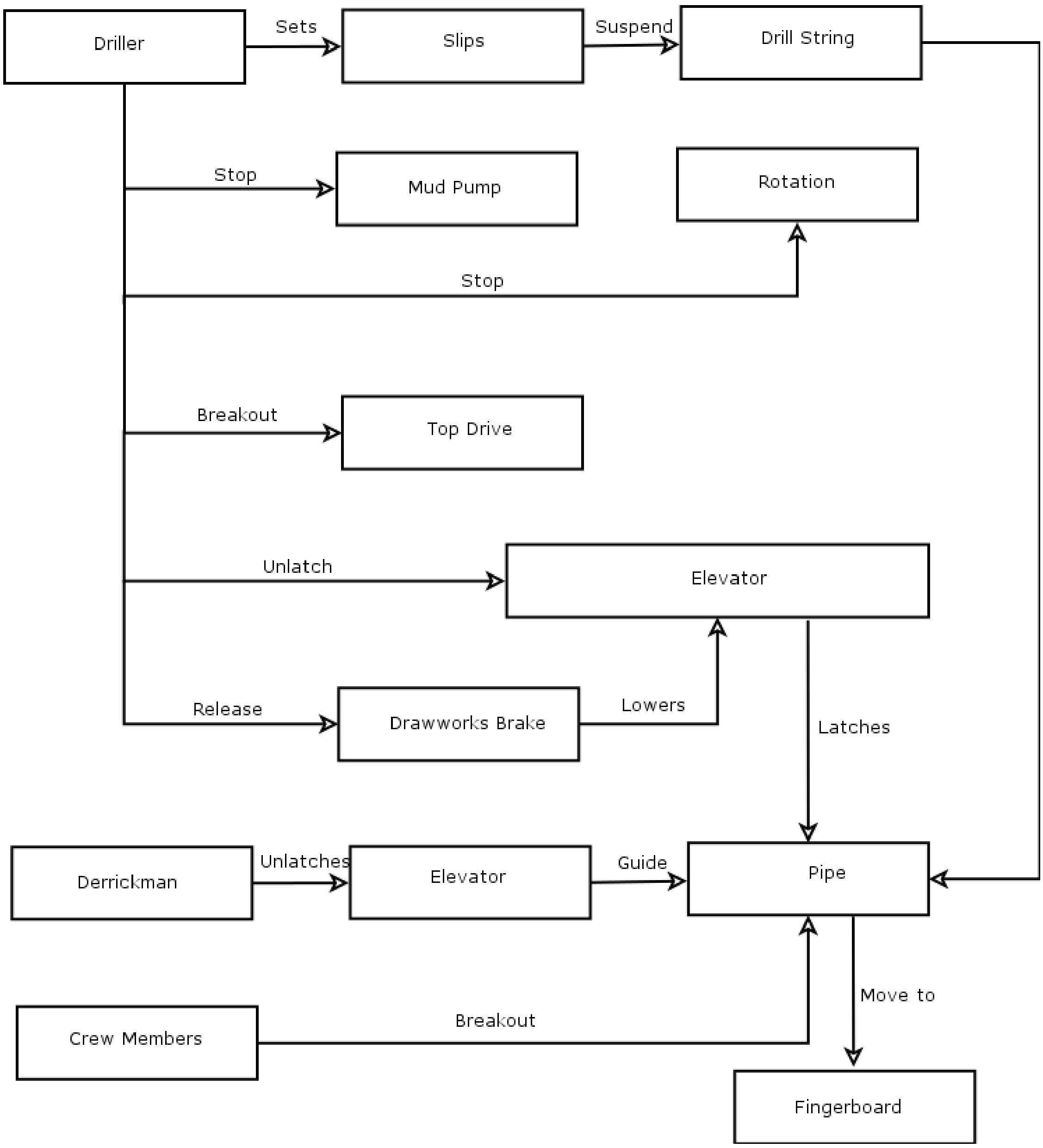


Figure 4-8: Design of collecting drill components with top drive system

4.6.2 Design of collecting drill components with rotary table system

This is the design methodology of collecting drill components with the rotary table system. The crew members set slips to suspend the drill string. Then the driller stops mud pump and rotation. The crew members breakout kelly and set into the rathole and prepare another arrangement for collecting components.

Initially, the crew members attach elevator to elevator links then the driller lowers traveling block which lowers the elevator. Elevator latches pipe where the derrickman guides pipe to the fingerboard. The crew members help to break out the pipe and derrickman moves the pipe to fingerboard. The process is repeated unless and until all the drill pipe is successfully moved to the fingerboard.

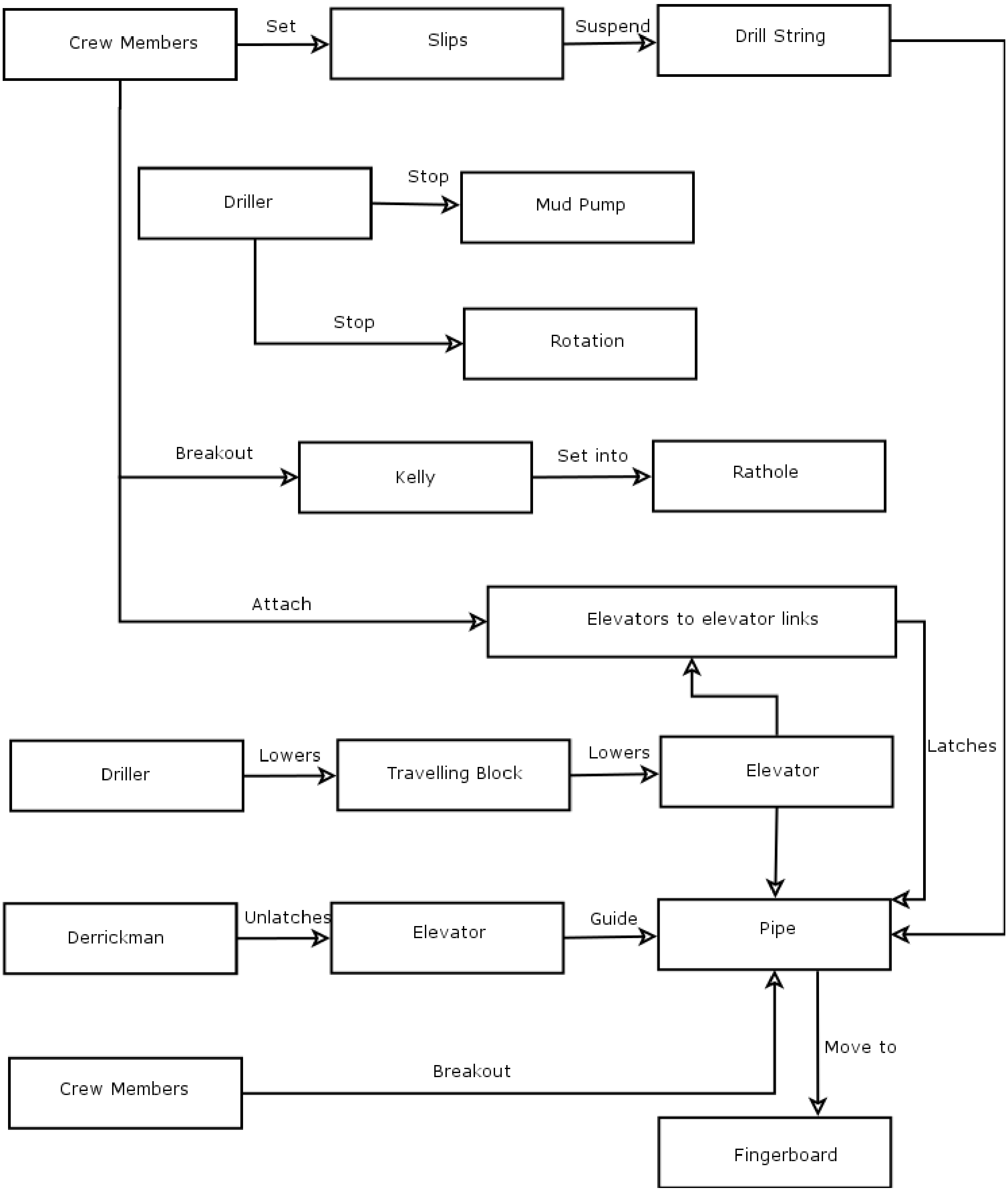


Figure 4-9: Design of collecting drill components with rotary table system

4.7 Running casing and cementing

After all the drill components are collected it's time for running casing first and then cementing the drilled well.

5. IMPLEMENTATION

This chapter includes the implementation of oil drilling activities. The design model is implemented in Petri Net using GPenSIM. First, the Petri Net model is created based on the design as described in the design section (Chapter 4). GPenSIM is a MATLAB tool which can model Petri Net designs. Hence, the created Petri Net model is implemented using GPenSIM in MATLAB environment.

5.1 Petri Net model of oil drilling activities

The Petri Net model is designed with places representing the drilling components, transitions representing the various actions and arcs joining the place to transition and vice versa. In addition, the inhibitor arc is used to check some conditional values. In this design, the token represents the length in meters. In each component, there is certain modification regarding token but in all the cases it means the length in meters anyways. Suppose, in case of adding new components, as already mentioned in design section (chapter 4) here it is assumed that each drill pipe is of 10 m long so 2 drill pipes make one drill stand which is represented with 20 tokens.

The complete model of overall drilling activates is illustrated below figure. This model drills the target depth of 80 m, 200 m and 800 m with final target depth. This system supports target depth of any value but for this simulation we have chosen these three values. The Petri Net model randomly selects either to drill 80 m, 200 m or 800 m target depth. As from figure given below, it is difficult to understand the complete model so it is divided into smaller section so that it is easier to understand.

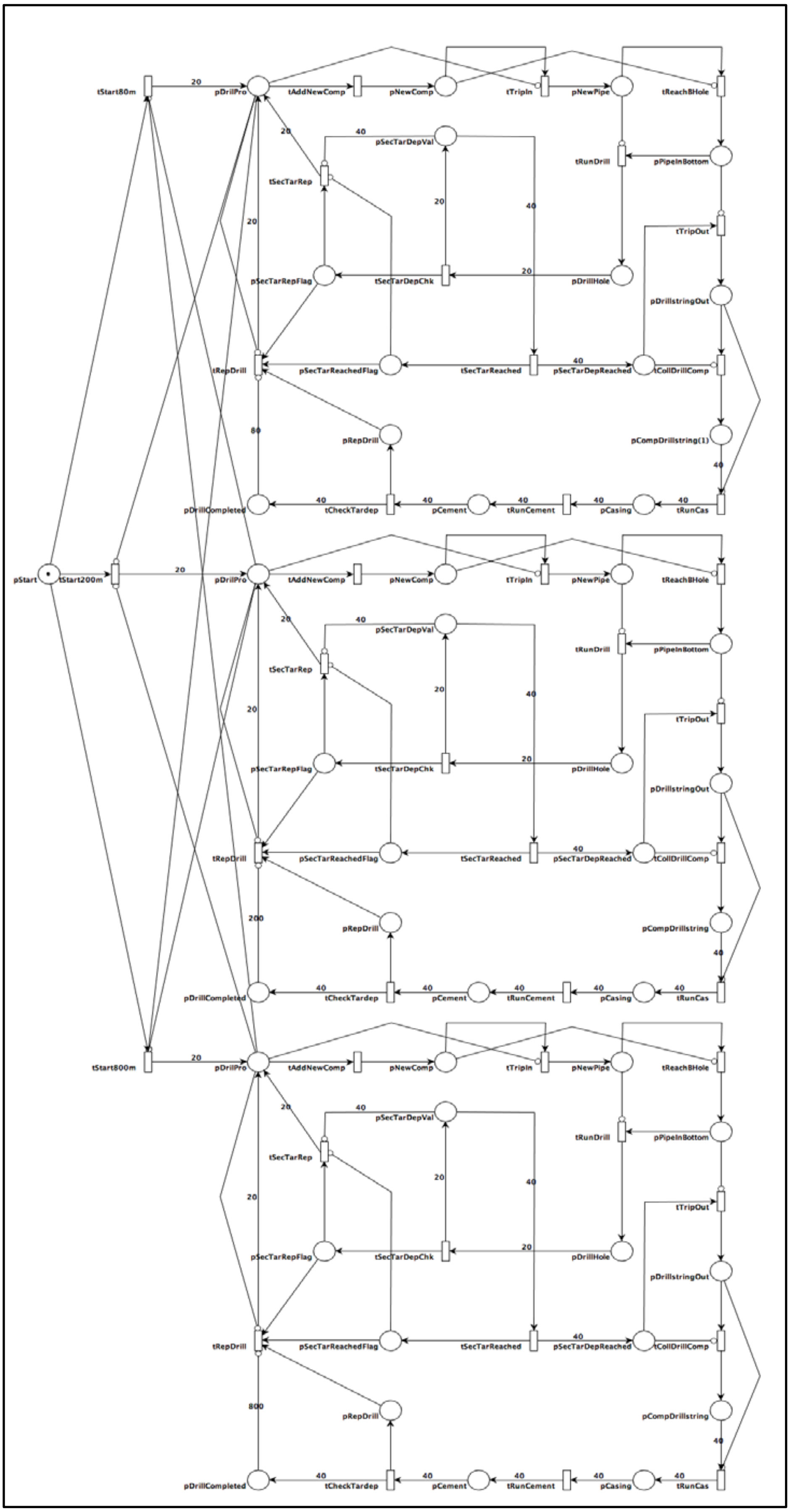


Figure 5-1: The complete Petri Net model of overall drilling activities

5.2 Petri Net model of drilling 80 m final target depth

The main block diagram is breaking down so the figure is clear to understand. The process starts with 1 token in pStart indicating the start of the process. When 'tStart80m' event or action is triggered it generate 20 tokens to start the overall drilling of 80 m targeted depth value.

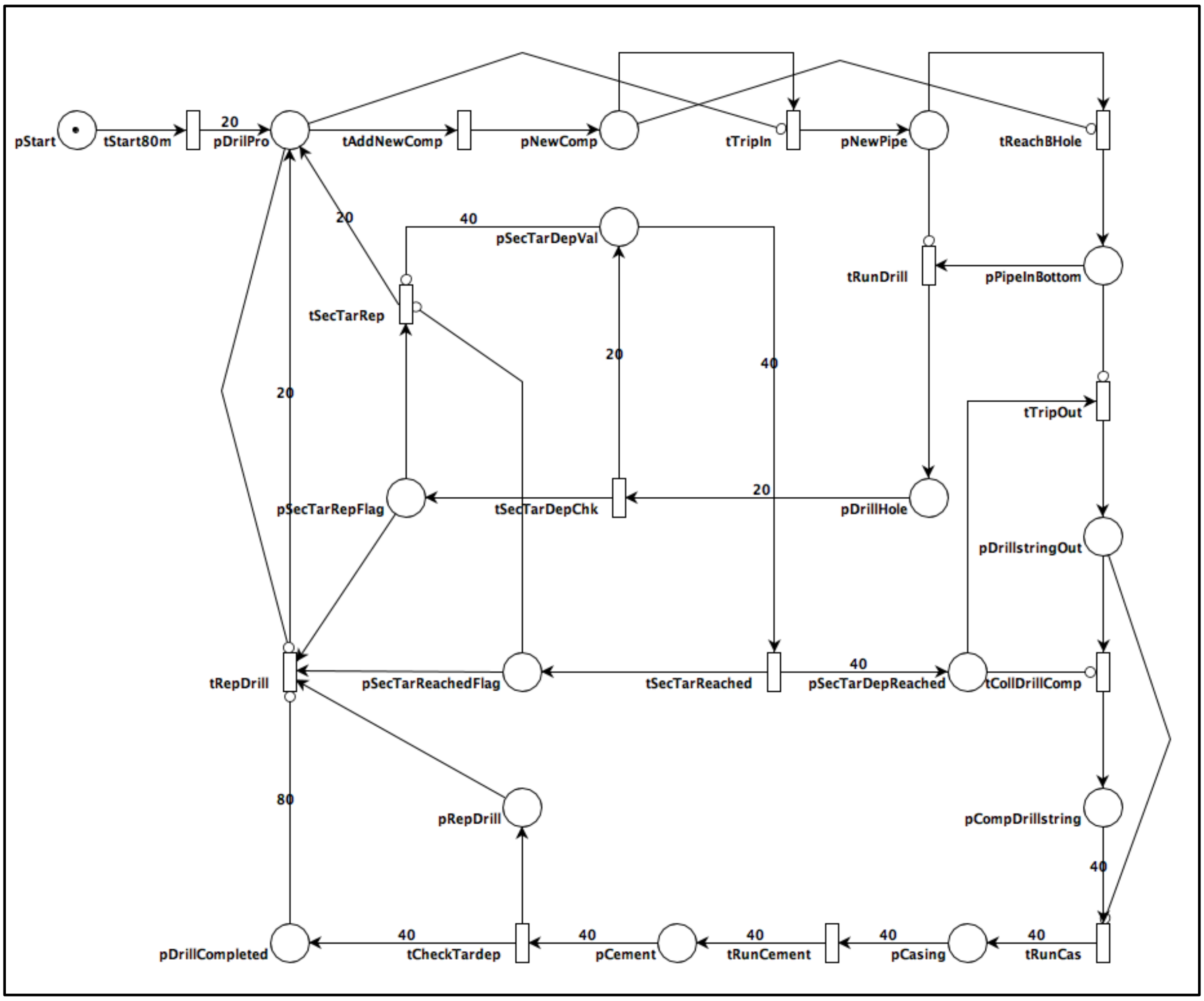


Figure 5-2: Petri Net model of drilling 80 m final target depth

Work details of individual drilling place

The table 5-1 below shows, the explanation of work details of each drilling place.

Places	Designated work
pStart	Holds single token to start drilling
pDrillPro	Holds tokens to begin driller chosen target depth drilling
pNewComp	Holds tokens indicating addition of drill components
PNewPipe	Holds tokens indicating pipe is tripping in the well
pPipeInBottom	Holds tokens indicating the pipe is in the process of reaching to the bottom of the hole
pDrillHole	Holds tokens indicating the drilling process is running
pSecTarDepval	Holds tokens indicating the section target depth value
pSecTarRepFlag	Holds token indicating the flag value to repeat the drilling
pSecTarReachedFlag	Holds single token indicating the section target depth value is reached
pSecTarDepReached	Holds tokens indicating section target depth value is reached
pDrillstingOut	Holds tokens indicating drill string is tripping out
pCompDrillstring	Holds token indicating drill components is being collected
pCasing	Holds token indicating run casing
pCement	Holds token indicating run cementing
pRepDrill	Holds single token indicating a repeat of the drilling process
pDrillCompleted	Holds tokens indicating depth value. The value equal to the targeted depth value indicates drilling process is completed

Table 5-1: Work details of individual drilling place

Work details of individual drilling transition

The table 5-2 below shows, the explanation of work details of each drilling transition.

Transitions	Designated work
tStart80m	Fires token from ‘pStart’ to ‘pDrillPro’ to begin 80 m drilling activities
tAddNewComp	Fires token from ‘pDrillPro’ to ‘PNewComp’ represents the addition of new components (drill pipes) to the drill string
tTripIn	Fires token from ‘pNewComp’ to pNewPipe represents drill string is tripping in the well
tReachBHole	Fires token from pNewPipe to ‘pPipeInBottom’ represents the tripped in pipe is trying to reach the bottom of the hole
tRunDrill	Fires token from ‘pPipeInBottom’ to ‘pDrillHole’ represents the drilling is progressing to reach the section target depth value
tSecTarDepChk	Fires token from ‘pDrillHole’ to ‘pSecTarRepFlag’ and ‘pSecTarDepVal’ represents checking the section target value
tSecTarRep	Fires token from ‘pSecTarRepFlag’ to ‘pDrillPro’ represents repeating the further drilling process
tsecTarReached	Fires tokens from ‘pSecTarDepVal’ to ‘pSecTarDepReached’ represents target depth value is reached
tTripOut	Fires token from ‘pSecTarDepReached’ to ‘pDrillstringOut’ represent the drill string are tripping out
tCollDrillComp	Fires token from ‘pDrillstringOut’ to ‘pCompDrillstring’ represent the drill components are being collected.
tRunCas	Fires tokens from ‘pCompDrillstring’ to ‘pCasing’ represents the casing activities
tRunCement	Fires tokens from ‘pCasing’ to ‘pCement’ represents the running cementing activities
tCheckTardep	Fires tokens from pCement to ‘pDrillCompleted’ and ‘pRepDrill’ represents checking of target depth value is obtained or not.

tRepDrill	Fires token from ‘pDrillCompleted’ to ‘pDrillPro’ to continue another round of drilling process.

Table 5-2: Work details of individual drilling transition

The drilling activities composed of different drilling components and action involved together to work with the different components. Each of the components and its working principle in this design is discussed below in details.

5.2.1 Petri Net model of adding new components

In this model, the standard drill pipe is 10 m long and 1 drill stand has 2 drill pipes. The place ‘pDrillPro’ has 20 tokens initialized in the beginning. So, the transition ‘tAddNewComp’ add the drill pipe of 20 tokens indicating equal to 1 drill stand. Tripping in, action will not trigger unless and until adding drill components job is not completed.

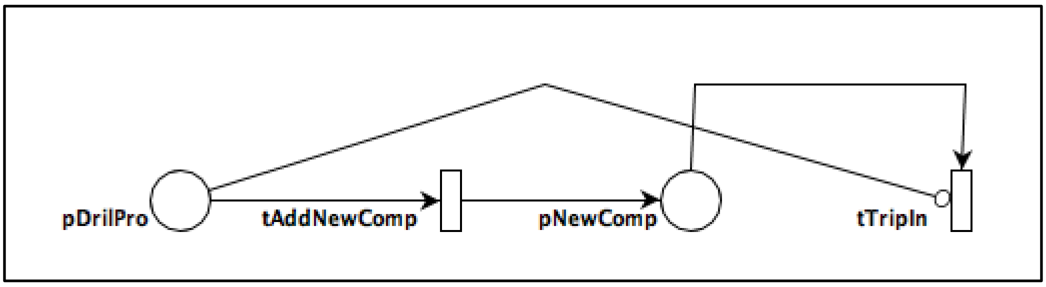


Figure 5-3: Petri Net model of adding new components

5.2.2 Petri Net model of tripping in new pipe

After adding 1 drill stand tripping in event get activated. When drill components are finished adding there begins the tripping in action. At first, the drill pipe of 10 m length starts trip in and when the job completed second drill pipe trip in begins. The tripping in process continues unless and unless it reaches to the bottom of the hole.

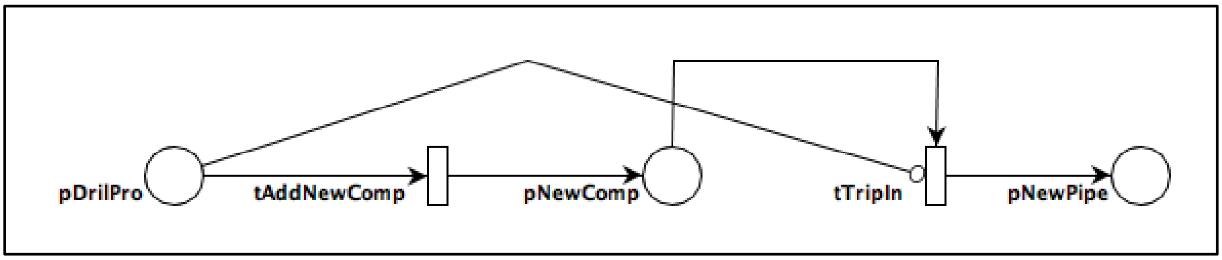


Figure 5-4: Petri Net model of tripping in new pipe

5.2.3 Petri Net model of reaching pipe to bottom of the hole

Once completing tripping in, it is mandatory to confirm that the pipe reached to the bottom of the hole or not. Before checking the pipe reach to bottom it is necessary that all the pipe is tripped in. This condition is confirmed from the Petri net model with the inhibitor arc from new components. Hence if all the pipe is tripped in i.e. ‘pPipeInBottom’ with 20 tokens indicate that the pipe reaches to the bottom of the hole.

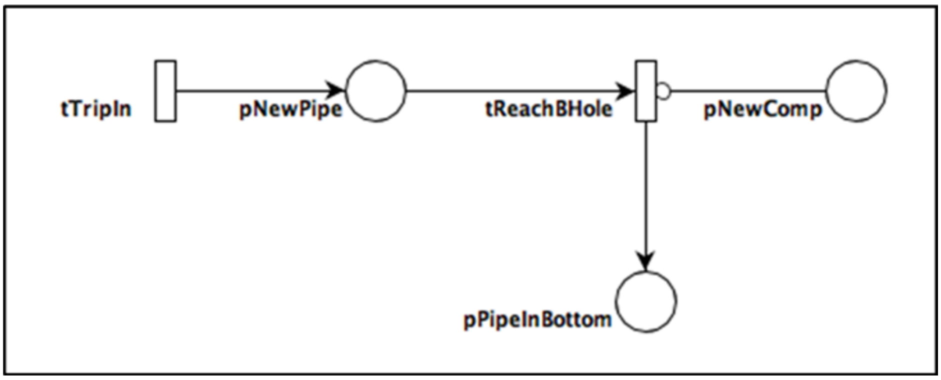


Figure 5-5: Petri Net model of reaching pipe to bottom of the hole

5.2.4 Petri Net model of drilling hole

When it is confirmed that, the pipe reaches to the bottom of the hole from the place ‘pPipeInBottom’ token information and also making sure that all the pipes are tripped in, the drilling process begins. The drilling continues equal to the length of the drill stand. When one drill stand is drilled next step is to check if it meets the section target depth or not. This is done in next step.

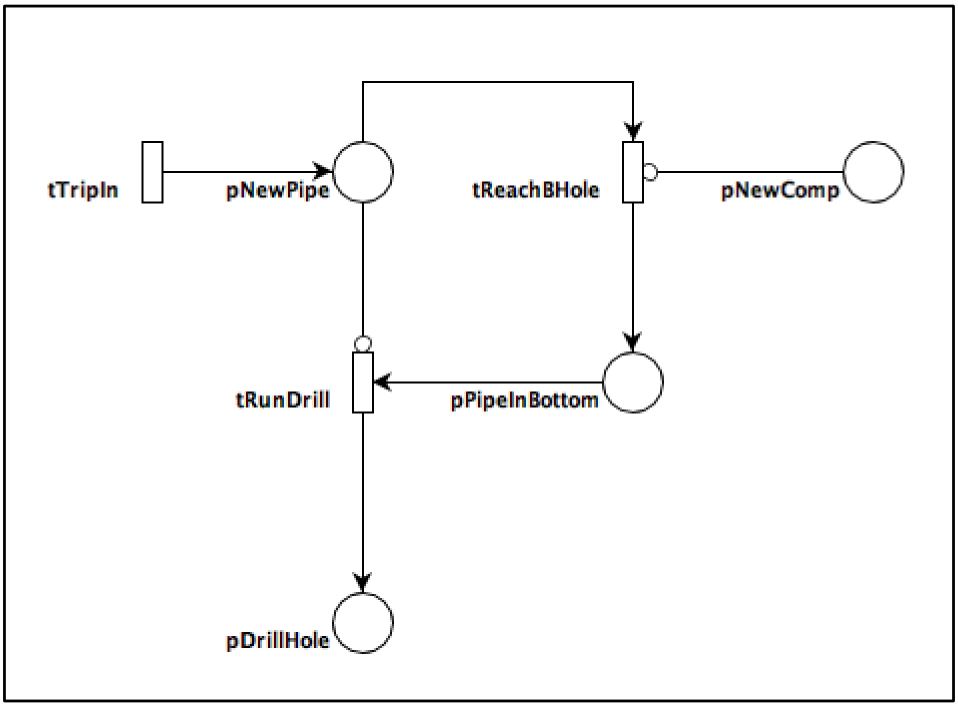


Figure 5-6: Petri Net model of drilling hole

5.2.5 Petri Net model of checking section target depth

In this model below, the section target depth is set to be 40 m in depth. When first-round drilling is finished, it drills equal to 20 m in depth so 'tSecTarDepChk' transition get fired and it sends 1 token to 'pSecTarRepFlag' and 20 tokens to 'pSecTarDepVal' place. So, the section target is not meet in this first round. So 'pSecTarReachedFlag' do not contain token means it indicates no section target meet. There is token in 'pSecTarRepFlag', it indicates to repeat the drill again and 'pSecTarDepVal' is not equal to 40. So, all these three conditions clearly agree to repeat the drilling process again. So, 'pDrillPro' has 20 tokens so the drill repeats.

In the second round, the drilling process repeats from the beginning with adding new components until drilling the hole. Again, check the section target depth value. This time 'pSecTarDepVal' is equal to 40 so the drill repeat condition fails so it continues forward to the 'tSecTarReached' transition indicating that the section target depth value is reached.

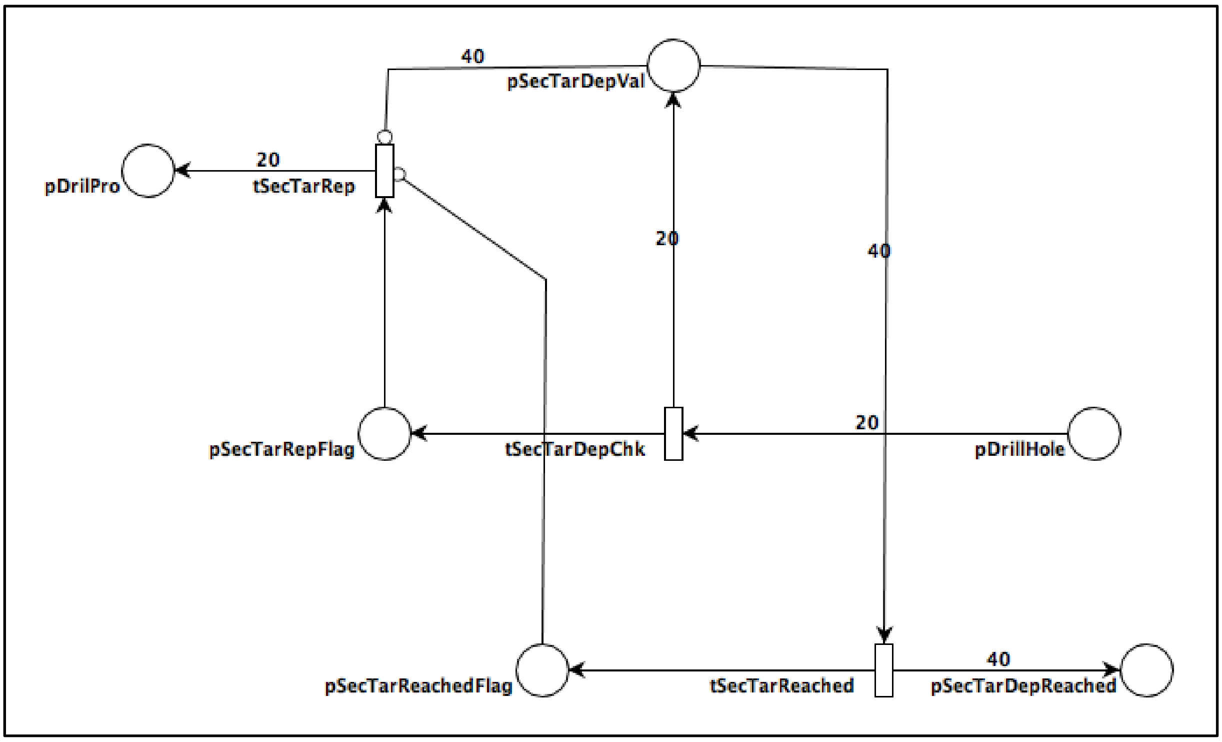


Figure 5-7: Petri Net model of checking section target depth

5.2.6 Petri Net model of tripping out drill string

It is checked when 'pSecTarDepReached' place reaches equal to 40 tokens and pPipeInBottom' do not have any tokens indicates it reaches to the bottom of the hole and reaches section target depth as well so the tripping out the drill string continues. Here it is necessary to trip out all which is equivalent to 2 drill stands.

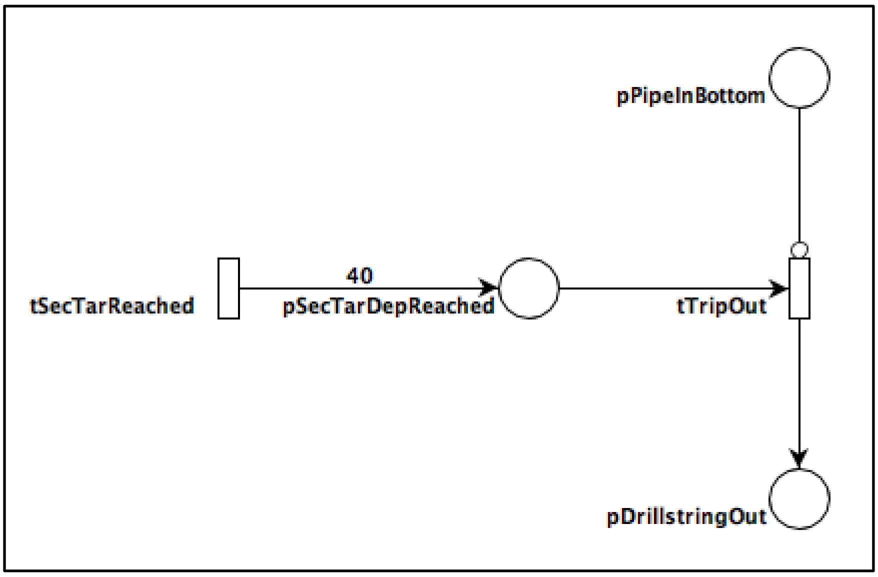


Figure 5-8: Petri Net model of tripping out drill string

5.2.7 Petri Net model of collecting drill components

This is the Petri net model to collect the drill components. There is no token in place ‘pSecTarDepReached’ and place ‘pDrillstringOut’ indicates that the all the components are trip out so next step is to collect all the components. ‘pCompDrillstring’ with token shows the drill components are collecting. When the tokens are equal to 40 it indicates all the drill components are collected.

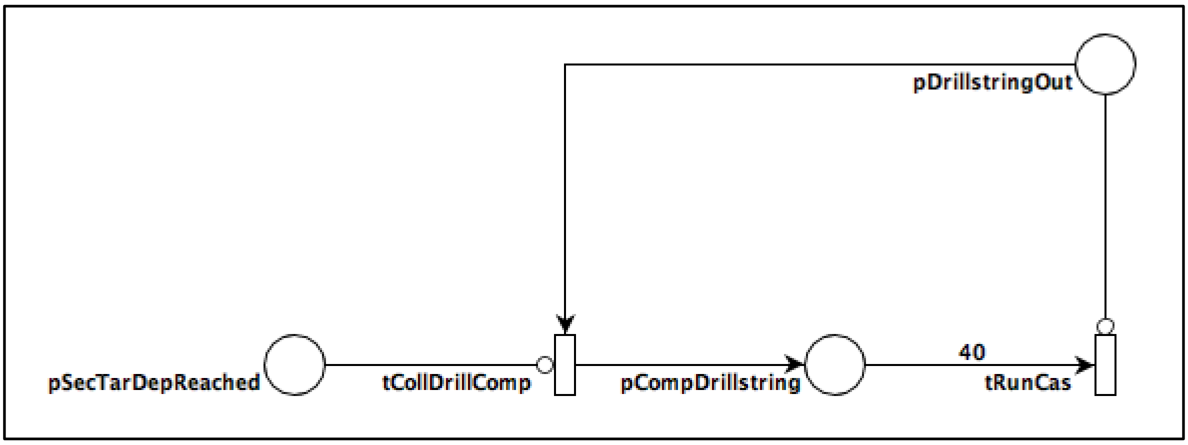


Figure 5-9: Petri Net model of collecting drill components

5.2.8 Petri Net model of running casing and cementing

This is the Petri net model for running casing and cementing. In this study, we and not focusing in detail about casing and cementing. Hence, showing the actions with places and transition simply executing casing and cementing activities.

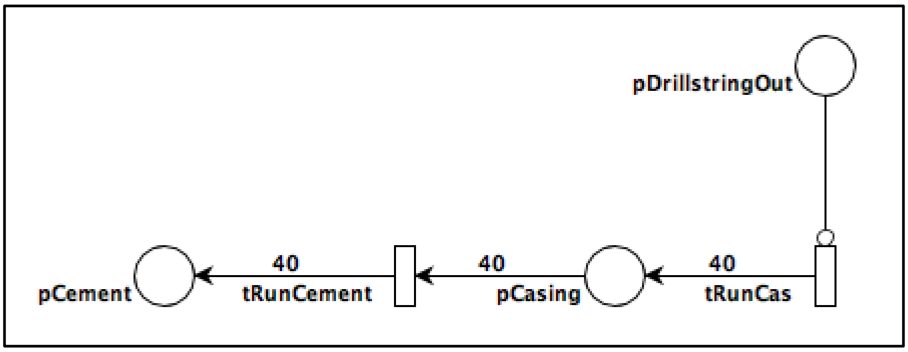


Figure 5-10: Petri Net model of running casing and cementing

5.2.9 Petri Net model of checking final target depth

This is the Petri net model for checking final target depth value. In the beginning, when started drilling the target depth value is set. Here, in this case, 80 m is the final target value. The transition 'tCheckTardep' gives 40 tokens to place 'pDrillCompleted' and in the meantime 1 token in place pRepDrill. In the first drill round transition, tRepDrill is enabled satisfying all the 4 conditions. First, place 'pDrillCompleted' do not have enough tokens to indicate the drilling have completed. Second, place 'pRepDrill' has 1 token. Third, place 'pSecTarReachedFlag' also have 1 token as this place get this token when section target is met. Fourth, 'pSecTarRepFlag' also have 1 token when transition 'tSecTarDepChk' is triggered. If the section target gets repeated there is no token but as it already reaches the section target depth there remain 1 token. In this way, all the four condition satisfies and the drilling process repeats from the beginning and it puts in place 'pDrilPro' 20 tokens.

The second round of drill continues with adding new components, tripping in, reach the bottom of the hole, drilling hole etc. Again, it checks for section target depth. It repeats until section target depth is reached and when condition satisfied indicating section target is reached. The rest of the activities tripping out, a collection of drill components, casing, cementing continues. Now, it comes to check the final target depth. The place 'pDrillCompeted' already have 40 tokens and in this drill round additional 40 tokens are added so total it reached 80 tokens. This indicates that 80 m depth is drilled which indicates drilling is completed for this particular target depth value.

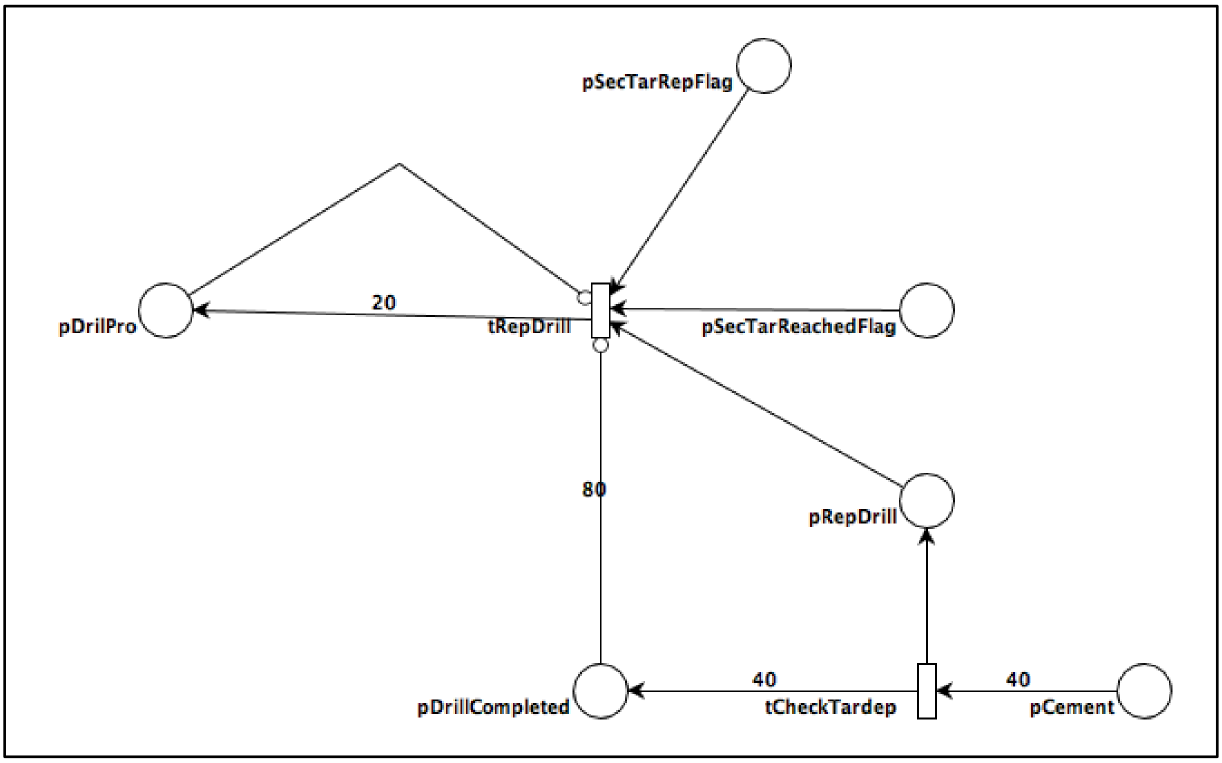


Figure 5-11: Petri Net model of checking final target depth

As discussed in chapter 3 GPenSIM has its own file format standards including Main Simulation File (MSF), Petri Net Definition Files (PDFs) and Transition Definition Files (TDFs). Hence, this chapter also deals with these files structure to show how oil drilling activities are implemented in GPenSIM model.

5.3 |Petri Net Definition Files (PDFs) for this model

In this implementation, Petri Net model is defined in Petri Net Definition File (PDFs). The PDFs file has information of places, transitions and arcs. The arc connects places to transitions and vice versa. So, in the beginning, it is necessary to recognize all the places, transitions along with their connecting arcs and its value from the Petri Net model (graph). Then, this information is supplied in the PDF file with its corresponding values.

In Petri Net Definition file as shown below, the set of all the places used in the model is stored in ‘pns.set_of_Ps’, the set of all the transitions used in the model is stored in ‘pns.set_of_Ts’, and the arc information between places to transitions and from transitions to places is stored in ‘pns.set_of_As’. Finally, the inhibitor link information from places to transitions is stored in ‘pns.set_of_Is. Hence, it is easy to say that the complete information of Petri Net model is supplied in Petri Net Definition File to simulate the model.

```
function [pns] = drill_pdf()
pns.PN_name = 'Oil Drilling Simulation';
pns.set_of_Ps = {'pStart', 'pDrillPro', 'pNewComp', 'pNewPipe', ...
    'pPipeInBottom', 'pDrillHole', 'pSecTarDepVal', 'pSecTarRepFlag', ...
    'pSecTarReachedFlag', 'pSecTarDepReached', 'pDrillstringOut', ....
    'pCompDrillstring', 'pCasing', 'pCement', 'pRepDrill', ...
    'pDrillCompleted'};

pns.set_of_Ts = {'tStart80m', 'tAddNewComp', 'tTripIn', 'tReachBHole', ...
    'tRunDrill', 'tSecTarDepChk', 'tSecTarRep', 'tSecTarReached', ...
    'tTripOut', 'tCollDrillComp', 'tRunCas', 'tRunCement', ...
    'tCheckTarDep', 'tRepDrill'};

pns.set_of_As = {'pStart','tStart80m',1, 'tStart80m','pDrillPro',20, ...
    'pDrillPro','tAddNewComp',1, 'tAddNewComp','pNewComp',1, ...
    'pNewComp','tTripIn',1, 'tTripIn','pNewPipe',1, ...
    'pNewPipe','tReachBHole',1, 'tReachBHole','pPipeInBottom',1, ...
    'pPipeInBottom','tRunDrill',1, 'tRunDrill','pDrillHole', 1, ...
    'pDrillHole','tSecTarDepChk', 20, 'tSecTarDepChk','pSecTarDepVal',20, ...
    'tSecTarDepChk','pSecTarRepFlag',1, 'pSecTarRepFlag','tSecTarRep',1, ...
    'tSecTarRep','pDrillPro',20, 'pSecTarDepVal','tSecTarReached',40, ...
    'tSecTarReached','pSecTarReachedFlag',1, ...
    'tSecTarReached','pSecTarDepReached',40, 'pSecTarDepReached','tTripOut',1, ...
    'tTripOut','pDrillstringOut',1, 'pDrillstringOut','tCollDrillComp',1, ...
    'tCollDrillComp','pCompDrillstring',1, 'pCompDrillstring','tRunCas',40, ...
    'tRunCas','pCasing',40, 'pCasing','tRunCement',40, ...
    'tRunCement','pCement',40, 'pCement','tCheckTarDep',40, ...
    'tCheckTarDep','pDrillCompleted',40, 'tCheckTarDep','pRepDrill',1, ...
    'pRepDrill','tRepDrill',1, 'pSecTarRepFlag','tRepDrill',1, ...
    'pSecTarReachedFlag','tRepDrill',1, 'tRepDrill','pDrillPro',20};

pns.set_of_Is = {'pDrillPro','tTripIn',1, 'pNewComp','tReachBHole',1, ...
    'pNewPipe','tRunDrill',1, 'pSecTarDepVal','tSecTarRep',40, ...
    'pSecTarDepReached','tSecTarRep',1,'pSecTarReachedFlag','tSecTarRep',1, ...
    'pSecTarDepReached','tCollDrillComp',1, ...
    'pDrillstringOut','tRunCas',1, 'pDrillCompleted','tRepDrill',80, ...
    'pDrillPro','tRepDrill',1};
```

The code sample as seen above is the Petri Net model of drilling 80 m target depth value. Similarly Petri Net model for drilling 200 m and 800 m target depth can be defined in a similar format.

5.4 Transition Definition File (TDFs) for this model

In this implementation, there require a Transition Definition Files as this implementation has the additional conditions before firing any transition also has additional conditions after firing any transition. Here defined COMMON_PRE to include all the conditions before firing the transition. COMMON_POST to include all the conditions to check after firing the transition.

The code shown below is an example of checking condition before adding new components. That is performed by action with transition ‘tAddNewComp’.

```
case 'tAddNewComp'

            currentTime = global_info.NEW_TIME;
            for l = 1:global_info.tAddNewComp_Settime
                global_info.NEW_TIME =  global_info.NEW_TIME + 1;
                if eq( global_info.NEW_TIME,86400)
                    global_info.NEW_DATE = addtodate(global_info.NEW_DATE,+...
                        1, 'day');
                    global_info.NEW_TIME = 0;
                    global_info.TOTAL_DAYS = global_info.TOTAL_DAYS + 1;
                end
            end


            if ( currentTime ~= global_info.NEW_TIME)
                fire = 1;
                global_info.tAddNewComp_TotalTime =
global_info.tAddNewComp_TotalTime + ...
                global_info.tAddNewComp_Settime;
            end
```

This implementation calculates the time taken for each component and also the overall time taken to complete the simulation. So before firing the transition 'tAddNewComp' it calculates the time taken to perform this action. If the time taken is more than 24 hours then the calculated time value should be in days and hour's format. So, every time if it performs some action related to adding components obviously it takes some time to perform this action. So, it will compare the current time with the newly calculated time values. If there seen a time difference then the transition is fired considering some effective activities is performed in drilling activities. Hence, in this case, the 'tAddNewComp' transition is triggered.

The transition is fired then it checks in COMMON_POST file to execute the necessary conditions if applicable. For example, in the same example after performing the action of adding components there are post conditions to execute. The following code below shows the example of post conditions implemented in this simulation.

```
case 'tAddNewComp'

          pToken1 = get_place('pNewComp');
          pToken2 = get_place('pDrillPro');
```

```
          if eq(pToken1.tokens,1)

disp('##############################################################################
######')
              disp(['----------------Drill Round: ',
```

```
num2str(global_info.DRILL_ROUND),    ',   Drill Section Depth Round: ',
 num2str(global_info.DRILL_SECTION_ROUND),'----------------']);

disp('#############################################################################
######')

              disp('-----------------------------------------------------------------
--------------------')
              disp([datestr(global_info.NEW_DATE),'   ', ...
                  num2str(string_HH_MM_SS(global_info.NEW_TIME)), ...
                  ' : ***** New Components are adding to the drill string *****']);
          end

          if ge(pToken1.tokens, 2) && le(pToken1.tokens, 19) && (pToken2.tokens ~=
0)
              if eq(pToken1.tokens, 2)
                  disp([datestr(global_info.NEW_DATE),'   ', ...
                      num2str(string_HH_MM_SS(global_info.NEW_TIME)), ...

                      ' : Progressing ....']);
              elseif eq(pToken1.tokens, 3)
                  disp([datestr(global_info.NEW_DATE),'   ', ...

                     num2str(string_HH_MM_SS(global_info.NEW_TIME)), ...
                      ' : Progressing ......']);
              elseif eq(pToken1.tokens, 4)

                  disp([datestr(global_info.NEW_DATE),'   ', ...

                      num2str(string_HH_MM_SS(global_info.NEW_TIME)), ...
                      ' : Progressing ........']);
```

The actions of adding components continue unless it is finished. The percentage of task completed shown with ‘progressing’ bar with dots indicating the percentage of task completed. The progressing bar is continuously popping indicating the progress of work. It checks the token value and identifies how much percentage of actions of adding components is completed. With this information of how much task completed it shows the increment of progressing bar. The progressing bar continues to increase unless the job is done. Once the adding component task is done. The post actions display the information that the adding component is finished.

The code below shows the adding component is completed and the information is written in a file named ‘AddComp.txt’. The information of Drill Round, Drill Section Round, Total Days and Total Hours taken to complete the action of adding a component in each Drill Round is written in this file. To convert second values to hours minutes and seconds the function sec2hms() [33] is used.

```
if eq(pToken2.tokens,0)
              disp([datestr(global_info.NEW_DATE),'   ', ...
                  num2str(string_HH_MM_SS(global_info.NEW_TIME)), ...
                  ' : ***** Finished adding new Components *****']);
              disp('-----------------------------------------------------------------
--------------------')

              global_info.tAddNewComp_TotalDays =
floor(global_info.tAddNewComp_TotalTime/86400);
              timeInSec = mod(global_info.tAddNewComp_TotalTime,86400);
              global_info.tAddNewComp_TotalHour = sec2hms(timeInSec);

             fid = fopen('AddComp.txt','a+');
             fprintf(fid, '%s\n%s\n%s\n%s\n', int2str(global_info.DRILL_ROUND), ...
               int2str(global_info.DRILL_SECTION_ROUND),...
               int2str(global_info.tAddNewComp_TotalDays),
global_info.tAddNewComp_TotalHour);

             fclose(fid);
          end
```

To print the summary report for the user, separate function 'printdrillsummary' is created which print the summary report of actions performed by each transition. This summary report provided at the end makes this simulation program more user-friendly.

5.5 Main Simulation File (MSF) for this model

In this model, MSF is the main simulation file. The necessary global variable which is being accessed by all of the files is defined in the beginning. The global variable can read by other files also can update if necessary. Some of the examples of a global variable defined are shown below,

```
global global_info
global_info.STOP_AT = 14000; % Run Simulation until 14000 times
global_info.NEW_DATE = 0; % Assign the date value to 0 initially
global_info.NEW_TIME = 0; % Assign time value to 0 initially
global_info.DRILL_ROUND = 1; % Assign drill round to start from 1
global_info.DRILL_SECTION_ROUND = 1; % Assign drill section round to start from 1
global_info.TOTAL_DAYS = 0; %Assign day value to 0 initially
```

Drill round starts with the initial value 1 if the more drill round is needed to reach the final target depth its value is incremented by 1 in each round unless the final target depth is obtained. Similarly, Drill section round also starts with initial value 1 when the target is not meet this value is increment by 1 in each round unless the section target value is obtained.

There is a provision given to the driller or any end user to select one of the final target depth value among the available options. The simulation program will execute according to the value chosen by the user. So, it is a nice feature as it is flexible to many depth values according to one's requirement. Currently, in this implementation, it displays three target depth values but it is possible to make it work for any target depth values.

There created a separate initialization file and it is defined in the MSF file to initialize value in the beginning. In the initialization file, time is set for each unit action of all the transitions. The data of time information is taken from [32]. For example, the code below shows the time set for some of the actions.

```
global_info.tAddNewComp_Settime = 1674; %sec
global_info.tTripIn_Settime = 540
```

In this file, each action total time, days and hours initial value is set to zero. For example, the code below shown the values initialize to zero initially for adding new component and tripping in new pipe values.

```
global_info.tAddNewComp_TotalTime = 0;
global_info.tAddNewComp_Days = 0;
global_info.tAddNewComp_Hours = 0;
global_info.tTripIn_TotalTime = 0;
global_info.tTripIn_Days = 0;
global_info.tTripIn_Hours = 0;
```

This simulation program asks the user to specify any one of the available target depth value. When the target depth value is specified by the user then the program starts working for the same given target value . The PDF file that created earlier for defining Petri Net model is the input parameter of a pstruct function of this file as shown in below code. In this simulation program here defined three PDF files for three different targets value so according to the specified target depth the program selects correct PDF file for processing.

```
%Provide the target depth value to run the simulation
global_info.t1 = input('Enter the target depth  : 80 m, 200 m or 800 m :');

if eq(global_info.t1, 80)||eq(global_info.t1, 200)||eq(global_info.t1, 800)

%Initialize the unit time for each action to work for component
    initialize()

    if eq(global_info.t1, 80)
        pns = pnstruct ('drill_pdf'); %Passing pdf file for 80m drill
        global_info.STOP_AT = 12000;


    elseif eq(global_info.t1, 200)
```

```
        pns = pnstruct ('drill_pdf200'); %Passing pdf file for 200m drill
        global_info.STOP_AT = 25000;

    else
        pns = pnstruct ('drill_pdf800'); %Passing pdf file for 800m drill
        global_info.STOP_AT = 98000;
    end
```

Now, Initial marking (token) is assigned to different places. But in this implementation, the initial making is assigned in a single place ‘pStart’ only to start the simulation program. The initial markings are assigned with the help of packet named ‘dyn’. There are many dynamic tools that can be initialized with the help of this packet like firing time, transition priority etc.

In this implementation, the firing time is defined using packet ‘dyn’. If firing time is chosen based on the real time it will take many days to execute this simulation program. So, to make our simulation feasible the firing time is taken 20 for each component actions and 10 for each transition verifying various conditions.

The ‘dyn’ packet and Petri Net graph are given to the function named ‘initialdynamics’.

The code below shows the initialization of firing time for each transition.

```
dyn.ft = {'tStart80m', 10,'tAddNewComp', 20, 'tTripIn', 20, 'tReachBHole', 20,...
     'tRunDrill', 20, 'tSecTarDepChk', 10, 'tSecTarRep', 10, ...
     'tSecTarReached', 10, 'tTripOut', 10, 'tCollDrillComp', 20, 'tRunCas', 10, ...
     'tRunCement', 10, 'tCheckTarDep', 10, 'tRepDrill', 10};
```

The results are displayed in the command window and also in graphs. The command window traces the execution of each action beginning from adding new component until drilling is completed. It traces all the activities performed during the process along with the time taken for each process in date and time format. When the simulation completes, it gives a summary report. The summary report includes first, shows the overall summary of the whole activities. Second, shows each action summary details. Also, the results are displayed in graphs which will be much easier to understand the overall process as the graph express words in a form of a picture. The graphical representation makes the overall oil drilling activities easy to perceive. The graph plot is divided into 4 different figures so it is better to visualize the process and easy to draw the conclusions.

The simulation process is executed by the function ‘gpensim’. The parameter of ‘initialdynamics’ is supplied to the function ‘gpensim’. This function checks TDFs during runtime to check if any pre or post conditions are set when firing any transition.

The following code below shows the plot of the results in form of graphs after the simulation is completed.

```
figure(1),plotp(Sim_Results, { 'pNewComp', 'pNewPipe', 'pDrillHole'});
figure(2),plotp(Sim_Results, { 'pSecTarDepVal'});
figure(3),plotp(Sim_Results, { 'pDrillstringOut', 'pCompDrillstring'});
figure(4),plotp(Sim_Results, { 'pDrillCompleted'});
```

Here, figure 1 includes the activities related to adding new components, tripping in new pipe and hole drilling. This figure is related to all the activities that are carried out before section target verification process. Then drilling activities continue with checking the section target depth value. Figure 2, shows the plot of action of checking section target depth value. If the section target value is not meet the activities of figure 1 is repeated or else if already reached the section target the activities of figure 3 executes. The figures 3 shows the activities related to tripping out drill string and collecting the drill components. Finally, the figure 4 shows the activities accomplishing the final target depth values which conclude the drilling process is completed and simulation stops.

6. TEST AND RESULTS

The Petri Net model of oil drilling activities is implemented using GPenSIM in MATLAB environment. The results are shown in command window during execution of simulation program indicating the progress of every action later provide the overall summary after completion of the simulation program. The results are also displayed in figures with the function ‘plotp’. This MATLAB function plots the simulation results in figures for better visibility for the simulation results and to read the results quickly. The results are divided into 4 figures to make it clear so it is easy to understand the results.

6.1 Results of oil drilling simulation

This is the test performed for running simulation for 80 m target depth value. The result shown below is the result obtained from command window during execution of oil drilling simulation. So simply it can be said that the result shown below is the runtime result of this simulation.

6.1.1 Runtime Results

This is the result obtained from MATLAB command window while running simulation program, the program runs and at the same time, the execution details are printing in the command window. The results shown below are for, Drill Round 1 and Drill Section Round 1.

```
Enter the target depth  : 80 m, 200 m or 800 m :80
28-May-2018  00:00:00 : Driller selected target depth is: 80 m
###############################################################################
----------------Drill Round: 1,   Drill Section Depth Round: 1---------------
###############################################################################
----------------------------------------------------------------------------------
28-May-2018  00:27:54 : ***** New Components are adding to the drill string *****
28-May-2018  00:55:48 : Progressing ....
28-May-2018  01:23:42 : Progressing ......
28-May-2018  01:51:36 : Progressing ........
28-May-2018  02:19:30 : Progressing ..........
28-May-2018  02:47:24 : Progressing ............
28-May-2018  03:15:18 : Progressing ..............
28-May-2018  03:43:12 : Progressing ................
28-May-2018  04:11:06 : Progressing ..................
28-May-2018  04:39:00 : Progressing ....................
28-May-2018  05:06:54 : Progressing ......................
28-May-2018  05:34:48 : Progressing ........................
28-May-2018  06:02:42 : Progressing ..........................
28-May-2018  06:30:36 : Progressing ............................
28-May-2018  06:58:30 : Progressing ..............................
28-May-2018  07:26:24 : Progressing ................................
28-May-2018  07:54:18 : Progressing ..................................
```

28-May-2018 08:22:12 : Progressing ....
28-May-2018 08:50:06 : Progressing ....
28-May-2018 09:27:00 : ***** Finished adding new components *****

28-May-2018 09:27:00 : ***** New pipe1 started to trip in *****
28-May-2018 09:36:00 : Progressing ....
28-May-2018 09:45:00 : Progressing ......
28-May-2018 09:54:00 : Progressing ....
28-May-2018 10:03:00 : Progressing ....
28-May-2018 10:12:00 : Progressing ....
28-May-2018 10:21:00 : Progressing ....
28-May-2018 10:30:00 : Progressing ....
28-May-2018 10:39:00 : Progressing ....
28-May-2018 10:48:00 : ***** Finished tripping new pipe1 *****

28-May-2018 10:57:00 : ***** New pipe2 stated to trip in *****
28-May-2018 11:06:00 : Progressing ....
28-May-2018 11:15:00 : Progressing ......
28-May-2018 11:24:00 : Progressing ....
28-May-2018 11:33:00 : Progressing ....
28-May-2018 11:42:00 : Progressing ....
28-May-2018 11:51:00 : Progressing ....
28-May-2018 12:00:00 : Progressing ....
28-May-2018 12:09:00 : Progressing ....
28-May-2018 12:18:00 : ***** Finished tripping new pipe2 *****

28-May-2018 14:15:00 : ***** Drilling hole started *****
28-May-2018 16:12:00 : Progressing ....
28-May-2018 18:09:00 : Progressing ......
28-May-2018 20:06:00 : Progressing ....
28-May-2018 22:03:00 : Progressing ....
29-May-2018 00:00:00 : Progressing ....
29-May-2018 01:57:00 : Progressing ....
29-May-2018 03:54:00 : Progressing ....
29-May-2018 05:51:00 : Progressing ....
29-May-2018 07:48:00 : Progressing ....
29-May-2018 09:45:00 : Progressing ....
29-May-2018 11:42:00 : Progressing ....
29-May-2018 13:39:00 : Progressing ....
29-May-2018 15:36:00 : Progressing ....
29-May-2018 17:33:00 : Progressing ....

29-May-2018 19:30:00 : Progressing ....
29-May-2018 21:27:00 : Progressing ....
29-May-2018 23:24:00 : Progressing ....
30-May-2018 01:21:00 : Progressing ....
30-May-2018 03:18:00 : ***** Finished drilling hole *****

30-May-2018 03:18:10 : ***** Checking Section Target: 20 m depth drilled *****
30-May-2018 03:18:10 : Progressing ....

30-May-2018 03:18:20 : Section Target Round 2 started

##
----------------Drill Round: 1,   Drill Section Depth Round: 2---------------
##

In the result shown above Drill Round: 1, Drill Section Depth Round: 1 is completed and it confirms that the section target depth is not meet so it runs further with Drill Round: 1, Drill Section Depth Round: 2 and repeat the process from adding components until finished drilling. Again, it checks the section target value is meet or not. The execution report below shows the drill section value is obtained now.

01-Jun-2018 06:36:30 : ***** Checking Section Target: 40 m depth drilled *****

01-Jun-2018 06:37:20 : Section Target Depth Reached

The execution report shown above confirm this time section target depth value is reached. So it processes further action like tripping out drill string, collecting drill components, run casing and cementing and checking for final depth value. The execution report below shows the same.

01-Jun-2018 06:46:20 : ***** Pipe1 started to trip out *****
01-Jun-2018 06:55:20 : Progressing ....
01-Jun-2018 07:04:20 : Progressing ......
01-Jun-2018 07:13:20 : Progressing ....
01-Jun-2018 07:22:20 : Progressing ....
01-Jun-2018 07:31:20 : Progressing ....
01-Jun-2018 07:40:20 : Progressing ....
01-Jun-2018 07:49:20 : Progressing ....
01-Jun-2018 07:58:20 : Progressing ....
01-Jun-2018 08:07:20 : ***** Finished tripping out pipe1 *****

```
--------------------------------------------------------------------------------
01-Jun-2018  08:16:20 : ***** Pipe2 started to trip out *****
01-Jun-2018  08:25:20 : Progressing ....
01-Jun-2018  08:34:20 : Progressing ......
01-Jun-2018  08:43:20 : Progressing ........
01-Jun-2018  08:52:20 : Progressing ..........
01-Jun-2018  09:01:20 : Progressing ............
01-Jun-2018  09:10:20 : Progressing ..............
01-Jun-2018  09:19:20 : Progressing ................
01-Jun-2018  09:28:20 : Progressing ..................
01-Jun-2018  09:37:20 : ***** Finished tripping out pipe2 *****
--------------------------------------------------------------------------------
--------------------------------------------------------------------------------
01-Jun-2018  09:46:20 : ***** Pipe3 started to trip out *****
01-Jun-2018  09:55:20 : Progressing ....
01-Jun-2018  10:04:20 : Progressing ......
01-Jun-2018  10:13:20 : Progressing ........
01-Jun-2018  10:22:20 : Progressing ..........
01-Jun-2018  10:31:20 : Progressing ............
01-Jun-2018  10:40:20 : Progressing ..............
01-Jun-2018  10:49:20 : Progressing ................
01-Jun-2018  10:58:20 : Progressing ..................
01-Jun-2018  11:07:20 : ***** Finished tripping out pipe3 *****
--------------------------------------------------------------------------------
--------------------------------------------------------------------------------
01-Jun-2018  11:16:20 : ***** Pipe4 started to trip out *****
01-Jun-2018  11:25:20 : Progressing ....
01-Jun-2018  11:34:20 : Progressing ......
01-Jun-2018  11:43:20 : Progressing ........
01-Jun-2018  11:52:20 : Progressing ..........
01-Jun-2018  12:01:20 : Progressing ............
01-Jun-2018  12:10:20 : Progressing ..............
01-Jun-2018  12:19:20 : Progressing ..................
01-Jun-2018  12:28:20 : Progressing ......................
01-Jun-2018  13:05:14 : ***** Finished tripping out pipe4 *****
--------------------------------------------------------------------------------
--------------------------------------------------------------------------------
01-Jun-2018  13:05:14 : ***** Start collecting components *****
01-Jun-2018  13:33:08 : Progressing ..
01-Jun-2018  14:01:02 : Progressing ...
01-Jun-2018  14:28:56 : Progressing ....
01-Jun-2018  14:56:50 : Progressing .....
01-Jun-2018  15:24:44 : Progressing ......
01-Jun-2018  15:52:38 : Progressing .......
```

01-Jun-2018 16:20:32 : Progressing ....
01-Jun-2018 16:48:26 : Progressing ....
01-Jun-2018 17:16:20 : Progressing ....
01-Jun-2018 17:44:14 : Progressing ....
01-Jun-2018 18:12:08 : Progressing ....
01-Jun-2018 18:40:02 : Progressing ....
01-Jun-2018 19:07:56 : Progressing ....
01-Jun-2018 19:35:50 : Progressing ....
01-Jun-2018 20:03:44 : Progressing ....
01-Jun-2018 20:31:38 : Progressing ....
01-Jun-2018 20:59:32 : Progressing ....
01-Jun-2018 21:27:26 : Progressing ....
01-Jun-2018 21:55:20 : Progressing ....
01-Jun-2018 22:23:14 : Progressing ....
01-Jun-2018 22:51:08 : Progressing ....
01-Jun-2018 23:19:02 : Progressing ....
01-Jun-2018 23:46:56 : Progressing ....
02-Jun-2018 00:14:50 : Progressing ....
02-Jun-2018 00:42:44 : Progressing ....
02-Jun-2018 01:10:38 : Progressing ....
02-Jun-2018 01:38:32 : Progressing ....
02-Jun-2018 02:06:26 : Progressing ....
02-Jun-2018 02:34:20 : Progressing ....
02-Jun-2018 03:02:14 : Progressing ....
02-Jun-2018 03:30:08 : Progressing ....
02-Jun-2018 03:58:02 : Progressing ....
02-Jun-2018 04:25:56 : Progressing ....
02-Jun-2018 04:53:50 : Progressing ....
02-Jun-2018 05:21:44 : Progressing ....
02-Jun-2018 05:49:38 : Progressing ....
02-Jun-2018 06:17:32 : Progressing ....
02-Jun-2018 06:45:26 : Progressing ....
02-Jun-2018 07:13:20 : ***** Finished collecting drill components

----

02-Jun-2018 13:13:20 : ***** Running Casing *****

03-Jun-2018 20:25:20 : ***** Running Cementing *****

Drilling completed depth is: 40 m
Total drilled depth is: 40 m
Repeating drilling activities to reach final target depth

The total drilled depth is 40 m and still, the final target 80 m is not obtained. So, repeating the process again from the beginning to reach the targeted value. The execution report shown below shows the target depth value is reached so simulation is stopped.

```
--------------------------------------------------------------------------------
Drilling completed depth is: 80 m
Drilling completed with target depth: 80 m
--------------------------------------------------------------------------------
```

6.1.2 Summary Report

After the simulation is completed it provides drilling overall summary report and also the summary report of each component actions summary report as shown below,

```
-------------------------------Drilling Summary-----------------------------------
Total Time Taken: 13 Days and 16:50:40 HH:MM:SS
Total Drill Round taken: 2
Total Depth Drilled: 80 m

----------ADD NEW COMPONENTS SUMMARY----------
Drilling Round :1
Drilling Section Round :1
Days :0
HH:MM:SS :9 hours and 18 minutes
Drilling Round :1
Drilling Section Round :2
Days :0
HH:MM:SS :18 hours and 36 minutes
Drilling Round :2
Drilling Section Round :1
Days :1
HH:MM:SS :3 hours and 54 minutes
Drilling Round :2
Drilling Section Round :2
Days :1
HH:MM:SS :13 hours and 12 minutes

----------TRIPPING IN SUMMARY----------
Drilling Round :1
Drilling Section Round :1
Days :0
HH:MM:SS :3 hours
Drilling Round :1
Drilling Section Round :2
Days :0
```

HH:MM:SS :6 hours
Drilling Round :2
Drilling Section Round :1
Days :0
HH:MM:SS :9 hours
Drilling Round :2
Drilling Section Round :2
Days :0
HH:MM:SS :12 hours

----------DRILLING HOLE SUMMARY----------
Drilling Round :1
Drilling Section Round :1
Days :1
HH:MM:SS :15 hours
Drilling Round :1
Drilling Section Round :2
Days :3
HH:MM:SS :6 hours
Drilling Round :2
Drilling Section Round :1
Days :4
HH:MM:SS :21 hours
Drilling Round :2
Drilling Section Round :2
Days :6
HH:MM:SS :12 hours

----------TRIP OUT SUMMARY----------
Drilling Round :1
Drilling Section Round :2
Days :0
HH:MM:SS :6 hours
Drilling Round :2
Drilling Section Round :2
Days :0
HH:MM:SS :12 hours

----------COLLECT DRILL COMPONENTS SUMMARY----------
Drilling Round :1
Drilling Section Round :2
Days :0
HH:MM:SS :18 hours and 36 minutes
Drilling Round :2

Drilling Section Round :2
Days :1
HH:MM:SS :13 hours and 12 minutes

----------CASING SUMMARY----------
Drilling Round :1
Drilling Section Round :2
Days :0
HH:MM:SS :6 hours
Drilling Round :2
Drilling Section Round :2
Days :0
HH:MM:SS :12 hours

----------CEMENT SUMMARY----------
Drilling Round :1
Drilling Section Round :2
Days :1
HH:MM:SS :7 hours and 12 minutes
Drilling Round :2
Drilling Section Round :2
Days :2
HH:MM:SS :14 hours and 24 minutes

First, the summary report of overall simulation is given. In the overall summary report, the total time taken for the whole drilling process, total drill round and total depth drilled in this simulation is given. Then the summary of each action is provided. Let's take example of 'ADD NEW COMPONENT SUMMARY'. This summary report gives the information of each Drilling Round, Drilling Section Round , how much time taken in Days and HH:MM:SS format.

The report presented above shows that 80 m of drill is completed with total 2 drilling round each drill round having two drilling section round (four drilling section round) for each component. For example for adding new components to the drill string the total times taken in this process to complete the action is 13 hours and 12 minutes. In the same way rest of the components summary report is displayed above. The report shows, drilling 80 m depth the estimated time taken to reach the target depth is 13 days, 16 hours, 50 minutes and 40 seconds to complete the task.

6.1.3 Graphical Report

Finally, the results are displayed in graphical format and plotted token Vs time. Here the figure is divided into 4 different diagrams so it is better to visualized and grasp the overall scenario of the activity. The vertical axis shows the flow of token and horizontal axis represents time.

Graphical Report of drilling hole

The Figure 6-1 and Figure 6-2 below shows the graphical information of adding new components, tipping new pipe and drilling hole, drilling with the target depth of 80 m and 200 m respectively. The illustration shows that the flow of token representing different components action in unit time.

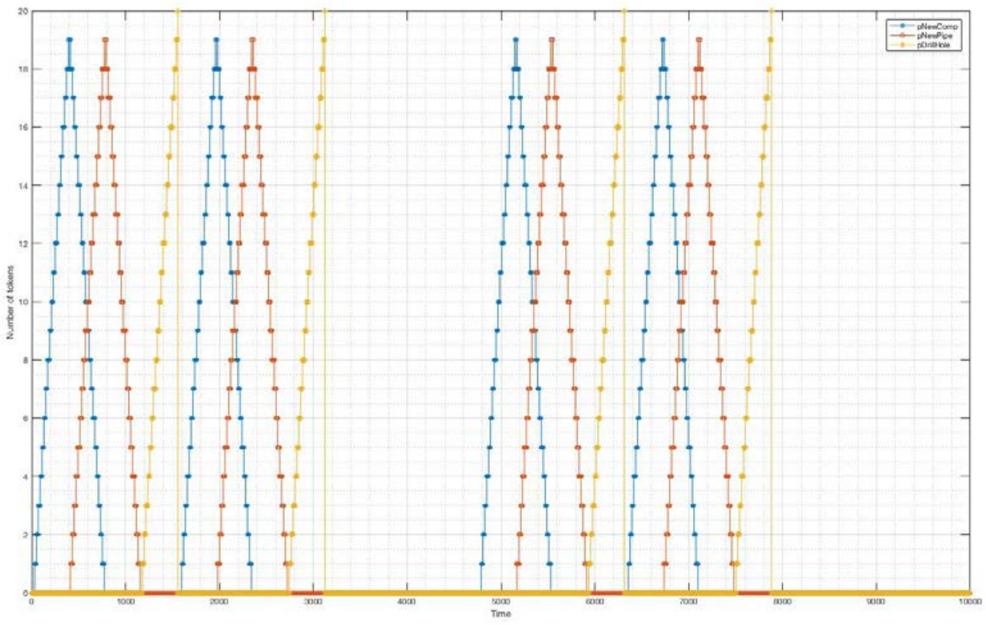


Figure 6-1: Output of drilling hole with target depth 80 m

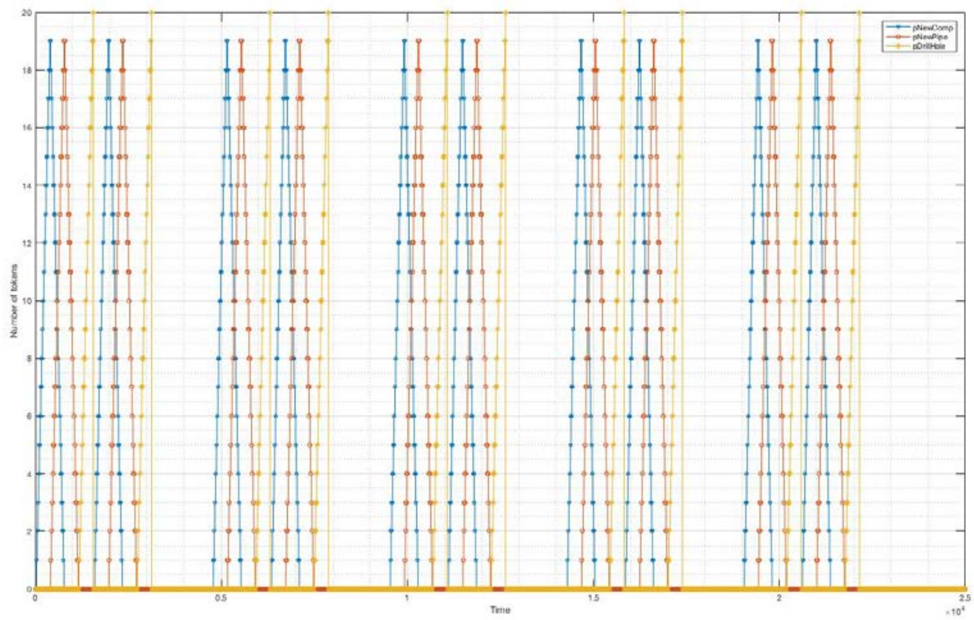


Figure 6-2: Output of drilling hole with target depth 200 m

Graphical Report of reaching section target depth

The Figure 6-3 and Figure 6-4 below shows checking section target depth in each drill round after drilling equivalent of one stand. In the first drill round, first drill section round the section target depth value is not meet with 20 tokens so it repeats the process and got 40 tokens to meet section target depth. After section target is reached the simulation proceeds further for other drilling activities like tripping out drill string, collecting drill components etc. So, this process repeated unless final target depth value is obtained.

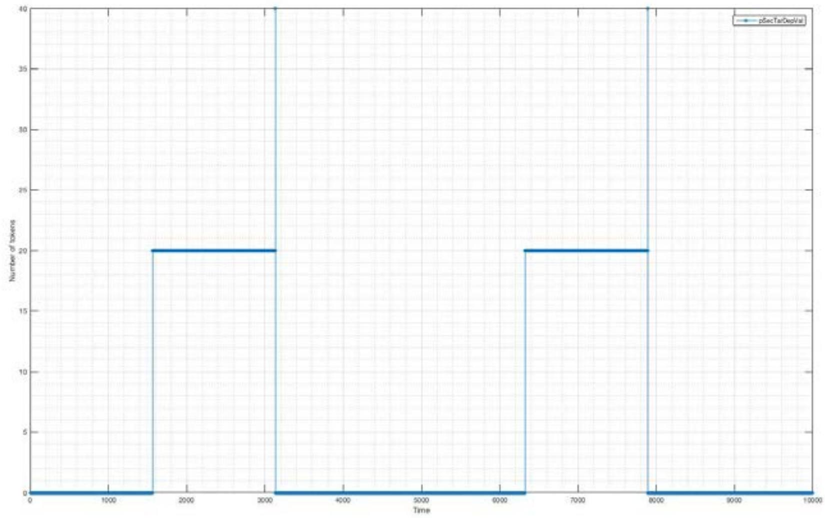


Figure 6-3: Output of reaching section target depth for 80 m drill

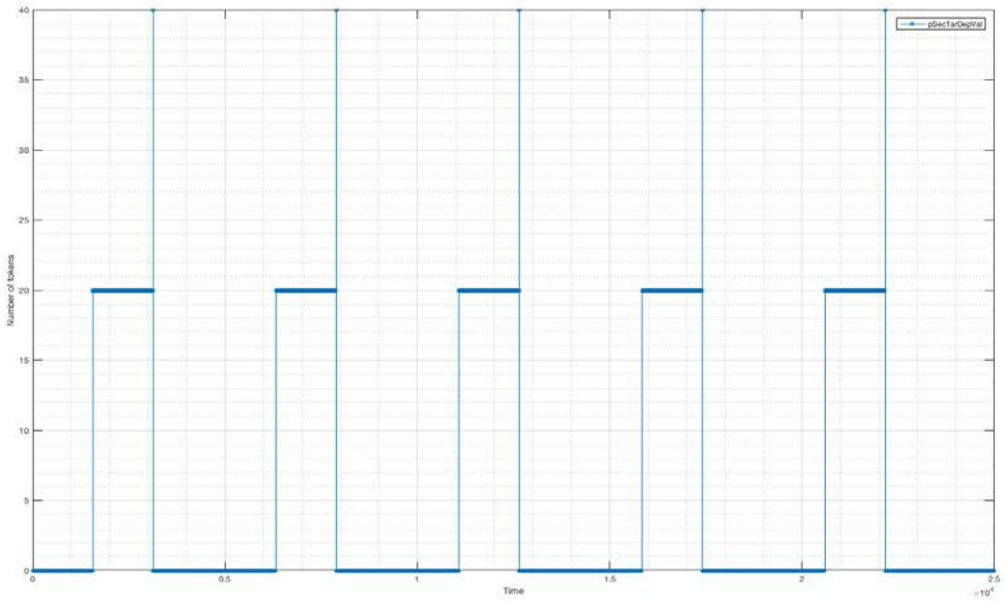


Figure 6-4: Output of reaching section target depth for 200 m drill

Graphical Report of tripping out and collecting drill components

The Figure 6-5 and Figure 6-6 shown below shows the activity of tripping out drill string and collecting the drill components of drilling 80 m and 200 m. It is seen clear from the figure that first tripping out is executed and then collection of drill components. Here showing 200 m drill is taking more drill rounds. If the target depth value is increased definitely more drill round and drill section round is needed to reach the target depth.

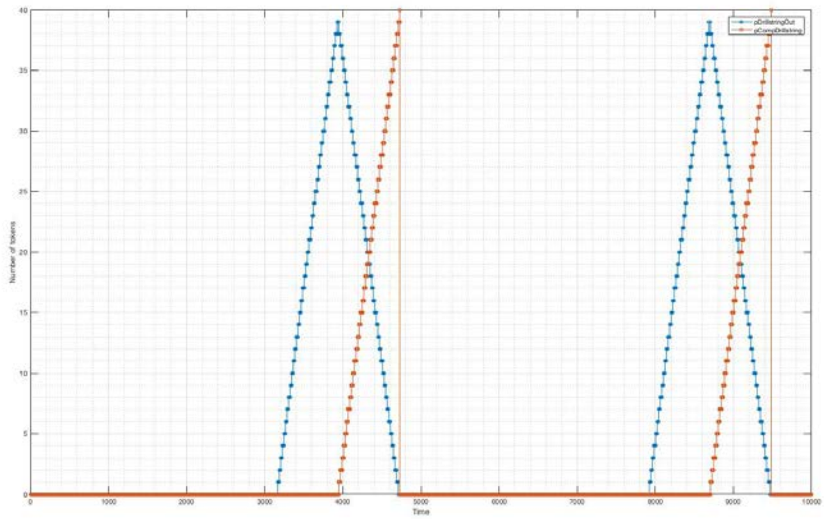


Figure 6-5: Output of tripping out and collecting drill components for 80 m drill

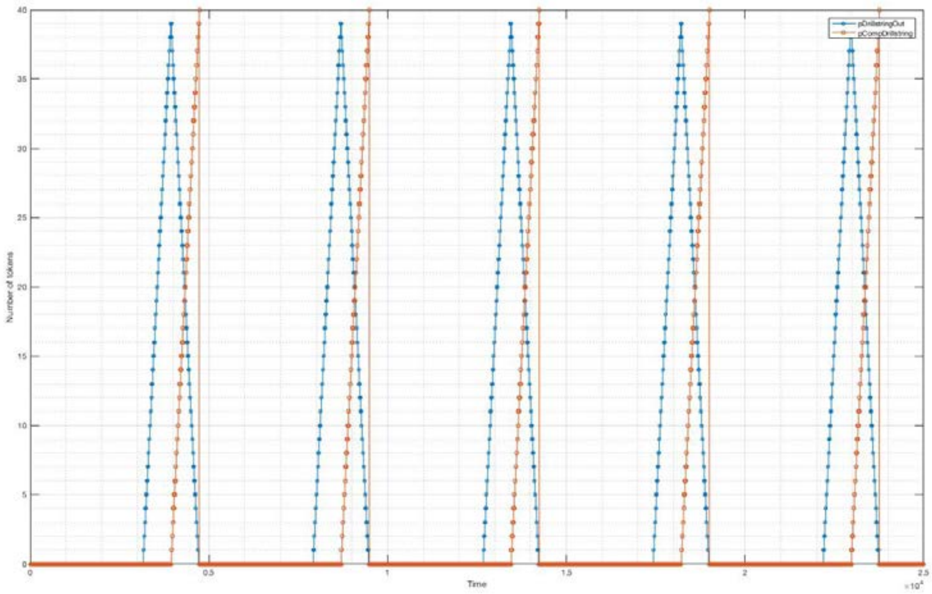


Figure 6-6: Output of tripping out and collecting drill components for 200 m drill

Graphical Report of reaching final target depth value

The Figure 6-7 and Figure 6-8 below shows the graphical activity graph reaching the final target depth value. It is clearly visible from the graph with stairs that 80 m target depth is reached with two drill rounds and 200 m in five drill rounds. In each drilling round drilling with 40 m depth and proceeding to reach the target depth. So, it is very easy to understand the overall drilling activities with the graphical results and helps to plan better for the real drilling activities.

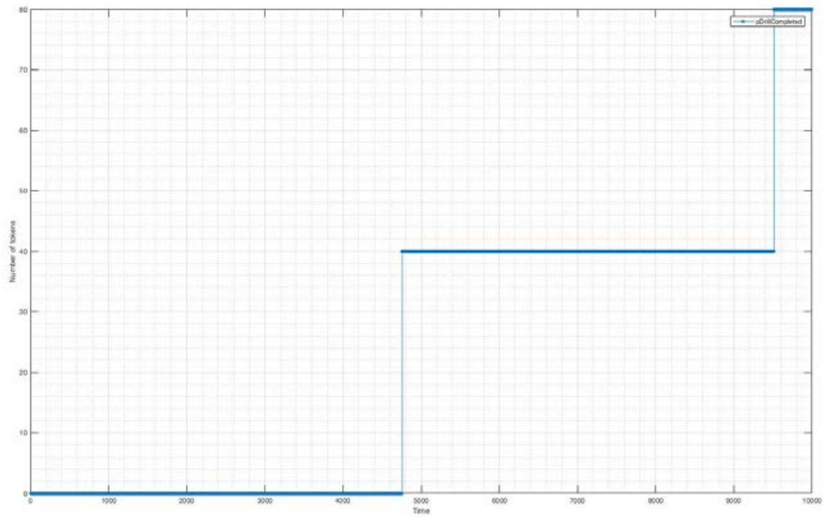


Figure 6-7: Output of reaching final target depth for 80 m drill

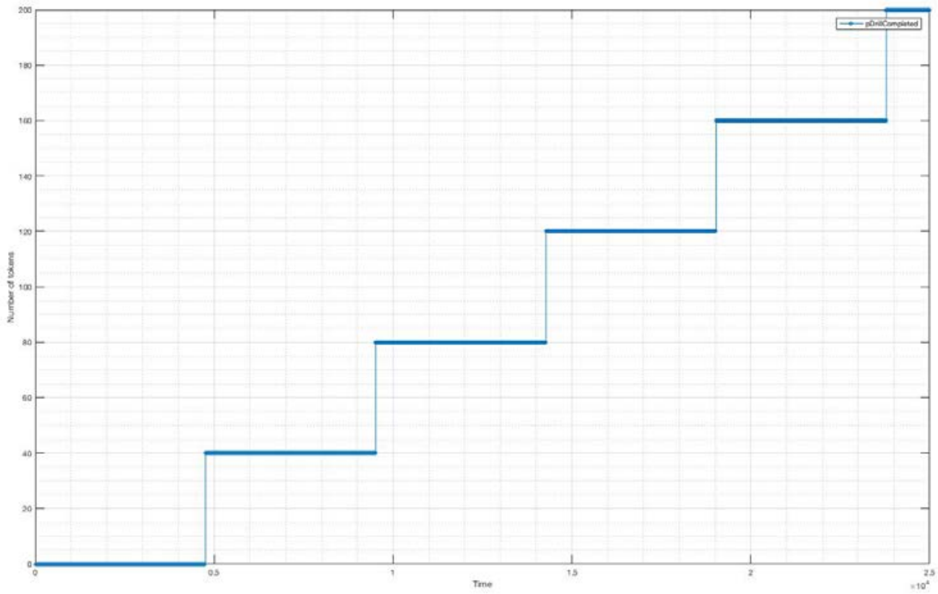


Figure 6-8: Output of reaching final target depth for 200 m drill

7. DISCUSSION AND CONCLUSION

In this thesis, the drilling process is analyzed in depth starting with visualizing the process from the top level and simplified each activity. The design of drilling activities that illustrated in Figure 4-1 is the top level view and rest of the design model illustrated in from Figure 4-2 to Figure 4-9 are the simplified model of each component activity of the drilling process. This study helped to understand the process and the working principle in the drilling system which helped for the implementation of drilling process model in Petri Net and implementing the process in GPenSIM successful.

Furthermore, drilling process is implemented and tested the oil drilling activities simulation with different target depth values. Although in this study, the simulation tested is shown for these three cases 80m, 200m and 800m only but this simulation tool can support for any target depth value. The simulation is run several times and analyzed the results displayed in command window for each step of actions and also from drilling summary that is displayed after the simulation is completed. Furthermore, the plotted graphs result also help better to analyze all the drilling activities and its strategy of reaching the targeted final depth.

The results that are displayed while running simulation gives the information about which components are performing its action in which time. Once the simulation stops it provides the overall summary report about total time taken and the ways how it completes the simulation activity. Lastly, it gives summarize report of each component action like how much time taken by each component and the information of each drill round and drill section round details. The graphical report shows the graphical information for each activity related to the drilling components.

From this result, it is easy to identify the section where it is taking maximum time. If the particular section taking long time to perform its activity is improved it reflect the result improving the whole drilling system performance. The system is analyzed from the top level in the beginning and simplified more reaching to the root level. Hence, this can be a nice tool to identify the loopholes in the system. It is very difficult to improve the system performance if the problem is not identified and it can take a long time just to identify the problem only. So, when the problem is identified it is easier to resolve the problem while executing drilling activities in a real scenario.

7.1 Future work

In addition, reaching the estimated target depth there comes cost and safety analysis are two major concern while planning an oil drilling activities. This simulation covers somehow the cost analysis. As this thesis, gives a good plan for reaching the target depth which helps to estimate the manpower and time. If drilling activities are planned in accordance with this simulation results it reduces the cost in oil drilling activities in actual field. But this tool does not calculate the total cost rather the cost can be optimized with the improvised drilling activities. Alternatively, creating an artificial intelligence tool estimating drilling cost with the reference of provided drilling plan is one of my future work. In addition to this, safety is also another hot topic in drilling activities as the oil drilling task seems very challenging with plenty of risks if proper safety methods are not applied. The driller should be careful and at the same time have trained with proper safety methods. Hence in case if something unwanted happens accidentally they can tackle easily. Furthermore, the oil drilling activities are equally important in the meantime the human life is more important. The driller should work with taking full precaution to themselves. So, drilling safety analysis will be another future work.

7.2 Conclusions

Simplified oil drilling activities are successfully modeled and simulated in Petri Net using GPenSIM in MATLAB environment. GPenSIM is a powerful tool to model any kind of Discrete Event Dynamic Systems. This makes this simulation task much easier to accomplish the goal. Moreover, this simulation acts as a helpful tool to gain the knowledge of overall drilling scenario before starting any oil drilling job in the actual field. From this simulation tool, it helps to minimize the drilling time which ultimately saves money and this is the goal we want. All the oil drilling companies main motive is to find the oil at the minimum cost. Hence, the drilling companies will be highly benefited from this simulation tool. They can easily compete in today’s competitive world with high oil production at low cost and manpower.

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APPENDIX 1

User manual for running "Simulation and Modeling of Oil Drilling Activities" are as follows:

There are two different methods of simulating oil drilling activities discussed earlier in the implementation section of this paper. First running simulation from Petri Net and second running simulation with GPenSIM in MATLAB platform. All the files and folders are arranged in the main folder named 'ModAndSim-OilDrillingActivities(MasterThesis2018)'.

Running simulation with Petri Net

1. First Platform Independent Petri Net Editor 2 (PIPE2) should be available on the PC to run this simulation.
2. There is subfolder inside the main folder named 'Modeling_with_PetriNets'. This folder has two files named 'OilDrilling_PetriNetSimulation_Drilling80m.xml' and 'OilDrilling_PetriNetSimulation_Complete.xml'.
3. Browse and open the file 'PetriNetSimulation_Complete.xml' to run the complete simulation program drilling with 80 m, 200 m and 800 m target depth.
4. Browse and open the file 'OilDrilling_PetriNetSimulation_Drilling80m.xml' to run simulation of drilling with 80 m target depth value.
5. Run the simulation manually or automatically from animation mode. Here the simulation program automatically chooses the target depth value for drilling.
6. Running simulation manually just need to click the enabled transition to fire in each step.
7. Running simulation automatically requires the information of number of firing to perform and time delay between firing /ms.

Running simulation with GPenSIM in MATLAB Platform

1. Running this simulation first make sure that GPenSIM is installed in the pc. This is available in zipped file format in website: http://www.davidrajuh.net/gpensim/. The latest version of GPenSIM software is used for this simulation i.e GPenSIM v.10 Software.
2. There is subfolder named 'OilDrillingSimulation' this folder include all the necessary files for simulation using GPenSIM in MATLAB.
3. The simulation can begin by running 'drill' from the editor menu or typing 'drill' in the command window of MATLAB.
4. After simulation started, it will ask to provide the target depth value from the available option provided. Give the target depth value then simulation starts running.
5. The simulation results is shown in the command window during execution of the simulation program of each steps of action currently doing.

6. When the simulation finished. It provides the summarize report of drilling activities. The information is also written in the text file with name of the component. For example for adding new components job. It makes a file named ‘AddComp.txt’.
7. Lastly, the results are displayed in a graphical format drawn token Vs time in four different figure. The details of this information is included in the ‘Test and Results’ sections of this paper.