DRILLING RIG SCHEDULE OPTIMIZATION

BY

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A Thesis Presented to the
DEANSHIP OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

In

COMPUTER SCIENCE

OCTOBER 2011

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

DEANSHIP OF GRADUATE STUDIES

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DEDICATION

This thesis is dedicated to my parents and loving wife

ACKNOWLEDGEMENT

All praise and thanks are to Almighty Allah, the most Gracious, the most Merciful. Peace and mercy be upon His Prophet.

Acknowledgment is due to King Fahd University of Petroleum & Minerals and Saudi Aramco for supporting this research.

I would like to express my deepest and sincere gratitude to my thesis advisor Dr. Mohammad Alsuwaiyel for his tremendous support, guidance and encouragement. I would also like to thank my thesis committee members: Dr. Lahouari Ghouti and Dr. Farag Azzedin for their valuable cooperation and support.

In addition I would like to thanks my Saudi Aramco colleagues for their help.

Last but not least, I would like to thank my mother, my wife and my family members for being patient and for their words of encouragement to spur my spirit at moments of depression.

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ABSTRACT

A group of drilling rigs with different specifications will drill a set of wells that have different characteristics; a schedule needs to be created assigning a specific set of wells to each drilling rig. This schedule should be optimal or near optimal in terms of cost. Note that drilling rigs are not the same, but are different in type, rating cost, moving cost, and capability. The same for the wells, as they differ in type, complexity, capability production rate, distance to other wells.

To solve this problem, there is a need to come up with a standard and unified scale that will use these different specifications and characteristics to come up with standard points. After that, analysis and studies of different algorithms will be needed to find solutions for various problems, such as the lightest weight network, job assignment, and matching. Finally the standard scale will be integrated with the proper algorithm to develop an engine that can solve this problem.

This study sets out to solve a real problem in a petroleum engineering discipline, particularly in drilling and production operation in order to substantially enhance the oil and gas companies’ net present value.

خلاصة الرسالة

الإسم : سالم بن حمود الغربي

العنوان : إيجاد الجدول المثالي لتوزيع مهمات منصات الحفر

الدرجة : ماجستير في العلوم

تاريخ الدرجة : حزيران 2011

هناك مجموعة من منصات الحفر ستقوم بحفر عدة آبار ، لذلك يجب تصميم جدول يعين لكل منصة حفر مجموعة خاصة من الآبار لكي يحفرها. هذا الجدول يجب أن يكون من مثاليا الناحية مالية (أو تقريبا مثالي).

يجب ملاحظة أن منصات الحفر ليست متشابهه فهي مختلفة مثلا في النوع و تكاليف الآجار اليومي و النقل و القوة الحصانية. الأمر نفسة ينطبق على الآبار ، فهي مختلفة أيضا في النوع و الطاقة الإنتاجية و صعوبة الحفر.

لإيجاد الجدول المثالي ، يجب أن نأتي بمقياس يمكننا من دمج الإختلافات بين منصات الحفر و الآبار و الخروج بوحدة قياسية ثابتة . ثم بعد ذلك دراسة و تحليل عدة خوارزميات لحل هذة المشكلة (مثل الشبكة ذات الوزن الأخف ، مشكلة توزيع المهام ، التوافقية) ثم إختيار أو إيجاد أفضل خوارزمية . في النهاية نستخدم المقياس الموحد اللذي أوجدناه في المرحلة الأولي مع الخوارزمية اللتي أوجدناها في المرحلة الثانية و نحاول أن نصمم برنامج يخرج لنا جدول الحفر المثالي .

هذة الرسالة ستقوم بحل مشكلة حقيقية متعلقة بصناعة النفط و الغاز و تحديدا عمليات الحفر و صيانة الأبار ، و يتوقع منها أن توفر مبلغ كبير من ميزانية هذة العمليات .

Chapter 1

INTRODUCTION

In today's world, oil and gas are sources of energy for almost everything in people's lives, from running households to manufacturing, and operating hospitals and public transportation. People rely on oil and gas to have a comfortable lifestyle, so it is highly important to maintain the sustainability of oil and gas supply, and to ensure that oil and gas products reach the market in a timely manner. Oil and gas companies have been conducting a number of research projects in order to improve and enhance their operations, as well as to increase their present net values. Unfortunately, it often takes a long time, and there is a high implementation cost for the results of these research projects to be applied in the industry.

The most expensive operation in oil and gas industry is the process of drilling wells. The first step in this operation involves the "Drilling Rig Schedule", which assigns a set of wells to each rig to drill as shown in the example illustrated in Table 1.1.

Rigs	Wells									
	2011							2012		
Rig A	W 22	W 20	W 27	W 25	W 39	W 45	W 90	W 43	W 42	W 43
Rig B	W 10	W 65	W 25	W 20	W 02	W 03	W 21			
Rig C	W 09	W 07	W 18	W 06	W 05	W 56	W 31	W 32	W 33	
...	W 29	W 71	W 72	W 73	W 74	W 75	W 76	W 77	W 78	

Table 1.1 Drilling Rig Schedule for 2011

The Drilling Rig Schedule, illustrated in Table 1.1, shows a set of rigs (Rigs A-C) along with a group of wells. It indicates, for example, that in 2011 Rig A will drill, in the given order, wells W 22, W 20, W 27, W 25, W 39, W 45, and W 90. The same rig will start drilling well W 43 before the end of the year. The same observation applies to Rigs B and C. This assignment is based on a complex logic, using the type and characteristic of the rig and the wells

The Drilling Rig Schedule governs and controls all the drilling operations. That means it controls a huge amount of money per year. As a result, any enhancement or improvement in the Drilling Rig Schedule will affect the whole drilling operation, and affect its present net value significantly; therefore, the objective of this thesis is to find the optimum (or near optimum) Drilling Rig Schedule.

The first step of this study is to generate a standard unit or scale, which can be used to measure and/or compare all the different and un-related problem parameters.

The second step is to study and analyze the different algorithms/ techniques in order to find or develop the best solutions for these problems. Finally, the generated standard scale will be integrated with the developed algorithm, using an engine. This engine will receive the rig and well parameters, then process them and generate the optimal (or near optimal) Drilling Rig Schedule.

This thesis is organized as follows: Chapter 2 will explain the preliminaries; Chapter 3 will provide a review of the current literature, with a focus on different approaches in finding an optimal Drilling Rig Schedule; Chapter 4 will discuss the generated standard unit and the proposed algorithm, along with the experiment setup and results; the conclusion is in Chapter 5; Chapter 6 will highlight some potential areas for future work.

Chapter 2

PRELIMINARIES

2.1 Drilling Rig Schedule

A group of drilling rigs with different specifications will drill a set of wells that have different characteristics. It is important to create a schedule in order to assign a specific set of wells to each drilling rig in a specific order. This schedule is called Drilling Rig Schedule, which is affected by different and unrelated factors, such as drilling rig factors and well factors.

2.1.1 Drilling Rig Factors

These are the factors affecting the Drilling Rig Schedule that relate directly to drilling rig specifications:

- Daily Rate: the daily cost of a drilling rig differs based on the rig properties
- Rig Capability: each rig has a horsepower rating that affects the maximum depth it can drill.
- Rig type: some rigs can be used for oil wells, others for gas wells or water, producer or injector wells, depending on the rig capability.

- Rig Speed: the speed of the rig while moving between wells.
- Moving Cost: the cost for moving the rig within a specific distance (usually calculated on a per-km basis).
- Maintenance Days off: It is important to specify the days and dates when the rig will be under maintenance.

2.1.2 Well Factors

These are the factors affecting the Drilling Rig Schedule that relate directly to well characteristics:

- Well Cost: the budget needed to drill a well.
- Well Operation Time: the time needed to drill a well.
- Well Type: oil, gas or water; producer or injector.
- Well Operation Type: drilling or workover
- Well complexity: the complexity of the well based on its type, depth and design.
- Fluid type: the quality of the fluid (API). There are different levels of oil and gas that results in a variety of prices.
- Production Rate: the amount (barrels) of fluid that a well is expected to produced.
- Improvement in production: in case of workover wells, the operation will increase the production rate.

- Dependability/ sequence: in some cases there are wells that depend on other wells, so the rigs must complete that well before it starts a new one. This is usually the case of water supply wells.
- Priority: due to some circumstances, some wells need a higher priority than others.

2.1.3 Other Factors

These are other factors that affect Drilling Rig Schedule:

- The distance between wells.
- The oil price.
- The emergency condition: an immediate increase or decrease in production is required in some cases, generally in the drilling operation or in a specific type of well/ fluid.

2.2 Drilling Rig Schedule Optimization

One of the problems of complexities in optimizing Drilling Rig Schedule as described by Irgens, Guzman, Stamatopoulos and Jackson (2008) is that "[o]ptimality is not usually well defined: Usually, companies don't fully know what constitutes an optimal solution" Therefore, it is important to define the Drilling Rig Schedule Optimization.

2.2.1 Drilling Rig Schedule Optimization Types

There are different forms of Drilling Rig Schedule Optimization, such as:

- Optimizing the Time: The need to have a Drilling Rig Schedule such as to make sure that all the wells are drilled in the shortest time. This schedule includes rig speed, distance between wells, and the drilling operation time. The optimization will ensure the operation is completed in the shortest time, and can help release rigs ahead of time to save cost.
- Optimizing the Production: Have the maximum production rate, and/or improve the production rate in the shortest time. This will focus on the well production rate. This optimization strategy can help increase the production in case of emergency need.
- Optimizing the drilling rigs: The need to drill the wells with a minimum number of drilling rigs. This optimization will be needed in the case of a shortage of drilling rigs.
- Optimizing the Rig Move: Producing the Drilling Rig Schedule with the minimum rig movement. This will focus on the distance between wells, and the current rig location.

- Optimizing the Cost: Generating the Drilling Rig Schedule with the most effective cost. This scenario is the difficult one, since it will combine and process all the problematic factors.
- Specific Optimization Need: In some cases, there is a need for a specific optimization, such as optimizing for a specific fluid type, or specific group of wells.

In this thesis, the target is the optimization of cost.

Chapter 3

DRILLING RIG SCHEDULE

3.1 Literature Review

First of all, I would like to note that there is only a very small body of literature about Drilling Rig Scheduling. The existing literature only addresses one or two factors of the large problem, but I will try to cover most of them in this literature review.

Drilling Rig Scheduling is an important function for Oil and Gas Companies, because it controls all the drilling operations. It is the part that implements the company strategies such as in increasing the level of exploration, drilling more wells, and maintenance of the operation. As a result of that, and due to the complexity of the drilling operation, the Drilling Rig Schedule is affected by many unrelated factors, such as the drilling schedule, rig allocation, facilities acquisition, number and location of wells, rate of production decline, water and/or gas injection systems and, mainly, the production profile (de Andrate Filho, 1994). Aloise et al. (2006) identify these factors as "well production, the current location of the workover rig in relation to the demanding well, and the type of service to be performed". Lasrado (2008) notes that these factors are "the biggest challenges", because they change continuously due to unplanned events, and the changes are sometimes on an almost daily basis.

Irgens, Guzman, Stamatopoulos and Jackson (2008) state that rig scheduling is a "large and complex problem". However, according to Vineet Lasrado (2008), spreadsheets are commonly used as one of the tools to manage schedules. Irgens et al. (2008) add that "it is common to use cyclical, calendar driven and business-unit focused decision-making processes". Most of the existing rig scheduling software applications are based on a specific factor, such as production only, time only or distance only, which are also referred as "specific target" or "single target" software (Lasrado, 2008).

Drilling Rig Scheduling has limitations in its applications and software. Furthermore, there are very few studies on this issue, and they only handle one or two parameters. As de Andrate Filho (1994) clarifies "[s]ometimes it is difficult to put all these parts together in a synchronized way", and "[h]andling multiple variables at the same time leads to a very complex problem. To first know the problem and identify its behaviour we based our investigation in a simple problem with two variables".

One of the problems of the complexity in optimizing Drilling Rig Schedules is that optimality is not usually well defined.

> "Usually, companies don't fully know what constitutes an optimal solution. They may recognize good solutions, but it is often hard for them to explain fully why they are good or to give them an absolute ranking. It is a waste of time to chase optimality if optimality is not well defined" (Irgens et al., 2008)

Brannan, Barnes and Knapp (1977) recognize the problem, and note "[e]ach day a well waits for a workover means potentially immediate production loss", They state "the order or sequence in which the workovers are performed can have a significant impact on the total amount of oil produced from those wells during the workover period" (Brannan, Barnes & Knapp, 1977), and they identify two parameters "Ti is the number of days needed to perform the well workover and Pi is the expected increase in productivity in barrels per day resulting from the workover" (Brannan, Barnes & Knapp, 1977) (Table 3.1.1). The proposed Drilling Rig Schedule is based on the order of either of these parameters. "One scheduling strategy is to arrange the workovers by descending values of Pi. This would be expected to increase the daily production quickly. Another strategy would be to schedule the wells by ascending values of Ti. This results in performing the quickest jobs first." (Brannan, Barnes & Knapp, 1977).

Well	A	B	C	D	E	F	G	H	I
Ti	5	6	16	5	7	11	5	1	5
Pi	51	112	106	102	51	108	88	57	40

Table 3.1.1 Scheduling a Backlog of Oil Well Workovers (Brannan, Barnes & Knapp, 1977)

Lasrado (2008) integrates a Drilling Rig Schedule with the reservoir simulation, and proposes an application prototype (Figure 3.1.1). He uses "an optimization program to take feedback from the reservoir simulator and change the input based on the optimization run" (Lasrado, 2008). "The output from the prototype application is used only as a tool to discuss the possible applicability of the approach to reduce rig related expenditure." (Lasrado, 2008). This approach is to "reduce rig movements and rigs required while maintaining the overall field production." (Lasrado, 2008,). The objective is to

> "…reduce the net distance traveled by the rig and the number of rigs utilized by analyzing the schedule and changing the rig assignment and field management strategy. The reduction in distance traversed by the rig would mean lower rig mobilization costs and hence reduce the rig operating expenses" (Lasrado, 2008,).

But "[n]o optimization algorithm has been used in this work." (Lasrado, 2008,).

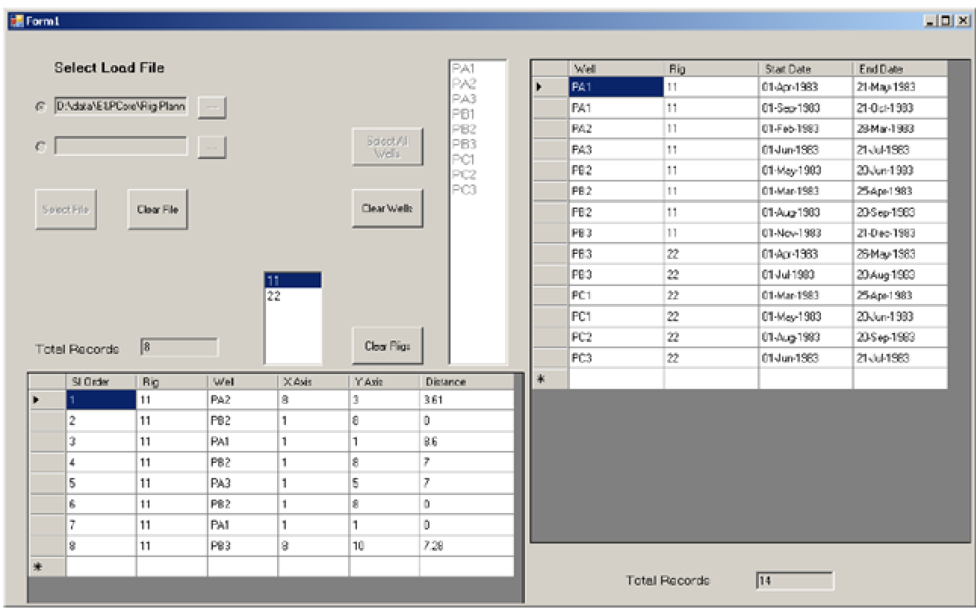

Figure 3.1.1 Snapshot of the prototype application to analyze rig schedule and movement

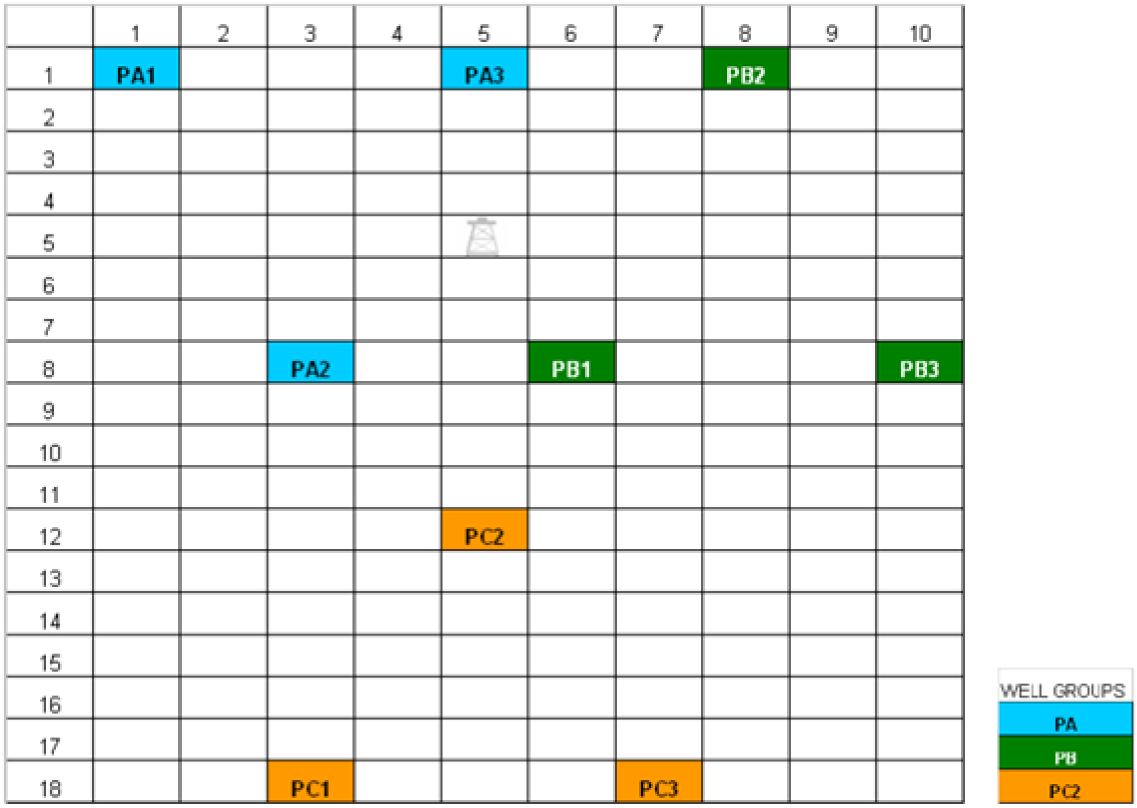

Figure 3.1.2 Area view of wells and start location of workover rig (Aloise et al., 2006)

Lasrado (2008) uses a single factor that focuses on reducing the net distance traveled by the rig, and “[n]o optimization algorithm has been used in this work” . Moreover, the effect of Drilling Rig Schedule on a reservoir simulation will be limited if the schedule is running across several reservoirs.

In Aloise et al.(2006)’s study, “[t]he problem of scheduling workover rigs consists in finding the best schedule for the available workover rigs, so as to minimize the production loss associated with the wells awaiting for service” . They propose a Variable Neighbourhood Search (VNS) heuristic for this problem. VNS is based on “the exploration of a dynamic neighborhood model” (Aloise et al., 2006). VNS consists of initial solutions that will be used to build initial solutions to the VNS heuristic (Aloise et al., 2006) (Figure 3.1.2).

```
Procedure H1:
Si ← 0; i=1, … m;
Last ← 1;
While R ≠ 0 do
   For i = 1, … n and R ≠ 0 do
      r* ← max r ∈ R {lossr (i, last)};
      Insert well r* in the last position of Si;
      R ← R – {r*};
   End-for;
   Last ← last + 1;
End-while
Return S = {Si, I = 1, … m};
End H1;
```

Table 3.1.2 Pseudo-code of the construction heuristic H1

The second part of VNS is local search, which is a "search procedure used at each iteration of the VNS heuristic is based on a swap neighborhood defined by all solutions which can be obtained by the exchange of a pair of wells from the current solution." (Aloise et al., 2006,) (Table 3.1.3)

```
Procedure VNSforWorkoverRigs
  Let S be the initial solution built by H1:
  K ← 1;
  While k ≤ kmax do :
      If the time limit is exceeded then return S;
      Randonly generate S' ∈ N(K) (S);
      Obtain S'' by applying local search to s';
      If w(S'') < w(S) then S ← S''; k ← 1;
      Else k ← k +1;
  End-while
  Return to step 2;
End VNSforWorkoverRigs
```

Table 3.1.3 Pseudo-code of the VNS heuristic for the problem of scheduling workover rigs

Compared to other techniques, Aloise et al. (2006) claims that VNS gives the best result (Figure 3.1.3)

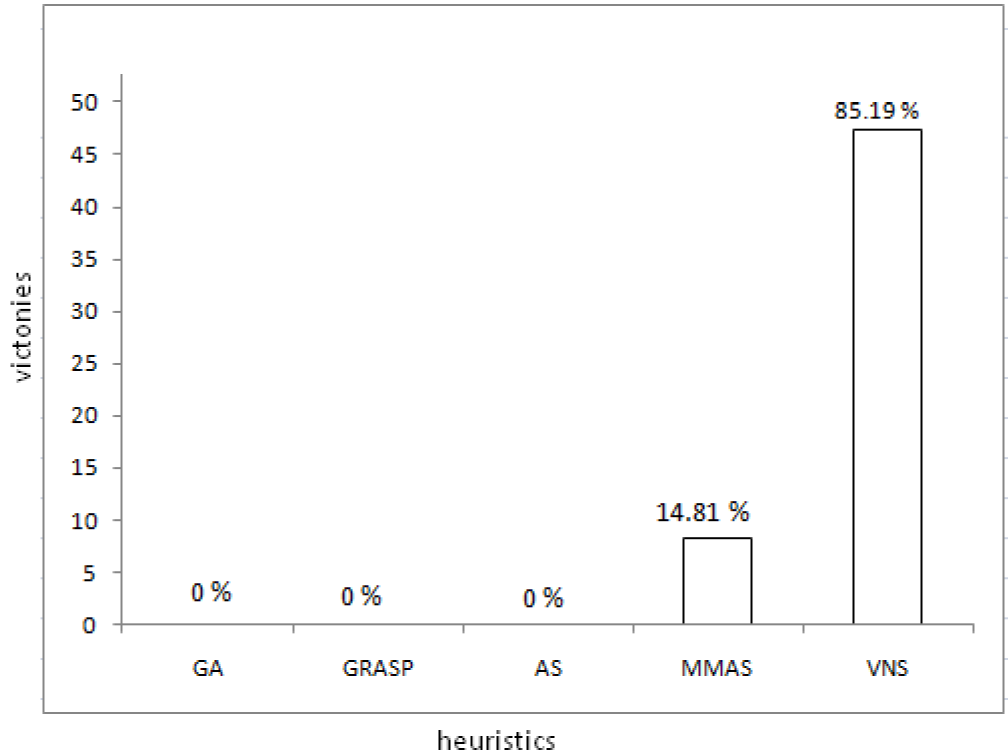

Figure 3.1.3 Absolute and percent numbers of victories of each heuristic in terms of their average results

The feature shows that Aloise et al. (2003) used an algorithm approach toward solving this problem.

de Andrate Filho (1994) uses a similar approach as Vineet Lasrado (2008). He highlights that the actual problem is of a multidimensional nature (de Andrate Filho, 1994). To solve that problem, he used two searching methods: “derivative-based methods and direct methods” (de Andrate Filho, 1994,). He also developed an interface using a reservoir simulation application (ECLIPS).

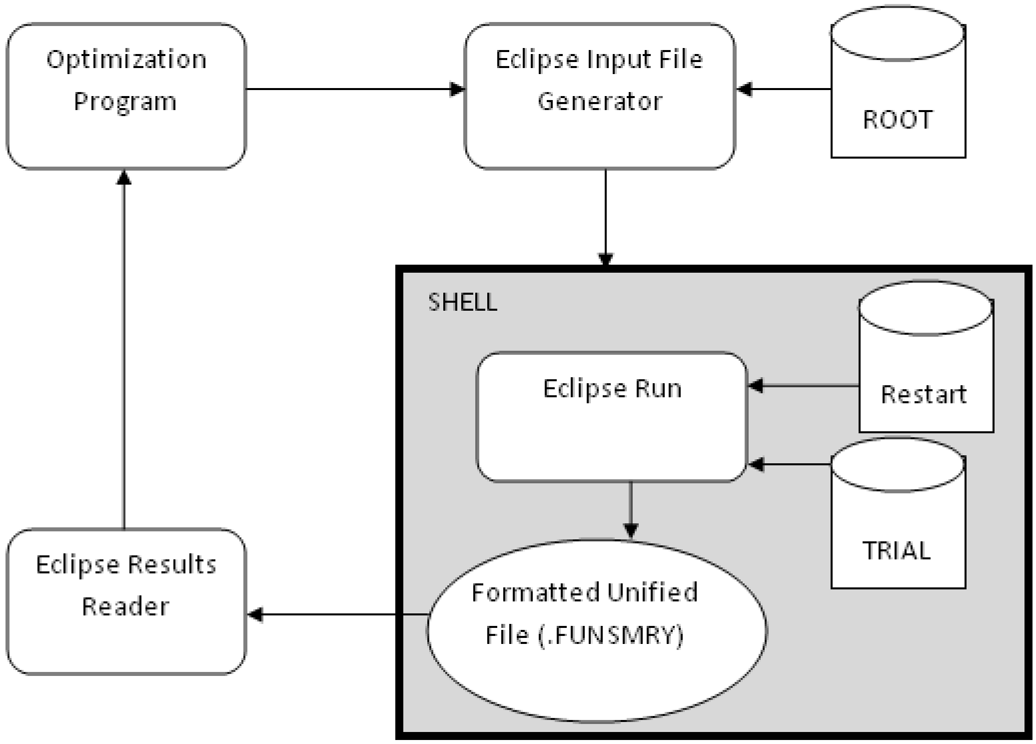

Figure 3.1.4 The developed interface with reservoir simulation application in de Andrate Filho (1994)

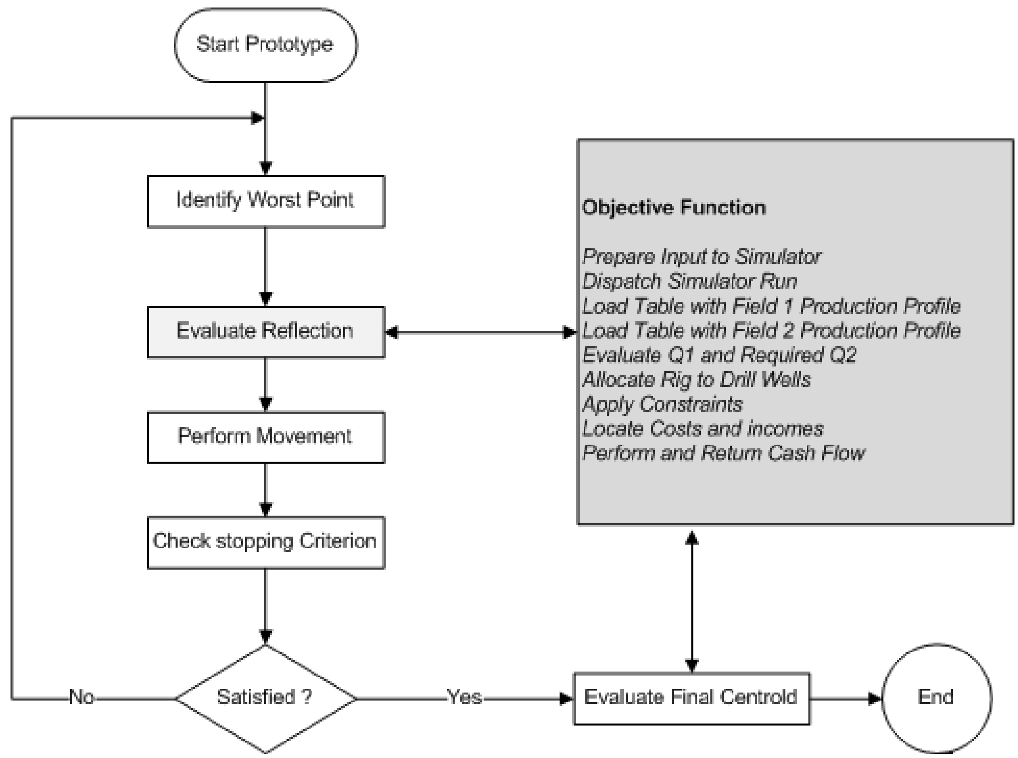

Figure 3.1.5 Flowchart of Algorithm proposed by de Andrate Filho (1994)

The limitation of de Andrate Filho's study is similar to Vineet Lasrado's, where this solution will be different and difficult to apply if the Drilling Rig Schedule is across several reservoirs, which is normally the case for oil and gas companies.

De Andrate Filho emphasizes that "[o]ne can obtain more profit without necessarily having more production" (Filho, 1994,).

Morton Irgens and his colleagues have a clear objective that is "… to schedule the rigs in order to minimize the transportation cost, while meeting or exceeding the target production delay" (Irgens et al., 2008). They claim "[t]he results show reduced planning time, reduced response time, reduction in scheduling errors, improved "what-if" abilities and decision-making" (Irgen et al., 2008,). They also argue

> "[t]he challenge in solving this problem is that the number of possible ways in which facts and decision points can connect to build a solution or make a reliable decision grows exponentially with small increases in the amount of data. As the problem also contains complex objectives and constraints" (Irgen et al., 2008,).

And "[t]he challenge therefore is to furnish the drilling planners with a decision support tool that ensures that the schedules stay optimized and aligned with the strategic objectives, while minimizing disruptions to operations." (Irgen et al., 2008,). They developed an application called the Rig Activity Scheduler (RAS) (Figure 3.1.6).

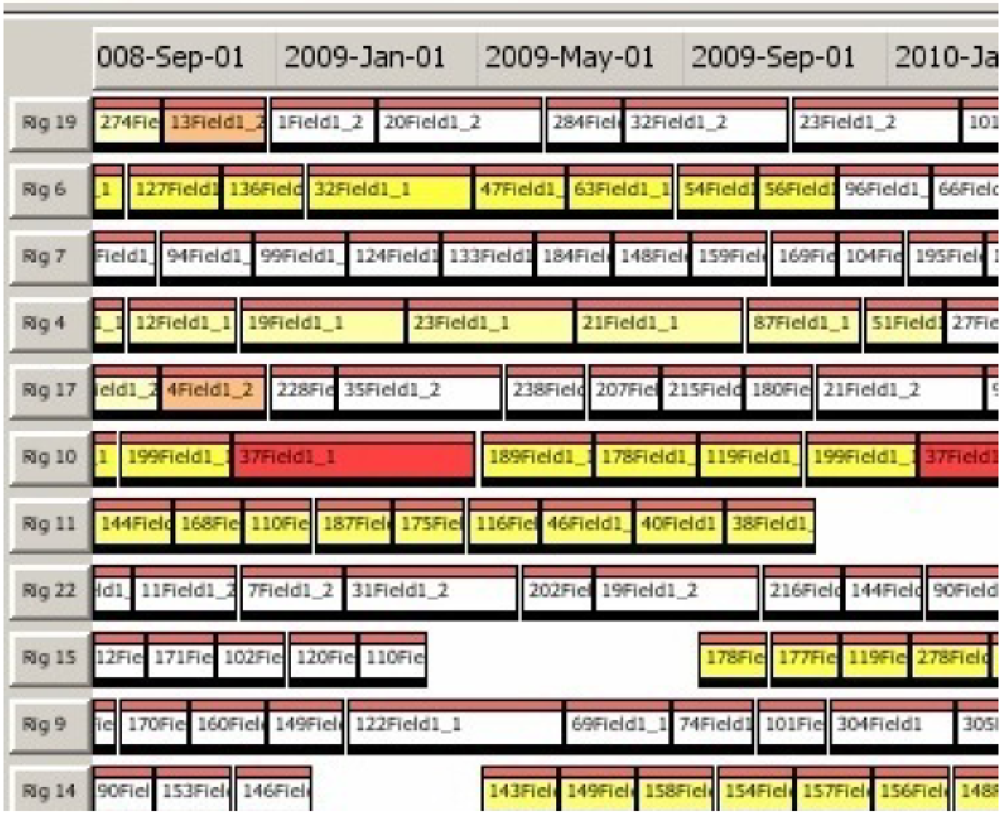

Figure 3.1.6. The developed application by Irgens et al. (2008).

The Rig Activity Scheduler (RAS) "provides rig management and scheduling optimization using a modern user interface, enabling interactive rig movement maps and Gantt charts." (Irgens et al., 2008,). The "algorithms H1 is a schedule construction method that approximates a technique observed in industry. Higher-performing wells are scheduled as early as possible and each rig is assigned a roughly equal number of wells" (Irgens et al., 2008,). (Table 3.1.4)

```
Procedure H1:
Rigs ← {all rigs}
Unscheduled ← {all activities }
While Unscheduled is not empty do
  For each rigs r in Rigs and Unscheduled is not empty do
     SelectedActivity ← min a in R {loss (a, rig)}
     Insert selectedActivity in the last position on rig
     Unscheduled ← Unscheduled - {selectedActivity}
  End for
End while
```

Table 3.1.4. H1 procedure

"The method is a variation of Stochastic Local Search (SLS) combined with very efficient underlying data structures, including an invariant network, they are similar to genetic algorithms. Each possible alteration is evaluated and the first acceptable alteration will be chosen and applied to the schedule." (Irgens et al., 2008,).

Irgens et al. (2008)'s approach is almost complete. They find a clear problem definition, use an algorithm and develop an application. However, they only address the problem from a single factor, which is to "minimize the transportation cost" (Irgens et al., 2008,). However, as an insider working in the oil and gas industry, I understand that the application is no longer used by end users due to some technical and logical issues.

3.2 Current Process

The current process of the Drilling Rig Schedule starts when the Scheduling Department receives a list of required wells to drill for the next one to three years. The list will have the name, location and detailed information about the drilling operation type of each well. It is worth noting that this information differs based on the purpose and objective of each well. Based on these details, the scheduler will classify the wells in accordance with their complexity and time needed to complete the drilling operation. Then, the scheduling operators will locate these wells on the map. Usually, the wells having a similar level of complexity will be close to one another geographically.

In normal conditions, a few capable rigs will be assigned automatically to operate on these new wells. If there is no capable rig in the area, the scheduler will select the nearest capable one and assign it to that specific well. Some scheduling experts will try to re-arrange the schedule in order to optimize it. However, they cannot process a large number of rigs and wells, so they work on a very small scale, trying to optimize the rig to move in distance only.

Chapter 4

THESIS WORK

As previously mentioned, a group of drilling rigs with different specifications will be used to drill a set of wells with different characteristics. It is necessary to come up with a schedule assigning a specific set of wells to each drilling rig. This schedule should be economically optimal (or near optimal).

There are differences and conflict factors that affect the optimization decision, some of which are:

- Cost: rig rate, rig move cost
- Time: drill all the wells in the shortest time
- Production: produce a specific amount in specific time

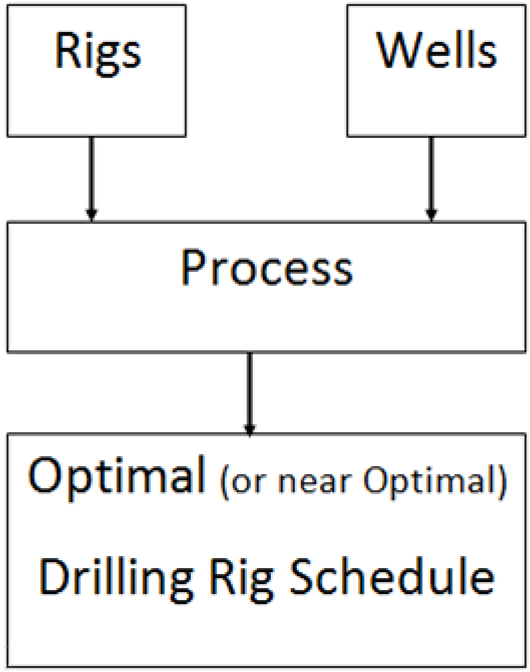

Table 4.1. The process to produce a Drilling Rig Schedule

This problem was motivated by the fact that the Oil and Gas industry is huge, complex, expensive and critical. A number of research studies have been conducted to support it. Most of these studies required large budgets and took a long time to apply within the industry. Buying, replacing and training with new technology, along with waiting for the technology to be mature, have been the factors that contributed in delaying, complicating and limiting the efficiency of these research studies once they were applied within industry operations.

This study aims to find a solution that helps the industry to minimize these problems. I find that planning-level enhancement will be the best, because it is centralized, and can control and affect a wide range of operations.

One of the major planning-level activities is the drilling rig scheduling. The Drilling Rig Schedule controls all the drilling operations, which is the most expensive operation in oil and gas industry. It also affects the production operation, which is the second expensive operation in this industry. As a result, any enhancement in drilling rig scheduling will affect the whole industry.

4.1 Standardizing Different Problem Factors

As previously mentioned, the problem consists of many different and un-related parameters, and requires generating and comparing several scenarios. Therefore, in order to come up with the best solution, it is necessary to find or generate a standard unit or scale that will be used to compare and analyze the different factors (Table 4.1)

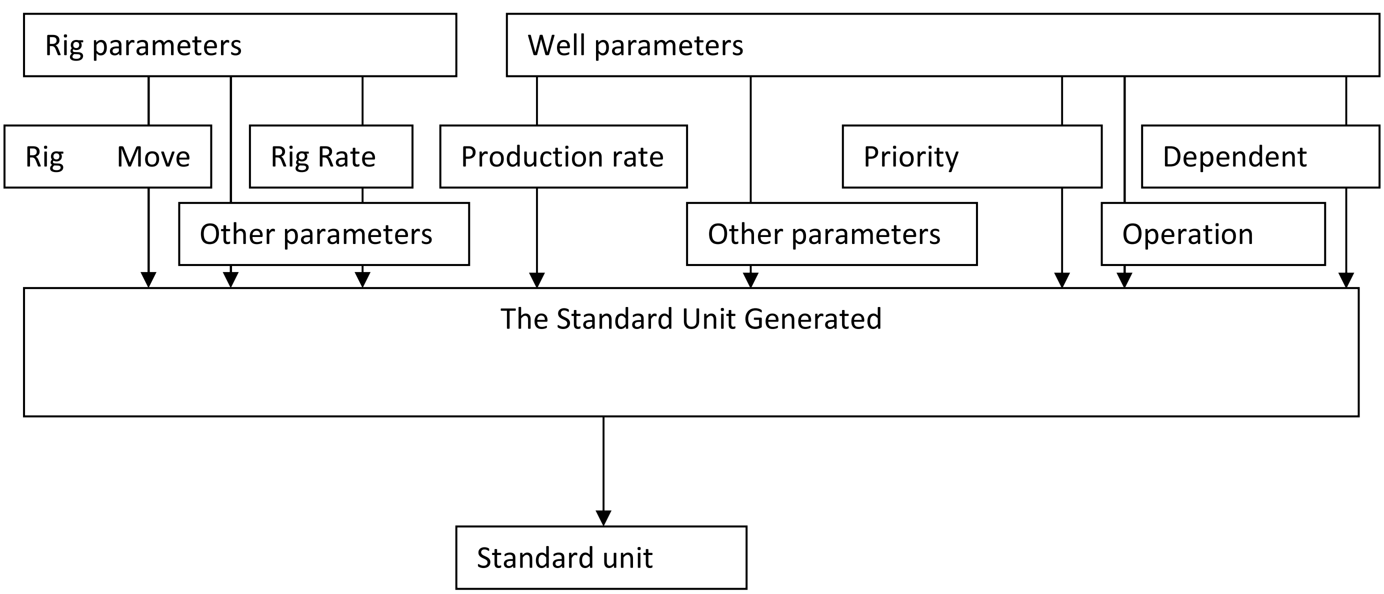

Table 4.2. There is a need to have one standard unit for all the factors

4.2 The Cost Function

Since the goal is cost-based optimization, all these factors will be converted to monetary values.

4.2.1 The Drilling Rig Factors

To convert the drilling rig factors to monetary values:

- Daily Rate: direct conversion, the rate of the drilling rig * number of day this drilling rig is in operation (working).
- Moving Cost: the drilling rig moving cost * the moving distance.
- Rig Speed: there will be a need to select the rig that can reach the well faster, since it will optimize the well production rate. So this factor will be affected by the drilling rig rate, drilling rig moving cost, well production, improvement in production and dependability / sequence.
- Maintenance Days Off: no direct conversion.
- Rig Capability: no direct conversion. This factor will be used to match drilling rig/ well.
- Rig type: no direct conversion. This factor will be used to match drilling rig/ well.

4.2.2 The Well Factors

To convert the Well Factors to monetary values:

- Well Cost: the cost of the well equals well operation time * average rig daily rate + cost of materials.
- Well Operation Time: this will affect the drilling rig daily cost. The more the well needs in operation, the more it will cost.
- Fluid type: the fluid type can be affected by the oil price.
- Improvement in production: the increase in production rate after its completion * oil price.
- Dependability/ sequence: no direct conversion, but this is an important factor if there are wells with a high production rate depending on this well.
- Priority: in some cases, the well priority waives the cost issue!
- Well Type: no direct conversion. This factor will be used to match drilling rig/ well.
- Well Operation Type: no direct conversion. This factor will be used to match drilling rig/ well.
- Well complexity: no direct conversion. This factor will be used to match drilling rig/ well.

4.2.3 The Other Factors

- The distance between wells: it will affect the drilling rig moving cost.
- The oil price: direct conversion.
- The emergency: in some cases, the emergency waives the cost issue.

The cost function of drilling rig *i* to operate (drill) well *j* could be the following:

```
(
(Distance from drilling rig i to well j *
moving cost of drilling rig i) +
(Daily rate of drilling rig i
* number of days needed to complete well j ) +
(Daily rate of drilling rig i
* time needed for drilling rig i to reach well j )
) * ω
* β (number of depended wells)
* ε (well fluid API)
* γ (oil price)
* α priority of the well




Note that drilling rig i can operate on well j based on drill
rig i capability and type and well j type, operation type and
complexity.
```

Algorithm 4.2.3.1. Proposed cost function

4.3 Experiment Setup

Drilling Rig Schedule optimization is a big problem that is affected by many different unrelated factors. This study sets out to solve this problem by conducting and running different scenarios, starting with simple basic factors (using the distance only in the first scenario), then more factors will be introduced in each scenario.

4.4 Assumptions

In this study, several assumptions were made with regards to several factors including the following:

4.4.1 Drilling Rig Factor Assumptions

- We will assume that the drilling operation will be onshore.
- We assume that all the drilling rigs are equally capable to drill all the wells.
- Since we assume that all the drilling rigs are equally capable to drill all the wells (this cannot be valid if we have “Drilling Rigs” and “Workover Rigs” since they had different capability), we assume that all the drilling rigs are of “Drilling type” being used to drill new wells (exclude workover rigs).

- We assume that all the rigs have the same moving speed, which will be neglected. In addition to the moving time, the daily cost of a drilling rig during the movement will be neglected.
- As an ideal situation, there will be no delay in the drilling operation, and all the rigs will be equally available.

4.4.2 Well Factor Assumptions

- Since the drilling rigs are onshore “drilling type” rigs, the wells are new and also onshore.
- We assume that all the wells are similar, so they all have the same fluid type, which is oil producer. The wells are equally important, and also there are no dependant ones.

4.5 Input

The problem of input data was randomly generated (based on actual ranges);

See Table 4.5.1 for drilling rig input, and Table 4.5.2 for the well input; the drilling rig and wells location are in Figure 4.5.1

Drill Rig Name	Location (X,Y)	Daily rate cost	Moving cost / km
1	(454,933)	10,922,000	1,092,200
2	(6,841)	11,485,000	1,148,500
3	(955,284)	11,494,000	1,149,400
4	(358,943)	12,347,000	1,234,700
5	(875,368)	11,698,000	1,169,800
6	(321,426)	11,370,000	1,137,000
7	(367,525)	11,362,000	1,136,200
8	(251,288)	11,268,000	1,126,800
9	(642,112)	10,201,000	1,020,100
10	(436,748)	12,059,000	1,205,900

Table **4.5.1 Drilling Rig Inputs**

Well Name	Location (X,Y)	Operation time
1	(599 , 160)	33
2	(313 , 758)	39
3	(145 , 226)	31
4	(307 , 917)	36
5	(189 , 942)	32
6	(859 , 973)	38
7	(313 , 573)	38
8	(627 , 566)	39
9	(946 , 48)	32
10	(376 , 278)	37
11	(303 , 936)	38
12	(939 , 529)	32
13	(704 , 775)	30
14	(625 , 771)	36
15	(559 , 548)	32
16	(318 , 854)	30
17	(370 , 606)	39
18	(299 , 880)	39
19	(57 , 32)	34
20	(741 , 293)	35

Well Name	Location (X,Y)	Operation time
21	(120 , 974)	34
22	(405 , 115)	38
23	(806 , 47)	31
24	(425 , 485)	39
25	(102 , 272)	30
26	(800 , 714)	39
27	(542 , 724)	39
28	(481 , 859)	32
29	(172 , 117)	37
30	(112 , 999)	30
31	(115 , 85)	31
32	(371 , 706)	33
33	(4 , 101)	35
34	(5 , 691)	33
35	(397 , 53)	33
36	(580 , 205)	31
37	(95 , 781)	34
38	(779 , 491)	36
39	(552 , 56)	31
40	(298 , 631)	30

Table 4.5.2 Well Inputs

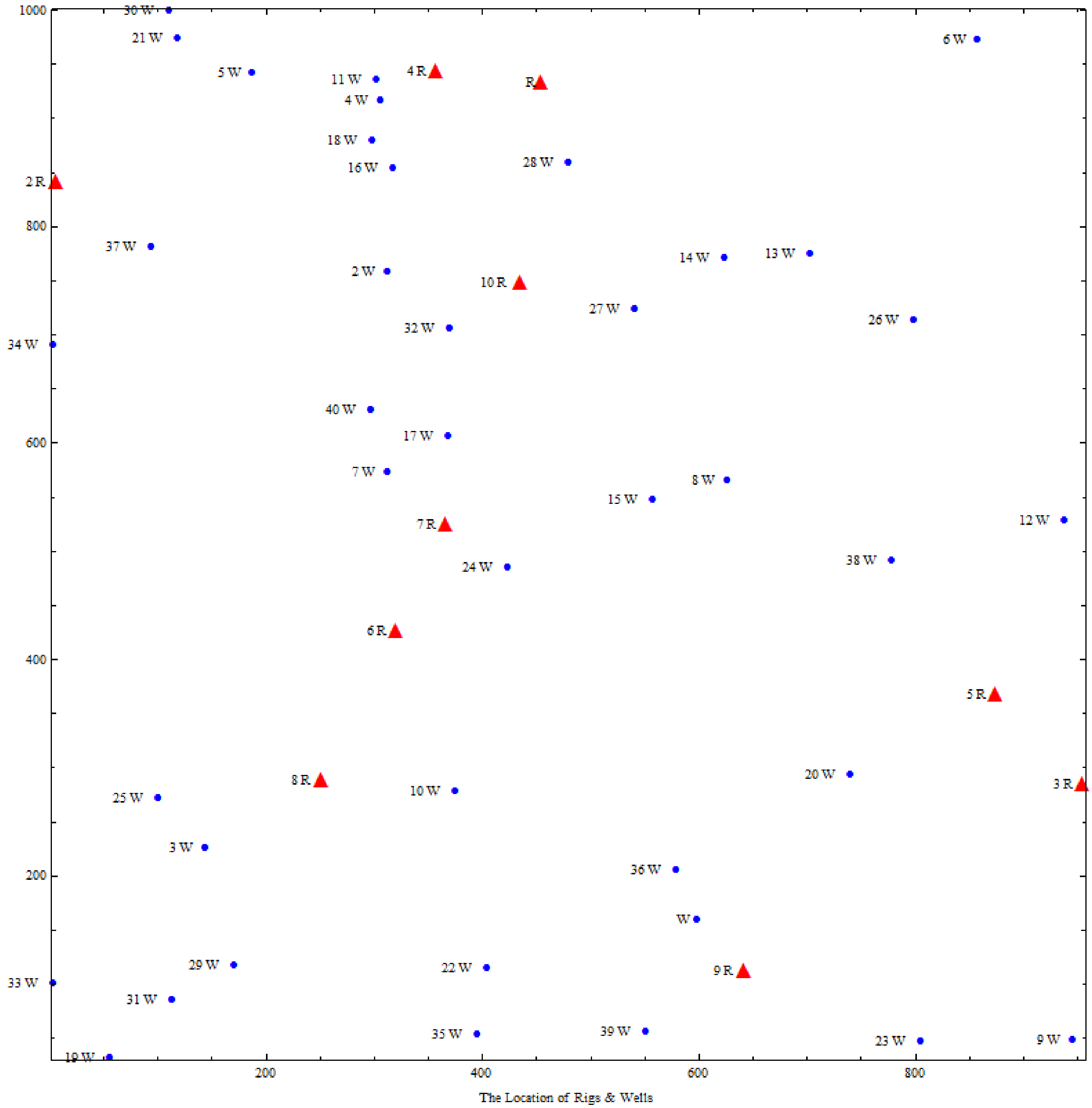

Figure 4.5.1 Drilling Rigs and Wells Location

4.6 Scenarios

In order to generate a good Drilling Rig Schedule, I will conduct and run different scenarios, starting with a simple problem factor. New factors will be added into each scenario.

4.6.1 Scenario One

This scenario solves a very basic factor of the Drilling Rig Schedule problem, which is the transportation issue. This scenario addresses only the distance between wells. It solves the problem as All Pair Shortest Path (APSP) problem. Floyd's Algorithm, or Dijkstra's algorithm can be used to solve this problem. The algorithm used in this scenario will be as follow:

```
W  = set of all wells
DR = set of all Drilling Rigs
SDM = the Shortest Distance Matrix based on Floyd's
Algorithm, or Dijkstra's algorithm
Drilling Rig Schedule = empty

Optimum (or near Optimum) Drilling Rig Schedule ODRS(DR,W):

Shortest Distance = infinity
Shortest Distance Pair = (null, null)
for i in DR

   for j in W and j not Drilled
        if (SDM(i,j) < Shortest Distance)
             Shortest Distance = SDM(i,j)
             Shortest Distance Pair = (i, j)



   set j as Drilled
   assign DR_i to Drill W_j
   update Drilling Rig Schedule

   if all j in W Drilled
   end

   else
    go to ODRS(DR,W) again



return
Drilling Rig Schedule
```

Algorithm 4.6.1.1 Scenario one algorithm

Since only the distance was considered in this scenario, the cost function was not used.

The optimization function: Select the minimum distance between Drilling Rig *i*, and Well j while Well *j* is not drilled.

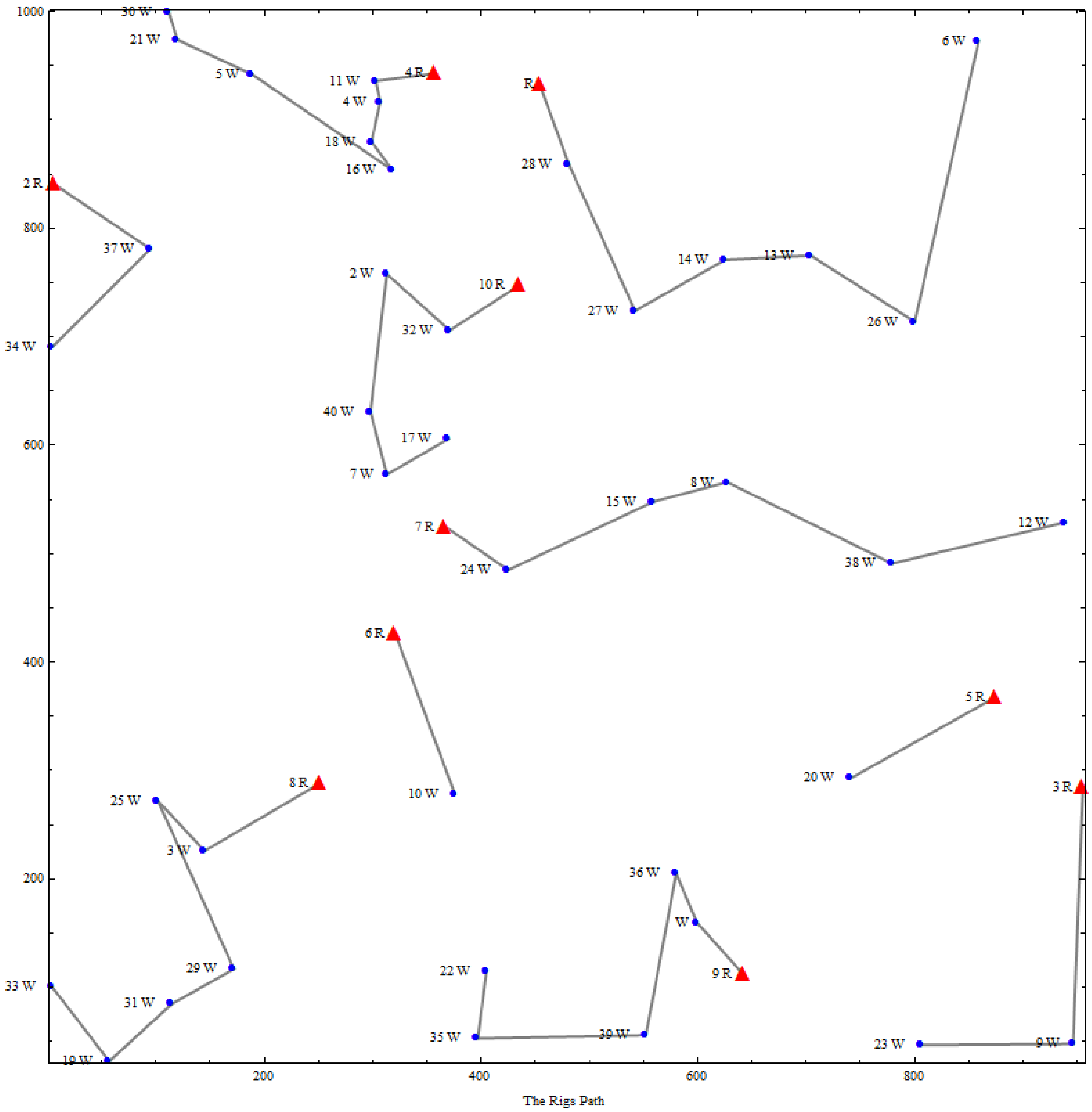

Figure 4.6.1.1 Scenario one output

Figure 4.6.1.2 presents the generated schedule. Note that rigs 1 & 4 were assigned to drill several wells while other rigs, such as rigs 5 & 6, are assigned to only one well. Even though the total operation days are not calculated, it is clear that the operation year will end without completing drilling all the due wells. This is a result of assigning more wells to fewer drilling rigs as in rig 4 and 8, and not optimizing the others.

In this scenario, the total distance was 4189 km; and it is clear that four drilling rigs are not optimized properly. Even though this is the basic scenario in this thesis, the same approach was used ultimately by Vineet Lasrado (2008) and Irgens et al. (2008).

4.6.2 Scenario Two

In this scenario, the well operation time will be introduced, so if a rig is drilling a well, it will be busy and will not be considered in the optimization process until it completes its original assignment. The first step is to find the shortest distance between all drilling rigs and wells using APSP algorithms (similar to scenario one). This scenario will subsequently search for the shortest distance between rigs and wells, then assign a rig to drill the closest well and keep it busy for a period of time that is equal to that well's operation time.

The algorithm for this scenario will be as follow:

```
W        = set of all wells
t(Wi)     = Well i operation time
t(DRi)    = time Drilling Rig i will be busy
DR  = set of all Drilling Rigs
SDM =  the  Shortest  Distance  Matrix  based  on  Floyd's
Algorithm, or Dijkstra's algorithm
Drilling Rig Schedule = empty

Optimum (or near Optimum) Drilling Rig Schedule ODRS(DR,W):

Shortest Distance = infinity
Shortest Distance Pair = (null, null)
for i in DR and t(DRi) = 0

   for j in W and j not Drilled
         if (SDM(i,j) < Shortest Distance)
               Shortest Distance = SDM(i,j)
               Shortest Distance Pair = (i, j)

    if(Shortest Distance = infinity)
    /* this indicate that all DR are busy*/
    For all i in DR
    t(DRi) = t(DRi) - 1

   else
   set j as Drilled
   assign DRi to Drill Wj
   set t(DRi) = t(Wj)
   update Drilling Rig Schedule


   if all j in W Drilled
   end

   else
    go to ODRS(DR,W) again

return
Drilling Rig Schedule
```

Algorithm 4.6.2.1 Scenario two algorithm

The main factors in this scenario are distance and well operation time; no cost function was used.

The optimization function in this scenario: Select the minimum distance between Drilling Rig *i* and Well *j* while Well *j* is not drilled, and Drilling Rig *i* is not busy.

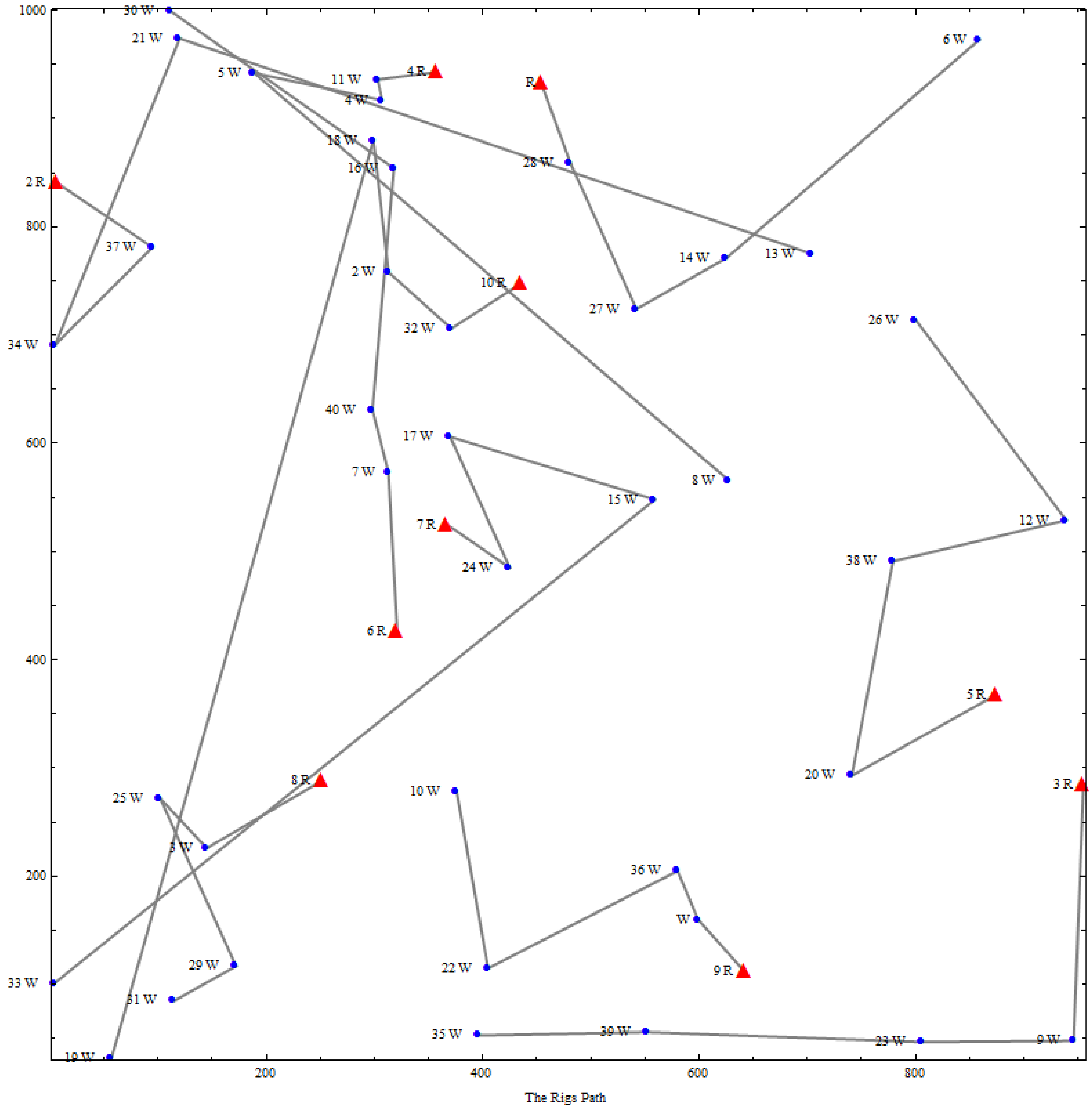

Figure 4.6.2.1 Scenario two output

Figure 4.6.2.2 gives a more realistic view of the Drilling Rig Schedule. Note that several drilling rigs are moving across the map. Rig 2 moves from Well 21 to Well 13 even if there are rigs very close to it; simultaneously Rig 10 is moving from Well 18 to Well 19. This is due to the fact that when some nearby rigs are busy and remote rigs are free, so they are assigned to these remote wells. In this scenario, the total distance is 7930 km and the total operation days is 112 days.

4.6.3 Scenario Three

In the second scenario, the issue was that some drilling rigs were assigned to drill remote wells even though there were closer drilling rigs. This third scenario tries to overcome this problem. The idea is to give the free drilling rigs a few days before they are assigned to new wells. These few days will allow other closer drilling rigs to complete their operations before getting involved in the next assignment, and they will be assigned to closer wells. The algorithm is similar to the second scenario, but with waiting mechanism:

```
W   = set of all wells
t(Wi)     = Well i operation time
t(DRi)    = time Drilling Rig i will be busy
DR  = set of all Drilling Rigs
SDM = the Shortest Distance Matrix based on Floyd's
Algorithm, or Dijkstra's algorithm
Drilling Rig Schedule total distance = infinity


Optimum (or near Optimum) Drilling Rig Schedule ODRS(DR,W):
for waiting Time = 1 to n
Temp Drilling Rig Schedule = empty
Shortest Distance = infinity
Shortest Distance Pair = (null, null)
for i in DR and t(DRi) = 0

    for j in W and j not Drilled
          if (SDM(i,j) < Shortest Distance)
                Shortest Distance = SDM(i,j)
                Shortest Distance Pair = (i, j)


     if(Shortest Distance = infinity)
     /* this indicate that all DR are busy*/
```

```
     For all i in DR
     t(DRi) = t(DRi) - waiting Time
     if(t(DRi) < 0) set t(DRi) = 0

    else
     set j as Drilled
     assign DRi to Drill Wj
    set t(DRi) = t(Wj)
     update Temp Drilling Rig Schedule


     if all j in W Drilled
    if  (Temp Drilling Rig Schedule total distance < Drilling
Rig Schedule total distance)
set Drilling Rig Schedule = Temp Drilling Rig Schedule

    go to ODRS(DR,W) with waiting Time +1

     if not all j in W Drilled
      go to ODRS(DR,W) again

    if waiting Time = n
    end

return
Drilling Rig Schedule
```

Algorithm 4.6.3.1: Scenario three algorithm

This scenario runs different loops. In each loop, it allows drilling rigs to wait for more days and calculate the total distance for the generated Drilling Rig Schedule. After all the loops are completed, it selects the one with shortest total distance.

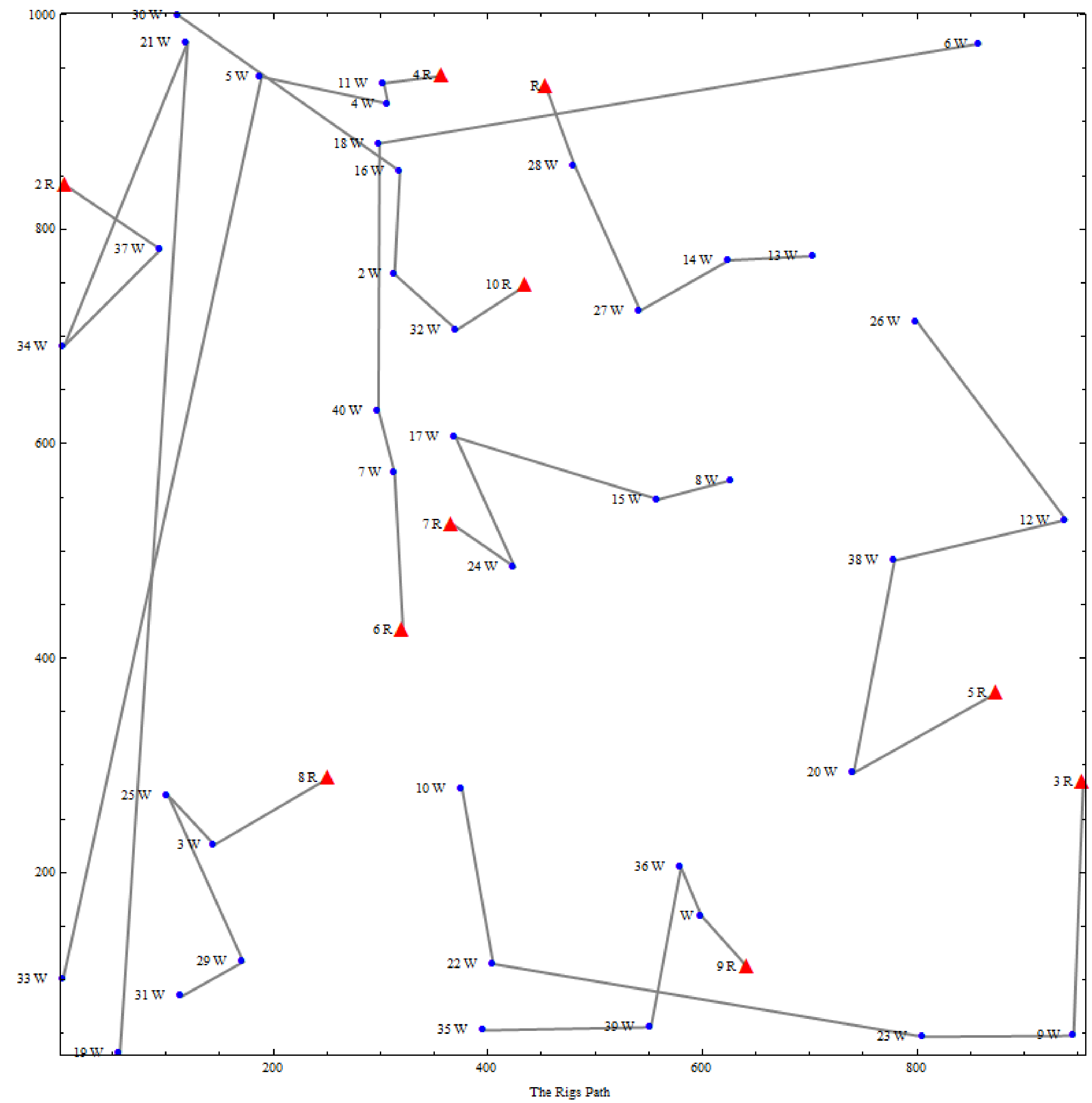

Figure 4.6.3.1 Scenario three output

Since no cost was used in this scenario, no cost function was used.

The optimization function: Run the second scenario with different waiting times, and generate the optimum Drilling Rig Schedule of each case, select the schedule with shortest total distance. The optimum Drilling Rig Schedule is the one with nine days of waiting time (Figure 4.6.3.1.2), and it gives a total distance of 7088 km and total operational days of 136. This scenario reduces the total distance by 10 percent, but increases the operation time by 21 percent.

4.6.4 Scenario Four

In some cases, the daily operation cost of a drilling rig is much more important than the moving cost, especially in the case of offshore drilling rigs. Therefore, optimizing the number of operation days will be more important than the total distance. The fourth scenario targets this issue. It is similar to scenario three, but it will optimize the number of operation days. In this scenario, several runs will be conducted; and the total number of operation days will be calculated in each run; and the one with least number of days will be considered the best Drilling Rig Schedule.

The algorithm:

```
W        = set of all wells
t(Wi)     = Well i operation time
t(DRi)    = time Drilling Rig i will be busy
DR  = set of all Drilling Rigs
SDM =  the  Shortest  Distance  Matrix  based  on  Floyd's
Algorithm, or Dijkstra's algorithm
Drilling Rig Schedule total number of days = infinity


Optimum (or near Optimum) Drilling Rig Schedule ODRS(DR,W):
for waiting Time = 1 to n
Temp Drilling Rig Schedule = empty
Shortest Distance = infinity
Shortest Distance Pair = (null, null)
for i in DR and t(DRi) = 0

    for j in W and j not Drilled
          if (SDM(i,j) < Shortest Distance)
                Shortest Distance = SDM(i,j)
                Shortest Distance Pair = (i, j)
```

```
     if(Shortest Distance = infinity)
     /* this indicate that all DR are busy*/
     For all i in DR
     t(DRi) = t(DRi) - waiting Time
     if(t(DRi) < 0) set t(DRi) = 0

    else
     set j as Drilled
     assign DRi to Drill Wj
    set t(DRi) = t(Wj)
     update Temp Drilling Rig Schedule


     if all j in W Drilled
    if  (Temp  Drilling  Rig  Schedule  total  number  of  days  <
Drilling Rig Schedule total number of days)
set Drilling Rig Schedule = Temp Drilling Rig Schedule

    go to ODRS(DR,W) with waiting Time +1

     if not all j in W Drilled
     go to ODRS(DR,W) again

    if waiting Time = n
    end

return
Drilling Rig Schedule
```

Algorithm 4.6.4.1 Scenario four algorithm

This scenario runs different loops. In each loop, it allows drilling rigs to wait for more days and calculate the total distance for the generated Drilling Rig Schedule. After all the loops are completed, it selects the one with the lowest number of operation days.

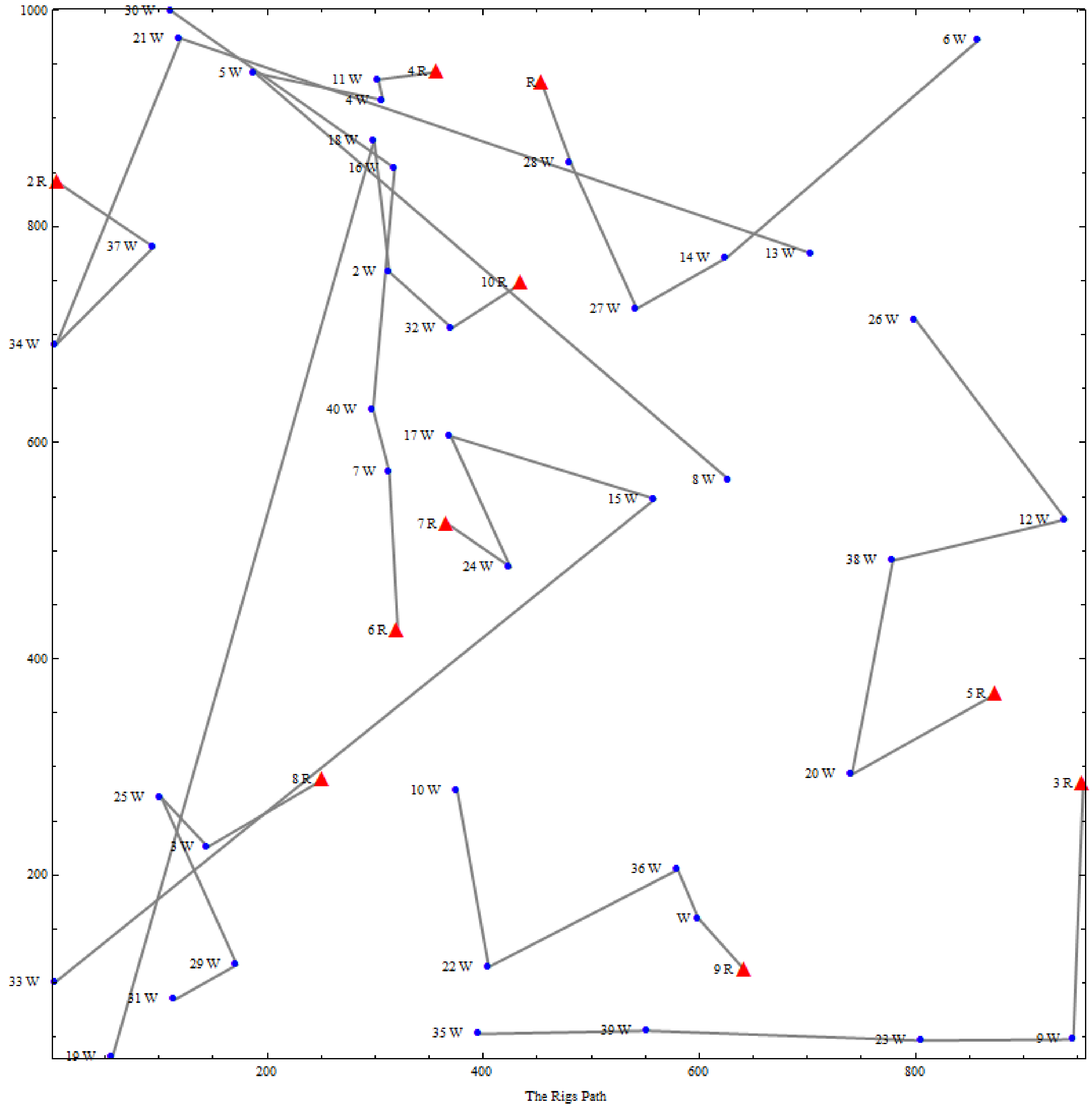

Figure 4.6.4.1 Scenario four output

Since the cost was not used in this scenario, no cost function was used.

The optimization function: Run the second scenario with different waiting time, and generate the optimum Drilling Rig Schedule of each case, select the schedule with lowest total operation days.

The optimum Drilling Rig Schedule is the one with one-day waiting time (Figure 4.6.4.1). It gives a total distance of 7930 km and a total operation days of 112 (similar to the result of scenario two).

4.6.5 Scenario Five

In this scenario, the cost factor was introduced as an output, not as a decision-making factor. This scenario runs the same algorithm as in the second scenario, but it calculates the total cost of the generated optimum Drilling Rig Schedule. For the algorithm used, see Figure 4.6.2.1

The total cost of a drilling rig will be calculated as follow:

```
W        = set of all wells
t(Wi)     = Well i operation time
DR  = set of all Drilling Rigs

total operation cost = 0
total moving cost = 0

For all i in DR
total moving cost = total moving cost + ( DRi moving cost *
distance DRi moves )
total operation cost = total operation cost + (DRi operation
cost * number of days DRi operate)

the total cost of the generated optimum Drilling Rig Schedule
= total moving cost + total operation cost
```

Algorithm 4.6.5.1 Scenario five cost function

This scenario will give us a sense of the cost of the optimum Drilling Rig Schedule, which will be used to compare with other advanced scenarios (see the next scenario).

From this scenario: the total moving cost is 9,130,357,400, the total operation cost is 15,722,310,000, and the total cost is 24,852,667,400.

4.6.6 Scenario Six

Optimizing the cost is the main objective of scenario six. This scenario will search for the rig that can drill a well with the lowest cost. It will identify each rig (DRi), and calculate the cost to drill each well, and then assign the best drilling rig to that well (Wi). After that, it will set (DRi) busy, and search again for other rig to drill other wells. Note that the busy rigs are not involved in the search process until they complete the drilling of their current wells.

The cost function that will identify the best rig to drill a well is as follow:

```
DRi = Drilling rig i
Wj = Well j
moving cost = DRi moving cost * the shortest distance from
DRi to Wj
operation cost = DRi operation cost * Wj operating time

the total cost of DRi to drill Wj =
moving cost + operation cost
```

Algorithm 4.6.6.1 Scenario six cost function

The algorithm of this scenario:

```
W   = set of all wells
t(Wi)    = Well i operation time
t(DRi)    = time Drilling Rig i will be busy
DR  = set of all Drilling Rigs
SDM = the Shortest Distance Matrix based on Floyd's
Algorithm, or Dijkstra's algorithm
Drilling Rig Schedule = empty
Cost Function(DRi,Wj) = the cost of DRi drill Wj =
```

```
(DRi moving cost * the shortest distance from DRi to Wj using
SDM(DRi, Wj)) +
(DRi operation cost * Wj operating time)

Optimum (or near Optimum) Drilling Rig Schedule ODRS(DR,W):

Best cost = infinity
Best cost Pair = (null, null)
for i in DR and t(DRi) = 0

   for j in W and j not Drilled
        if (Cost Function(i,j)  < Best cost)
             Best cost = Cost Function(i,j)
             Best cost Pair = (i, j)


    if(Best cost = infinity)
    /* this indicate that all DR are busy*/
    For all i in DR
    t(DRi) = t(DRi) - 1

   else
   set j as Drilled
   assign DRi to Drill Wj
   set t(DRi) = t(Wj)
   update Drilling Rig Schedule


   if all j in W Drilled
   end

   else
    go to ODRS(DR,W) again



return
Drilling Rig Schedule
```

Algorithm 4.6.6.2 Scenario six algorithm

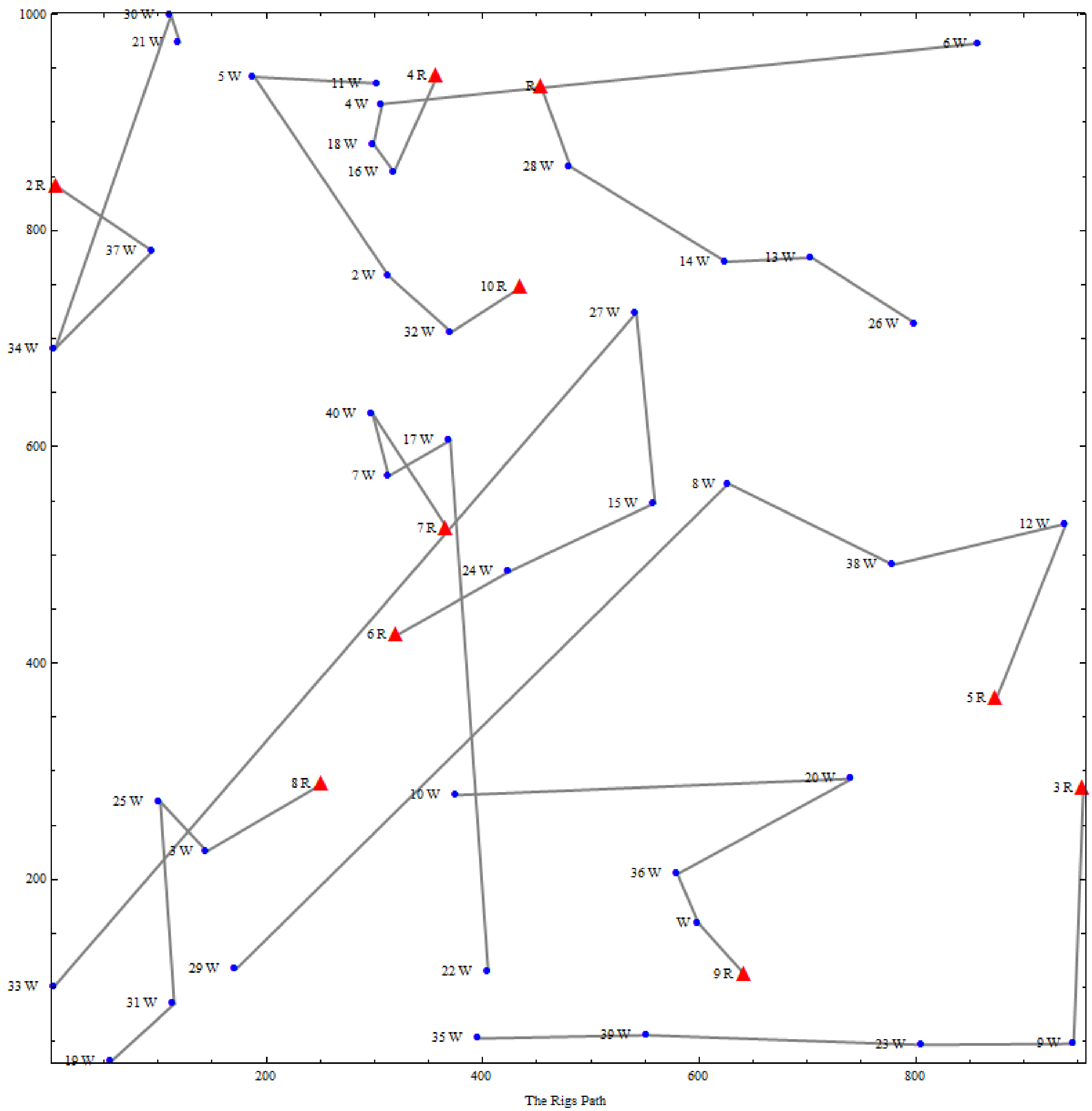

Figure 4.6.6.1 Scenario six output

The total distance is 7279 km, the total operation days is 111 days, the total moving cost is 8,332,240,600, the total operation cost is 15,726,342,000, and the total cost of the generated Drilling Rig Schedule is 24,058,582,600

4.6.7 Scenario Seven

It is worth noting that the same problem that occurs in scenario two is appearing in scenario six, in which rigs have to move a further distance because the nearby rigs are busy. In order to solve this problem, it is important to forecast the rig cost by calculating the drilling rig cost even when it is busy drilling other wells, and include this calculation in the searching process, and compare it to other drilling rigs.

Therefore, if DR1 is busy drilling W1, and DR2 is free, this scenario will calculate the cost of moving DR1 and drilling W2 after completing W1, and compare it with DR2 drilling W2 directly. If W2 is very close to DR1, then the cost of DR1 drilling W1 + W2 will be better than moving DR2 a long distance to drill W2. This logic will prevent rigs from moving a long distance if there are better rigs closer to those wells.

In this scenario, each drilling rig keeps track of the cost of each well it drills, and uses this cost value before it moves to the next well. As a result, the cost function will be as follow:

```
DRi = Drilling rig i
Wj = Well j
moving cost = DRi moving cost * the shortest distance from
DRi to Wj
operation cost = DRi operation cost * Wj operating time
the previous DRi costs = the cost of DRi drilling all the
wells before Wj

the total cost of DRi to drill Wj =
the previous DRi costs + moving cost + operation cost
```

Algorithm 4.6.7.1 Scenario seven cost function

The algorithm of this scenario:

```
W   = set of all wells
t(Wi)    = Well i operation time
t(DRi)   = time Drilling Rig i will be busy
DR  = set of all Drilling Rigs
previous costs (DRi) = the current total cost for DRi only
SDM = the Shortest Distance Matrix based on Floyd's
Algorithm, or Dijkstra's algorithm
Drilling Rig Schedule = empty
Cost Function(DRi,Wj) = the cost of DRi drill Wj =
(DRi moving cost * SDM(DRi , Wj)) +
(DRi operation cost * Wj operating time)+
(previous costs (DRi))

For all i in DR
set previous costs (DRi) = 0
t(DRi)   = 0


Optimum (or near Optimum) Drilling Rig Schedule ODRS(DR,W):

Best cost = infinity
Best cost Pair = (null, null)
for i in DR
```

```
    for j in W and j not Drilled
          if (Cost Function(i,j)  < Best cost)
                Best cost = Cost Function(i,j)
               Best cost Pair = (i, j)



    set j as Drilled
    assign DRi to Drill Wj
    set t(DRi) = t(Wj)
    update Drilling Rig Schedule
     set previous costs (DRi) = Cost Function(i,j)


    if all j in W Drilled
    end

    else
     go to ODRS(DR,W) again



return
Drilling Rig Schedule
```

Algorithm 4.6.7.2 Scenario seven algorithm

The generated Drilling Rig Schedule

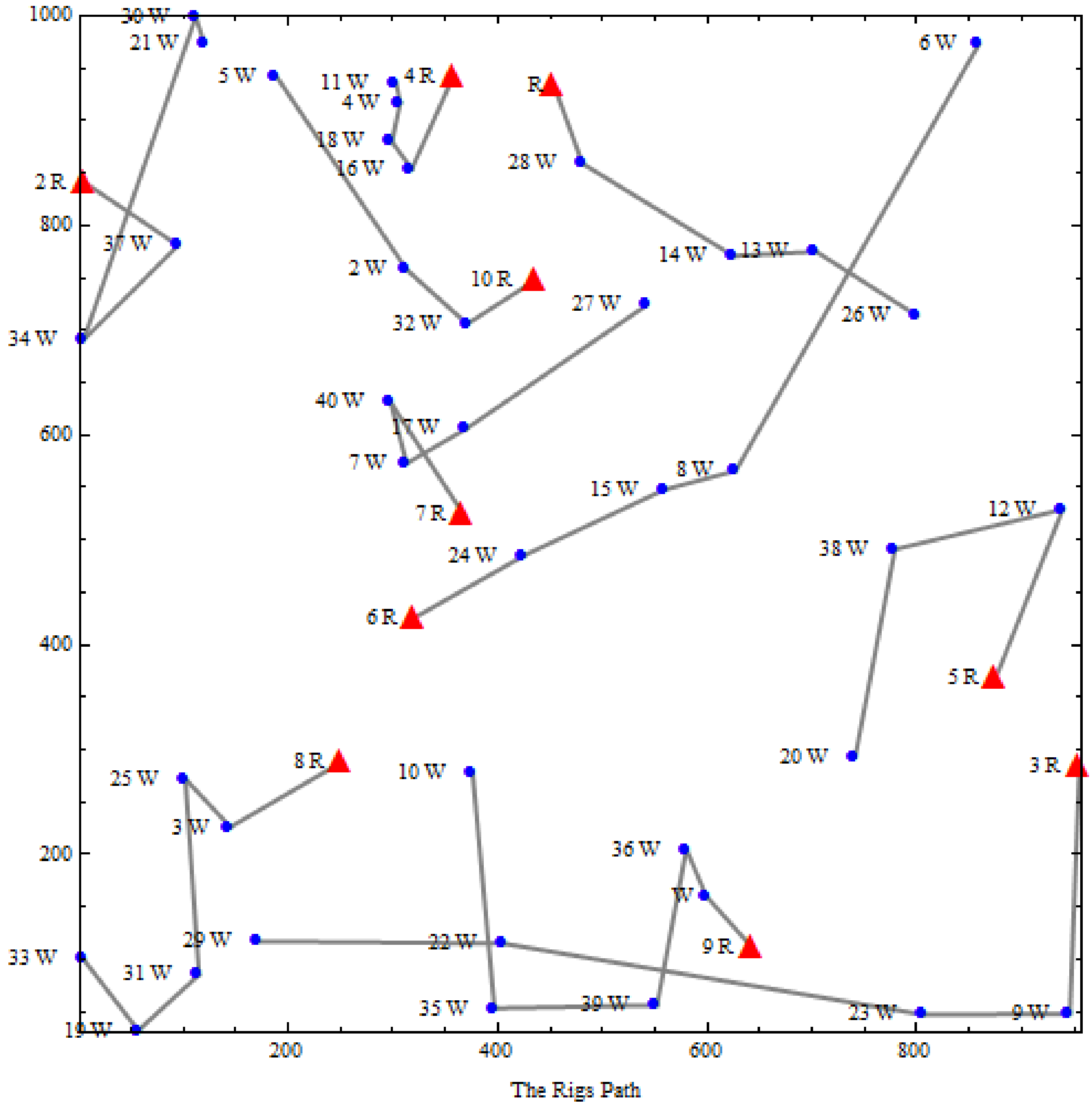

Figure 4.6.7.1 Scenario seven output

Note that the drilling rigs are moving in shorter distances, assigned almost the same number of wells and working in a smaller area. As a result, the total distance is

5579 km, the total operation days is 165 days, and the total cost of the generated Drilling Rig Schedule is 21,974,180,700.

In contrast to other scenarios, almost all the drilling rigs do not cross others area in this scenario. In addition, each drilling rig is operating in a specific area; for example, rigs 6 & 7 are in the center of the map, rig 2 is in the left upper corner of the map, rig 8 in the lower left corner of the map, and rig 4 is only handling a very close set of wells (Wells 16, 18, 4 and 11)

4.7 Case Study

The scenario five in this thesis is similar to the current process used in the industry. In this section, I try to run a real case, and compare a real industry drilling schedule with the result from scenario five, starting with getting a historical drilling schedule and finding out its total cost. I then use the same set of rigs and wells and try to generate another schedule using the algorithm that was used in scenario five. After that, I compute the total cost of the schedule generated by the algorithm of scenario five.

The total cost of the historical drilling schedule is compared with the one generated by the fifth algorithm, and the total cost of the historical drilling schedule is found to be better than the one in this study by only .05%. This small difference in total cost gives me the confidence that the algorithm in this study is very similar to the current industrial process handled manually.

4.8 Findings

The first scenario solved the problem based on distance only, and it resulted in moving a fewer number of drilling rigs, but other drilling rigs became ideal. In addition, since a fewer number of drilling rigs were used, I expect that it will take longer time to complete all the wells, and subsequently, the operation plan and the production will be delayed, affecting the company tremendously.

Even though the first scenario is not reflecting the actual work in preparing a Drilling Rig Schedule, it can be applied to a small-scale schedule that only requires a very few number of drilling rigs; for example, scheduling a very few number of drilling rigs in a specific reservoir.

This study considers the first scenario to be the most basic one, which is in contrast to some other studies, such as Lasrado (2008)'s and Irgens et al., (2008)'s, that consider this output to be the best result.

To give a more realistic result, rigs were set to be busy during drilling wells in the second scenario. This scenario involved all the rigs, so the total distance increased by 89 percent as a result. Actually, the process used in second scenario is almost matching the current process used in oil and gas companies. The difference is that their processes are manually applied and take days to weeks to generate one non-flexible drilling schedule. The second scenario can generate the schedule accurately in a very short time, and can adopt any changes in drilling rig or well. In addition, it can be more accurate than the manual process.

In the second scenario, the Drilling Rig Schedule moved the drilling rigs far distances even if there were closer rigs, because it moved the rig as soon it was free regardless of whether there were closer rigs that might be free in a few days. To solve this issue, scenario three allowed drilling rigs to wait a few days before it searched and moves to other wells. These few waiting days allowed other closer drilling rigs to complete their tasks and then to be included in the search process.

To make this scenario more advanced and smart, this scenario allowed all drilling rigs to wait for one day, generated the Drilling Rig Schedule, and then calculated the total distance. It repeated the same process from the beginning, but allowed drilling rigs to wait for two days, and so on for *n* times. It generated the drilling rigs and calculated the total distance in each loop. Finally the algorithm selected the Drilling Rig Schedule with the minimum total distance.

Based on current inputs, the total distance was 7088 km, the total operation was 136 days and waiting time was nine days.

By comparing the second scenario with the third scenario, this study found that the third scenario reduced the total distance by 10 percent, but increased operation days by 21 percent.

Optimizing the total moving distance of drilling rigs is a great achievement in a Drilling Rig Schedule. However, in some cases such as offshore drilling rigs, the daily operational cost is much higher than the moving cost.

In the fourth scenario, the objective was to optimize the drilling rig operation time. The process was similar to scenario three, in which several Drilling Rig Schedules were generated. In each schedule, the drilling rig waited for a specific number of days, and at the end the algorithm selected the Drilling Rig Schedule that had the minimum number of total operation days.

Based on the current input, the total distance was 7930 km, the total operation was 112 days, and the waiting time was one day. That means, there’s no difference between the second scenario and the fourth scenario.

It is clear that the optimum Drilling Rig Schedule, from an operational time point view, is the one with no waiting time. However, if the moving speed of drilling rigs is very slow, it is obvious that optimizing the distance will result in optimizing the time.

The main objective for optimizing the Drilling Rig Schedule’s total moving distance or total operation time is actually optimizing the total cost. Regardless of the type of drilling rig, or the type of optimizing process, the planning department in any oil and gas company would go with the Drilling Rig Schedule that optimizes the cost.

In the fifth scenario, the cost factor was introduced. This scenario used the generated Drilling Rig Schedule from scenario two and generated the total cost as follow:

```
The total cost =
SUM(
DRi moving cost * total moving Distance for DRi
+
DRi daily Rate cost * total operation days for DRi
)
```

The cost function in scenario five was not used as a decision factor; however, the objective was only to calculate the total cost to compare it with the following scenarios.

Scenario six used the cost function as the main decision factor. The cost function in this scenario used the drilling rig moving cost, drilling rig daily rate and well operation time, it then generated the cost for each drilling rig before it was assigned to a particular well. That means, this scenario searched for a drilling rig that could drill a well in the most cost effective way.

The cost function used in scenario six was the following:

If rig *i* will drill well *j* then the cost will be:

```
Cost (DRi, Wj)=
Moving cost of DRi * Distance from DRi to Wj
+
DRi daily cost * Operation days needed to complete Wj
```

The generated Drilling Rig Schedule gave a total distance of 7279 km, the total Operation of 111 days, and total cost of 24,058,582,600. This shows that the sixth scenario improved the operation days by 18 percent compared to the third scenario, the total distance by eight percent compared to the fourth scenario, and the cost by 3.12% compared to the fifth scenario.

The problem in the sixth scenario is that when a drilling rig is free, it is directly assigned to another well even if the distance is far away, and even if there are other rigs close by, but busy. For example, Drilling Rig 6 moves from Well 27 to 33, even there are other closer rigs, such as 7 and 8. This problem will result in increasing the total moving distance, and subsequently increasing the cost.

As shown earlier in the sixth scenario, some drilling rigs had to move a far distance when closer rigs were busy. I thought of applying the same to scenario three or four, but the problem in the real scenario is that a drilling rig cannot be still ideal. Even if the drilling rig is ideal, there is the daily cost; therefore, I included the forecast of the drilling rig cost even when it is busy. The idea is to involve the drilling rig in the search process even when it is actually busy drilling other wells.

In order to apply this concept, each drilling rig needs to keep track of the operational cost in the well that it is drilling, which will be used in the search process. Therefore, if Rig 1 is busy in W1, and Rig 2 completed W2 and now is free, in order to decide which one will drill W3 the following comparison will be applied:

The cost of Rig 1 drilling Well1 + the cost of Rig 1 drilling Well3 against the cost of Rig 2 drilling Well2 + the cost of Rig 2 drilling Well 3. So, if the distance between Rig 2 and

Well 3 is much higher than Rig 1 to Well 3, it will not be economically feasible for drilling Rig 2 to go and drill Well 3.

As a result the cost function will be is as follow:

```
DRi = Drilling rig i
Wj = Well j
moving cost = DRi moving cost * the shortest distance from
DRi to Wj
operation cost = DRi operation cost * Wj operating time
the previous DRi costs = the cost of DRi drilling all the
wells before Wj

the total cost of DRi to drill Wj =
the previous DRi costs + moving cost + operation cost
```

Even though this function will reduce the total distance and reduce the cost, it has an additional important effect. Linking the distance with cost will ensure that drilling rigs will work in a small circle/ small geological area and not moving too much, therefore limiting the operation for each drilling rig to a specific reservoir. This feature by itself will not only optimize the cost, but will also result in optimizing the drilling rigs' crew experience and knowledge, which is a very important byproduct of this algorithm.

From the generated Drilling Rig Schedule, the rigs are moving shorter distance, assigning an almost similar number of wells. In addition, the drilling rigs are working in a closed area; for example, Rig 4 is working on a very close series of wells, Rig 2 is focusing on the upper left corner of the map, Rig 8 is working only in the lower corner of the map. This specific assignment will allow the drilling rig crew to get more familiar with that specific geographic area that will help improve the drilling operation’s quality of work.

Chapter 5

CONCLUSION

The oil and gas industry is an old industry, but most of the enhancements and improvements have been in the hardware/ material level. This study tries to improve a different, but very important area of the industry. This study targets one of the most centralized and important processes, which is the planning level. This study develops an algorithm to optimize the Drilling Rig Schedule.

Currently, most of the processes used to generate Drilling Rig Schedule are a manual process, which is lengthy and complex, and has a large space for human error. This thesis develops an automated algorithm that generates an optimal (or near optimal) Drilling Rig Schedule.

This algorithm compared to the existing process will improve the result as follow:

	Current process	Developed algorithm	improvement
Total moved distance	7,930 km	5,579 km	30 %
Total operation days	112 days	165 days	- 47%
Total cost	24,852,667,400	21,974,180,700	11.5 %

Table **5.1 Compare current process with developed algorithm**

Table 5.1 compares the current process with a developed algorithm (the current process is based on the result from scenario five which is similar to the current manual process). The total moved distance was improved by 30 percent, the total operational days was reduced by 47 percent, and the total cost was improved by 11.5 percent. Even if the operation time increases a lot, the total cost, which is the main goal, is reduced by 11.5 percent. If the Drilling Rig Schedule deals with a large budget, the expected improvement in cost will be significant.

Optimizing the Drilling Rig Schedule and generating the most effective Drilling Rig Schedule are the main objectives of this thesis, and they were achieved. Moreover, extra benefits/ byproducts, which improved the Drilling Rig Schedule, were found during the development process of this algorithm. These benefits / byproducts include:

- the developed algorithm, which will be much faster and more accurate compared to the current human manual process;

- the Drilling Rig Schedule that include several dynamic factors, making updating the schedule in timely manner more challenging. However, the developed algorithm will overcome this problem and generate the schedule in a very short time.
- an analysis of the generated Drilling Rig Schedule that can indicate unutilized drilling rigs, so the planner can drop them from schedule plan for a more optimum Drilling Rig Schedule.
- a generated Drilling Rig Schedule that can identify the busy drilling rigs and busy area, enabling more resources to be introduced and/or assigned to that particular area.
- a developed algorithm that can limit the travel of drilling rigs, allowing drilling rigs to work in specific geological area and limiting the operation in a specific area. This algorithm will also optimize the drilling rig crew's experience and knowledge, helping them become more familiar and more knowledgeable with the geological structure and operational type of the rig. This is a very important achievement.

Chapter 6

FUTURE WORK

This study set out to develop a full solution for optimal Drilling Rig Schedules, but due to the large scale of the problem, the solution was limited to the developed one. Therefore, the findings of this study set the foundation for further research about drilling rig scheduling. Recommendations for future work include:

- extending the problem assumption: schedule for oil/ gas wells, and introduce drilling rigs with different capabilities or consider the drilling rig moving time.
- including other problem factors: such as dependent wells, add some noise such as well completion delay, or drilling rig maintenance event.
- optimizing the drilling rig: the algorithm can be smarter if it was allowed to drop unutilized drilling rig, or introduce new ones in the busy area, and generate the schedule based on these new factors
- optimizing the production: the current algorithm optimizes the cost of Drilling Rig Schedule. If this schedule is integrated with the production schedule (the schedule that indicates when each well will be linked to the production network) and

generate a schedule that optimizes the drilling and production operation. If this approach can be achieved, it will highly improve the oil and gas industry.

- different optimization goal: the main objective of this algorithm was to optimize the cost. In some cases, it was necessary to optimize the production, number of operation days, number of drilling rigs; or it could be more specific, such as optimizing a specific types of oil wells based on its fluid quality (API). It may be necessary to generate algorithms in order to address these issues.

APPENDIX

Source code

```
(* Clear All Old Variables and functions*)
Clear["`*"]
<< Combinatorica`

(*Set the Date*)
(*get the Number of Rigs& Wells*)

NumberOfRigs = 10;
NumberOfWells = 40;
NumberOfRigsAndWells = NumberOfRigs + NumberOfWells;

RigsPoints                                                          =
{{454,933},{6,841},{955,284},{358,943},{875,368},{321,426},{3
67,525},{251,288},{642,112},{436,748}};
WellsPoints                                                         =
{{599,160},{313,758},{145,226},{307,917},{189,942},{859,973},
{313,573},{627,566},{946,48},{376,278},{303,936},{939,529},{7
04,775},{625,771},{559,548},{318,854},{370,606},{299,880},{57
,32},{741,293},{120,974},{405,115},{806,47},{425,485},{102,27
2},{800,714},{542,724},{481,859},{172,117},{112,999},{115,85}
,{371,706},{4,101},{5,691},{397,53},{580,205},{95,781},{779,4
91},{552,56},{298,631}};
GraphPoints = Join[RigsPoints, WellsPoints];

(* set Min Max Opertation Days  *)
OperationDaysMin = 30;
OperationDaysMax = 40;

(* Set Operation Days *)
RigsOperationDays   = Table[0 , {NumberOfRigs}];
WellsOperationDays  = Table[0 , {NumberOfWells}];

WellsOperationDays                                                  =
```

```
{33,39,31,36,32,38,38,39,32,37,38,32,30,36,32,30,39,39,34,35,
34,38,31,39,30,39,39,32,37,30,31,33,35,33,33,31,34,36,31,30};
OperationDays = Join[RigsOperationDays, WellsOperationDays];


(* Set Rig Rate + Moving Cost *)
RigsRate = Table[0 , {NumberOfRigs}];
RigMovingCostPerKM = Table[0 , {NumberOfRigs}];

RigsRate                                                    =
{10922000,11485000,11494000,12347000,11698000,11370000,113620
00,11268000,10201000,12059000};
RigMovingCostPerKM                                          =
{1092200,1148500,1149400,1234700,1169800,1137000,1136200,1126
800,1020100,1205900};

RigTotalCost        = Table[0 , {NumberOfRigs}];
RigTotalOperationDay     = Table[0 , {NumberOfRigs}];
RigTotalMovedDistance    = Table[0 , {NumberOfRigs}];


(* Prepare the Data *)

(*the Labels*)
RigsLabel = Table["R" i, {i, NumberOfRigs}];
WellsLabel = Table["W" i, {i, NumberOfWells}];
GraphLabels = Join[RigsLabel, WellsLabel];

RigsData = Table[0, {NumberOfRigs}, {7}];

For[i = 1 , i <= NumberOfRigs, i ++,
 RigsData[[i, 1]] = RigsLabel[[i]];
 RigsData[[i, 2]] = RigsPoints[[i]];
 RigsData[[i, 3]] = RigsRate[[i]];
 RigsData[[i, 4]] = RigMovingCostPerKM[[i]];
 RigsData[[i, 5]] = RigTotalMovedDistance[[i]];
 RigsData[[i, 6]] = RigTotalOperationDay[[i]];
 RigsData[[i, 7]] = RigTotalCost[[i]];
 ]

 Print["The Rigs Problem Data"];
Print[MatrixForm[RigsData,
 TableHeadings -> {{}, {"Label", "(X,Y)", "Rigs Daily Rate",
"Rig  Moving  Cost  /  KM",  "Total  Moved  Distance",  "Total
Operation Day", "Total Cost"}}]]
```

```
WellsData = Table[0, {NumberOfWells}, {4}];

For[i = 1 , i <= NumberOfWells, i ++,
 WellsData[[i, 1]] = WellsLabel[[i]];
 WellsData[[i, 2]] = WellsPoints[[i]];
 WellsData[[i, 3]] = WellsOperationDays[[i]];
 WellsData[[i, 4]] = "No";
 ]

 Print["The Wells Problem Data"];
Print[MatrixForm[WellsData,
 TableHeadings -> {{}, {"Label", "(X,Y)", "Operation Day",
"Done"}}]]



(*Define a function to compute the distnace between Two
Points *)
distanceBetweenPoints[p1_, p2_] := ((p2[[1]] - p1[[1]])^2 +
(p2[[2]] - p1[[2]])^2)^.5

(*Floor the Distance Between Two Points*)
fdbp[p1_, p2_] := Floor[distanceBetweenPoints[p1, p2]]

(* Compute the Distance *)
distanceMatrix = Table[0, {NumberOfRigsAndWells},
{NumberOfRigsAndWells}];

For[i = 1 , i <= NumberOfRigsAndWells, i++,
 For[j = i , j <= NumberOfRigsAndWells, j++,

(*no direct distance between Rigs .. *)
If[i <= NumberOfRigs && j <= NumberOfRigs,
distanceMatrix[[i, j]] = Infinity,
distanceMatrix[[i, j]] = fdbp[GraphPoints[[i]],
GraphPoints[[j]]]
]

;distanceMatrix[[j, i]] = distanceMatrix[[i, j]]

  ]
 ]
```

```
(*Plot the Date*)
(*Plot the Location of Rigs -in Red- & Wells*)
PointLocation =
 Graphics[{Style[Text["\[FilledUpTriangle]",       #]       &/@
RigsPoints, FontColor -> Red, FontSize -> 20],
 Style[Text["\[FilledCircle]", #] &/@ WellsPoints, FontColor
-> Blue, FontSize -> 8],
 MapThread[Text[#1,    #2,    {2,    0}]    &,    {GraphLabels,
GraphPoints}]},
  PlotRangePadding -> 2, Frame -> True, FrameLabel -> { "The
Location of Rigs & Wells "}, ImageSize -> {400}]
Print["\n\n"]
Print[PointLocation]


(*All Pair Shortest Path*)

(* Convert From Matrix to Graph*)
distanceGraph      =      FromAdjacencyMatrix[distanceMatrix,
EdgeWeight, Type -> Directed];
Dijkstra[distanceGraph, 2];
APSP = AllPairsShortestPath[distanceGraph];

(* Show the Distance *)
Print["\n\n"]
Print["All Pairs Shortest Path Matrix :"]
Print[MatrixForm[APSP,    TableHeadings    ->    {GraphLabels,
GraphLabels}]]


(* Remove the Distance Between Rigs  (set to infinity) *)
For[i = 1, i <= Length[APSP], i++,
 For[j = 1, j <= Length[APSP], j++,
If[i  <=  NumberOfRigs  &&  j  <=  NumberOfRigs,  APSP[[i,  j]]  =
Infinity, True];
(* the Distance to itself = 0*)
If[i == j , APSP[[i, j]] =0, True]
  ]]

(* Show the Distance From Rigs Only*)
APSPRigs = Drop[APSP, {NumberOfRigs + 1, Length[APSP]}];
Print["\n\n"]
Print["All Pairs Shortest Path Matrix (Rigs Only):"]
Print[MatrixForm[APSPRigs,   TableHeadings   ->   {GraphLabels,
GraphLabels}]]
```

```
(*Optemize Drilling Rig Schedule*)
AllWellsAreDrilled = False;

rigsPathLine  = Table[0, {NumberOfWells}];
rigsPathLineCounter = 1;

debugString = Table[0,{100000}];
debugStringCounter  = 1;

ODRS = Table[".", {NumberOfRigs}, {NumberOfWells}];
ODRSCounter   = 1;

While[!AllWellsAreDrilled ,

   debugString[[debugStringCounter++]] = "\n\n";

   AllWellsAreDrilled = True;



   currentMinCost  = Infinity;
   currentMinRig   = -1;
   currentMinWell  = -1;
   cost       = 0;



   For[i = 1 , i <= NumberOfWells, i++,
   debugString[[debugStringCounter++]]  =  ToString[i]  <>  ")
can we drill Well :" <> ToString[WellsData[[i,1]]] <>" ?";

   For[j = 1 , j <= NumberOfRigs, j++,

        If[!StringMatchQ[WellsData[[i,  4]],  "No"],  Break[],
True];
        cost   =   RigsData[[j,   7]]   +   (RigsData[[j,4]]   *
APSPRigs[[j,  NumberOfRigs  +  i]])  +  (RigsData[[j,  3]]  *
WellsData[[i,3]]);

   debugString[[debugStringCounter++]]  =  "("<>  ToString[i]<>
","<>  ToString[j]<>  ")     "  <>ToString[RigsData[[j,  1]]]
<>"[["<>ToString[WellsData[[i,         1]]]<>"]]:"         <>
```

```
ToString[RigsData[[j,       7]]       <>"       +       ("<>
ToString[RigsData[[j,4]]]  <>"  *  "<>  ToString[APSPRigs[[j,
NumberOfRigs  +  i]]]  <>  "  )  +  (  "<>ToString[RigsData[[j,
3]]]<>"     *     "<>ToString[WellsData[[i,3]]]<>"     )     =
"<>ToString[cost];

         If[cost < currentMinCost,
         currentMinCost  = cost;
         currentMinRig   = j;
         currentMinWell  = i;
         , True];
   ];(*End For[j = 1 , j <= NumberOfRigs, j++,*)
   ];(*End For[i = 1 , i <= NumberOfWells, i++,*)




   (**)
   WellsData[[currentMinWell, 4]] = "Yes";
   RigsData[[currentMinRig,  5]]  =  RigsData[[currentMinRig,
5]]     +     APSPRigs[[currentMinRig,     NumberOfRigs     +
currentMinWell]];
   RigsData[[currentMinRig,  6]]  =  RigsData[[currentMinRig,
6]] + WellsData[[currentMinWell,3]];
   RigsData[[currentMinRig,  7]]  =  RigsData[[currentMinRig,
7]] + (RigsData[[currentMinRig,4]] * APSPRigs[[currentMinRig,
NumberOfRigs + currentMinWell]]) + (RigsData[[currentMinRig,
3]] * WellsData[[currentMinWell,3]]);


   debugString[[debugStringCounter++]]  =  "The  Minimum  Cost
is:  "<>ToString[RigsData[[currentMinRig,  1]]]  <>  "  Drill
"<>ToString[WellsData[[currentMinWell,   1]]]   <>   "   :"
<>ToString[currentMinCost]<>".";


   (* Capture teh generated schedule*)
   ODRS[[currentMinRig,           ODRSCounter++]]           =
WellsData[[currentMinWell, 1]];

   (*Capture the Path*)
   rigsPathLine[[rigsPathLineCounter++]]                    =
Line[{RigsData[[currentMinRig,2]],WellsData[[currentMinWell,2
]] }];

   (*
```

```
    Print[RigsData[[currentMinRig, 1]], " will drill ",
WellsData[[currentMinWell,1]], " cost:", currentMinCost];
    *)

    (*Update Distance Matrix*)
    For[i = 1, i <= Length[APSPRigs[[currentMinRig]]], i++,
    APSPRigs[[currentMinRig, i]] = APSP[[NumberOfRigs +
currentMinWell, i]];
    If[i <= NumberOfRigs, APSPRigs[[currentMinRig, i]] =
Infinity, True];
    If[i == currentMinRig, APSPRigs[[currentMinRig, i]] = 0,
True];
    ];

    (*Update the Location of the Rig*)
    RigsData[[currentMinRig, 2]] =
WellsData[[currentMinWell,2]];

    debugString[[debugStringCounter++]] = "Updated Distance
Matrix:";
    debugString[[debugStringCounter++]] = MatrixForm[APSPRigs,
TableHeadings -> {GraphLabels, GraphLabels}];

    (*is there still Well not Drilled ?*)
    For[i = 1 , i <= NumberOfWells, i++,
    If[WellsData[[i, 4]] == "No", AllWellsAreDrilled = False;
Break[], True ]];



];(* End While[!AllWellsAreDrilled*)





(* Debug
(*debug? 0 = No, 1 = Yes*)
debug = 0;

If[debug == 1 ,
For[i = 1 , i <= debugStringCounter, i++,
    Print[i, " ", debugString[[i]]]]
, True];

*)
```

```
(*OutPut and Result*)

(*Plot the Rigs Path *)
PointLocation =
 Graphics[{{Thick, Gray,rigsPathLine}, Style[Text["\[FilledUpTriangle]", #] &/@ RigsPoints, FontColor -> Red, FontSize -> 20],
   Style[Text["\[FilledCircle]", #] &/@ WellsPoints, FontColor -> Blue, FontSize -> 8], MapThread[Text[#1, #2, {2, 0}] &, {GraphLabels, GraphPoints}]},
  PlotRangePadding -> 2, Frame -> True, FrameLabel -> { "The Rigs Path "}, ImageSize -> {500}];

  Print[PointLocation]

TotalMovedDistance  = 0;
TotalOperationDay   = 0;
TotalCost           = 0;

For[i = 1 , i <= NumberOfRigs, i ++,
 TotalMovedDistance += RigsData[[i, 5]];

If[RigsData[[i, 6]] > TotalOperationDay, TotalOperationDay = RigsData[[i, 6]], True];

(* TotalOperationDay     += RigsData[[i, 6]];*)
 TotalCost          += RigsData[[i, 7]];
 ]


Print["The Optemize Drilling Rig Schedule :"];
Print[MatrixForm[ODRS, TableHeadings -> {GraphLabels}]];
Print["The Schedule Total Distance = ", TotalMovedDistance];
Print["The Schedule Total Number Of Days = ", TotalOperationDay];
Print["The TotalCost Total Rig Cost = ", TotalCost]


 Print["Details Operation data (By Rig)"];
Print[MatrixForm[RigsData,
 TableHeadings -> {{}, {"Label", "(X,Y)", "Rigs Daily Rate", "Rig Moving Cost / KM", "Total Moved Distance", "Total Operation Day", "Total Cost"}}]]
```

```
Print["\n\n End Main Run"];
```

BIBLIOGRAPHY

Aloise, D.J., Aloise, D., Rocha, C.T.M., Filho, J.C.R., Moura, L.S.S., & Ribeiro, C.C. (2006). Scheduling Workover Rigs for Onshore Oil Production. Discrete Applied Mathematics, 154(5), 695-702. DOI: 10.1016/j.dam.2004.09.021

Alsuwaiyel, M.H. (1999). Algorithms: Design Techniques and Analysis. Dhahran: KFUPM

Brennan, J.J., Barnes, J.W., & Knapp, R.M. (1997). Scheduling a Backlog of Oilwell Workovers. Journal of Petroleum Technology, 29(12), 1651-1653. DOI: 10.2118/5986-PA.

de Andrate Filho, A.C.B. (1994). Optimal Scheduling of Development in an Oil Field. Petroleum Engineering Department: Stanford University. Available at http://ere.stanford.edu/pdf/pereports/MS/Bittencourt94.pdf

Fanchi, J.R. (2006). Petroleum Engineering Handbook, Volume I: General Engineering. TX: SPE.

Irgens, M., Guzman, R.P., Stamatopoulos, J., & Jackson, K. (2008). Optimization for Operational Decision Support: The Rig Fleet Management Case. Paper presented at the SPE Annual Technical Conference and Exhibition, 21-24 September, Denver, Colorado, USA. DOI: 10.2118/116616-MS

Irgens, M., & Lasher, W. (2007). Use of Advanced Optimization Techniques To Manage a Complex Drilling Schedule. Paper presented at the SPE Annual Technical Conference and Exhibition, 11-14 Novembe, Anaheim, California, U.S.A. DOI: 10.2118/110805-MS.

Israel, M. (2008). Advances in Rig Scheduling Techniques, Upstream Technology, 3(4), 2-5. Available at http://www.actenum.com/files/PR_Upstream_technology_Apr08_Rig_Scheduling.pdf

Lasrado, V.K. (2008). Workover Rig Scheduling Using Reservoir Simulation. Paper presented at the Intelligent Energy Conference and Exhibition, 25-27 February, Amsterdam, The Netherlands. DOI: 10.2118/111477-MS.

Mitchell, R.F. (2006). Petroleum Engineering Handbook, Volume II: Drilling Engineering TX: SPE.

Richard H. Schulze (1977) Scheduling a Backlog of Oil well Workovers, SPE 5986

R. M. Aiex, M. G. C. Resende, & C. C. Ribeiro,(2002).Probability distribution of solution time in GRASP: An experimental investigation, Journal of Heuristics, 8, 343–373.

D. Aloise,(2002). New Metaheurısticas Optimization Approaches to the problem of Off-Shore Production, MSc Thesis, Department of Computer Science and Applied Mathematics: Federal University of Rio Grande do Norte, Brazil

D. Aloise, T. F. Noronha, R. S. Maia, V. G. Bittencourt, & D. J. Aloise,(2002).Ant Colony Optimization Metaheuristic Method for Path-relinking Problem in the Optimization of Rig Assignment, present at the XXXIV Brazilian symposium, Operations Research, Rio de Janeiro

M. Dorigo & T. Stutzle,(2003).The ant colony optimization metaheuristic: Algorithms, applications, and advances. F. Glover and G. Kochenberger, 251–285, Kluwer Academic Publishers.

P. Hansen & N. Mladenovic,(1999).An introduction to variable neighbourhood search, S. Voss, S. Martello, I.H. Osman, & C. Roucairol, 433–458, Kluwer Academic Publishers

P. Hansen & N. Mladenovic(2003).Variable Neighborhood Search, F. Glover & G. Kochenberger, 145–184, Kluwer Academic Publishers.

N.Mladenovic & P. Hansen(1997), Variable Neighbourhood Search, Computers and Operations Research, 24, 1097–1100.

T. F. Noronha,(2001).GRASP Metaheuristic Methods for Rig Assigmnent and Scheduling, MSc Thesis, Department of Computer Science and Applied Mathematics:Federal University of Rio Grande do Norte, Brazil

T. F. Noronha, F. G. Lima, & D. J. Aloise,(2001).A greedy heuristic algorithm applied to the problem of managing interventions in oil wells, published in the XXXIII Brazilian Symposium on Operations Research, page 135, Campos do Jordao.

Aranofsky, J. S.& Williams, A. C.,A use of linear programming and mathematical models in underground oil production, Management Sciences,8,394-407.

Bohannon, J. M.,A linear programming model for optimum development of multi-reservoir pipeline systems,J. Pet. Technol., 22, 1429-1436.

Brooke, A.& Kendrick, D.,Meeraus A.,(1992). GAMS: A Users Guide, Scientific Press: Palo Alto, CA

Costa, L. R.(1975), Optimization models for offshore oil field development, Ph.D Dissertation, Case Western Reserve University, Cleveland, OH.

Devine, M. D.; Lesso, W.G, "Models for the minimum cost development of offshore oil fields," Manage. Sci. 1972, 18, 378-387.Dogru, S. The optimization of profitability for offshore oil field operations. Ph.D Dissertation, University of Texas, Austin, TX,1975.

Frair, L. C.,(1973). Economic optimization of offshore oil field development, Ph.D Dissertation, University of Oklahoma, Tulsa, OK.

Garcia-Diaz, I. C.,(1996). A new methodology for minimizing investment in the development of offshore fields, SPE Prod. Facil. ,10, 22.

Harding, T. J., Radcliffe, N. J.& King, P. R.,(1996). Optimisation of Production Strategies Using Stochastic Search Methods, present at the NPF/SPE European 3-D Reservoir Modelling Conference 16-17 April, Stavanger, Norway, SPE33518

Lee, A. S.& Aranofsky, J. S.,(1958). A linear programming model for scheduling crude oil production, Pet. Trans. AIME , 213,389-392.

Nemhauser, G. L.& Wolsey, L. A.,(1988). Integer and Combinatorial Optimization, Wiley: New York, .

Sullivan, J., (1982). A computer model for planning the development of an offshore oil field, J. Pet. Technol. 34, 1555.

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