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Integrated Project and Supply Chain Management in Well Drilling Process

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Integrated Project and Supply Chain Management in Well Drilling Process

by

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Abstract

This thesis work provides a mixed integer programming model to help integrating the drilling operation and supplier selection in well drilling process of oil/gas production. The appropriate decisions on the services orders are taken based on three criteria including service duration, cost and timely deliverance. The schedule of drilling operation is based on regular working time and overtime. The research outcomes provide the optimal or rational solutions for the decisions on: supplier selection, regular working time vs. overtime planning for each activity, and the total project duration with the minimum total project cost. The two typical drilling operation project cases from a local oil/gas company are collected and conducted to validate the feasibility and effectiveness of the model. In the thesis, the conflicts and trade-offs on the business profits and project time control between the operator company and its suppliers are also discussed. To solve the problem resulted from divergent positions between the operator company and its suppliers, the sharing risk and incentive contract are suggested to be adopted by the operator companies in oil/gas production from other manufacturing research and applications. In short, this study is novel and beneficial for drilling project management as it could improve the performance of drilling operations and to integrate the activities of the suppliers.

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Chapter One: Introduction

1.1 Background

Global competition has been forcing the oil industry to be more efficient and green. Such pressure is driving drilling projects to move towards to integrated supply chain management and project management. Using supply chain management techniques such as just-in-time (JIT) delivery and opportunity scheduling in drilling project could improve the efficiency and reduce the environment impact of the project. Supply chain management is well-known in many industries, but it is somehow not widely applied in oil industry. For all different size drilling operations either on land or offshore, the rigs require person to operate. On the other hand, these operations are technically complex which normally requires different companies and individual contractors being involved in a drilling project. These companies or contractors may include operating company (i.e. so-called oil company), drilling contractors, service companies and supply companies (Bommer, 2008). For simplicity, this thesis work considers the drilling contractors, service companies and supply companies generally as suppliers. How to manage and coordinate these suppliers can dramatically affect the drilling project schedule, cost and its impact on the environment. It is not rare that a drilling project runs out its budget, beyond its deadline and causes a lot of environment pollution problems due to the uncertainty and poor management of these suppliers as well as the project management itself. Therefore, to integrate supply chain management techniques and project management techniques to manage a drilling project becomes an interesting research topic and yet a promising

approach to solve the project management problems in drilling projects. This is the motivation for carrying out this thesis research project.

Well service is a kind of outsourcing operations and the well service operations constitute more than 70% of a drilling project. Since these outsourcing operations have the most direct effect of drilling efficiency, supplier evaluation and selection is becoming an important decision in a drilling project. A good or suitable supplier will reduce the uncertainty in the project management and smooth coordination with an oil company. Otherwise, it could cause excessive project delay, poor-quality and environment problems. Therefore, this thesis research project needs to deal with the combined problem of project schedule and supplier's evaluation and selection.

Finally, to minimize overall project cost is obvious a critical concern to every oil company. In practice, quite a few pieces of expensive drilling and service equipment are not used efficiently and they are most of time idle. To integrate and manage well service operations and drilling operations will reduce these idle times which could lead to dramatically shorted project duration and hence the total drilling cost.

1.1.1 Supplier involvement

Supply chain management (SCM) is defined as the integration of key business processes from end user through original suppliers that provide products, services, and information and hence add value for customers and other stakeholders (Lambert, Cooper, & Pagh, 1998). As Simchi-Levi (2000) summarized, SCM is a set of approaches utilized to effectively integrate suppliers, manufacturers, warehouses, and stores, so that the merchandise is produced and distributed at the right quantities, to the right locations, and at

the right time, in order to minimize system wide cost while satisfying service level requirements.

As suppliers are being involved into a drilling process, evaluation and selection of the suppliers is getting increasingly critical to an oil industry. Selecting a wrong supplier could be harmful to deteriorate the whole supply chain's financial and operational position. Several factors affect a supplier's performance, such as quality, cost, and delivery time. It is necessary to make a trade-off between tangible and intangible factors to find the best supplier. Thus, supplier evaluation and selection, along with the mechanism and methodologies of supplier involvement in drilling project are worth of being researched.

1.1.2 Drilling operation

Oil and gas are a necessity in society and as well-known they are found under the ground. A drilling project aims at perforating the earth's surface and rock layers in order to make a well to extract oil and gas on the ground. A typical wellbore architectural diagram for an on land well is shown in Figure 1-1.

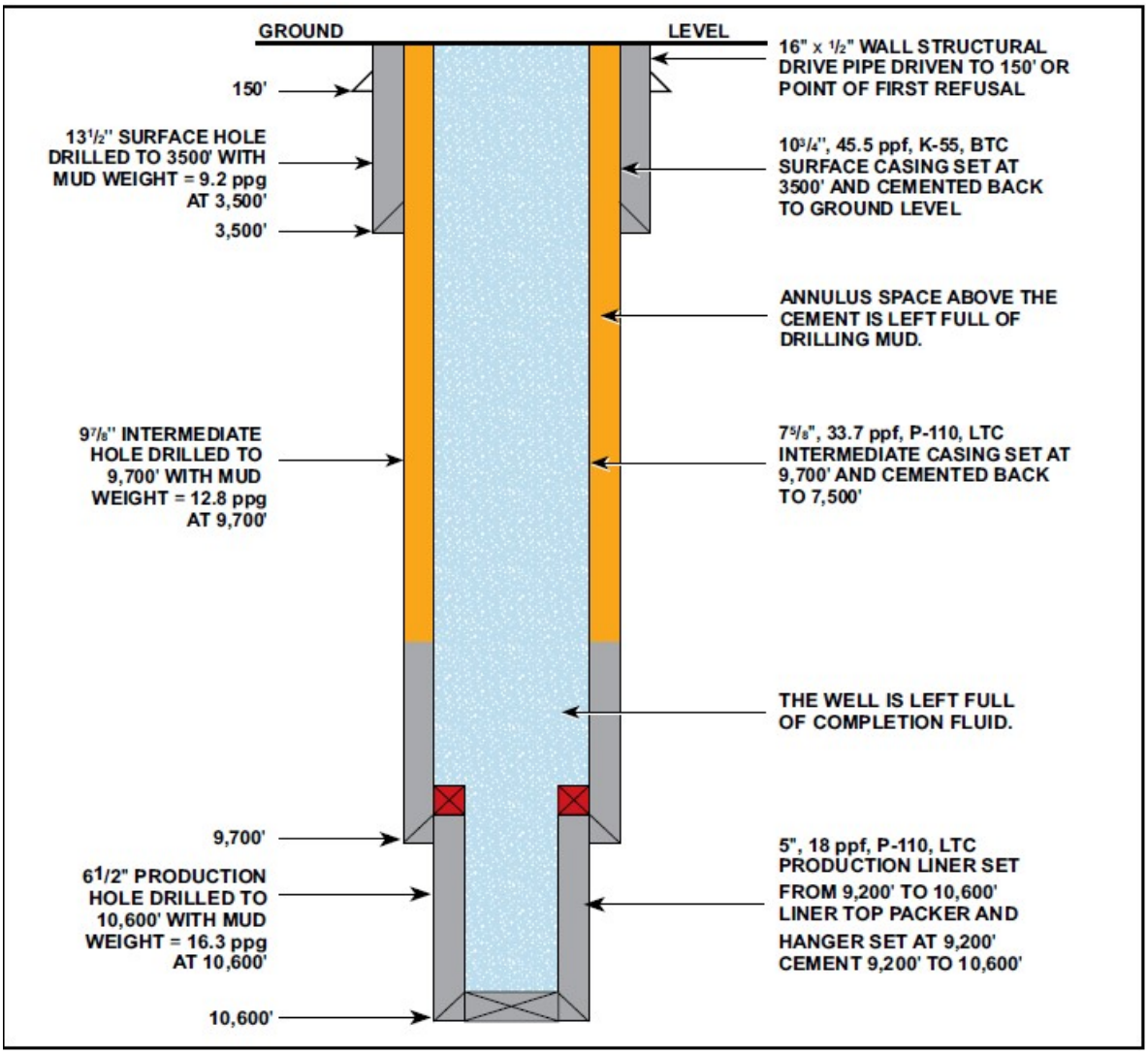


Figure 1-1 Typical wellbore architecture (Bommer, 2008)

A drilling project encompasses a wide range of disciplines and job functions, from geology, geophysics and engineering to operations of support and logistics, safety and regulatory compliance, as well as project management and administration. It is complex and employs numerous pieces of enormous equipment as shown in Figure 1-2. The well service companies provide specialized equipment, expertise and operations at various stages of the project. Normally, the drilling operations are combined with well service operations. Some

of these operations are performed in strict in accordance with the working procedure, whereas some operations are head-to-toe. The typical well drilling and service operations include drilling rig service, drilling bit supplying, casing running, cementing, well logging, directional drilling, coring and analysis, communication, transportation and trucking, inspection and repairs, fuel supplying, equipment rentals, water acquisition and hauling, environmental, drilling mud/fluids/chemicals, etc. The well services are normally provided by several companies. To select good well service companies is critical in improving the efficiency of a drilling project. In practice, good service companies can be recorded for future projects since most service operations are common, which include highly specialized and expensive equipment. However, in different projects, the equipment may need different setups, transportations, operations, utilizations and operating crews.

Figure 1-2 Drilling rig and equipment (Bommer, 2008)

1.2 Research objective and approach

This thesis project focuses on well service supplier evaluation and selection, supply chain management and on-land drilling project scheduling. In practice, the on-land well drilling service companies can be classified into two categories. One type of company can shorten its project duration or speed up the project progress according to the customer needs. In project management, to shorten the project duration or to speed up project progress is called

to crash a project. However, there is another type of on-land well drilling service companies which cannot crash their project due to the limitation of the technology, equipment, staff skill, tools, etc. The thesis works considers both type of on-land well drilling services companies and discuss the results under these two cases. The goal of the thesis work is to reduce the total drilling cost by controlling total drilling project duration. To achieve this goal, the following research objectives are identified: (1) Develop methods and models for supplier evaluation and selection; (2) integrate supplier selection and project schedule. The overall objective is to minimize the project cost and duration. Figure (1-3) illustrates this thesis project scope.

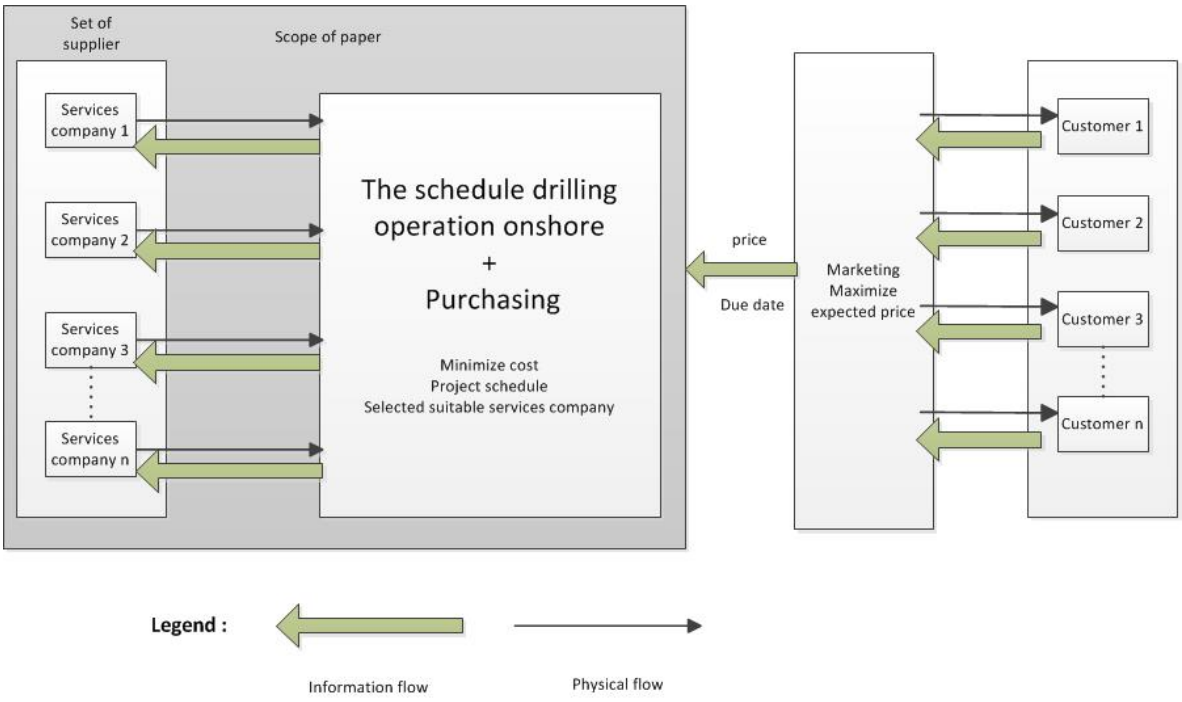


Figure 1-3 Scope of the thesis work.

In project planning, the thesis work develops a mix-integer programming model to select suitable supplier and integrate drilling project and well services activities. The data from a local oil company have been collected to validate the feasibility of the developed methods and models and their merits will also be discussed and compared against the two cases. Moreover, the simulation of testing the quality of delivery time and duration will be demonstrated in the end of these empirical studies.

In project processing, the relationship between time delay and total drilling cost will be simulated. Furthermore the divergent positions of the service companies and the oil company will be analyzed. From the result it could be found that to make an incentive contract between an oil company and its suppliers has significant effects on their coordination and project efficiency improvement.

Chapter Two: Literature Review

2.1 Drilling operation management

Well drilling in oil/gas production is the process of drilling a hole in the ground for the extraction of natural gas or petroleum, for the injection of a fluid from surface to a subsurface reservoir or for subsurface formations evaluation or monitoring(Committee, 1997). The prime role of the drilling engineering department in an oil/gas company is to be responsible for the management on the drilling and completion of wells in a cost-efficient manner. One of the challenges is how to provide high service level to platform and drilling units to keep them operating 24/7 in the most effective way (Favilla, Claessens, Mello, & Flach, 2012). To solve this problem, some publications suggest using incentive contract to optimize drilling process. The incentive contract is based on two contracts which are footage contract and turnkey contract. Footage contract is base remuneration on the number of metres drilled and turnkey contract requires the drilling contractor to drill a hole to a predetermined depth at a fixed lump sum cost. Both contract concepts have disadvantages. The main disadvantage of the turnkey contract may leave a drilling contractor more risks than he/she expected in a drilling project, whereas the footage contract does not reduce the risk although its reward is calculated by drilling depth meter by meter since party A in the contract will not pay more for some hard drilling meters than these easy drilling meters (C. A. Moomjian Jr, 1992). Cahuzac(1987) indicates incentive contract could create more motivation for improvement in rig performance which will result in reduced well costs. Spoerker and Ringhofer (2002) develop an incentive scenarios for mature operating which could overcome the pitfalls and obstacles in new contractual concepts in a traditional

operating environment and could increase operating efficiency. Osmundsen (2006) analyse the influence of an operator effect the actions of a drilling contractor with the aid of financial and other incentives, both in connection with the tender process and contract design. He also indicates that financial incentives in contracts can impact contractor's focus on safety. There will be more discussions about incentive contracts in Chapter 4.

Some authors indicate that to reduce waste to cut off cost is also a good way (Marinescu, Buchner, & Mertin, 2007; Thurber, 1992). Some others indicate that using software to track data is a popular way, like Randolph (1995) and Durham et al. (2003). The former uses a computer facilitated management system to integrate the work processes of alliance organizations. It describes a drilling management system which uses commercial software to improve the performance and considers every member of the supply chain to use the system to generate the well plans. When all the necessary data are input into the software system, the system could dynamically control the entire supply chain process, and hence it could reduce the drilling operation cost. Durham et al. (2003) indicate that using supply chain management techniques could improve the utility of services and equipment. Both Randolph (1995) and Durham et al. (2003) track the equipment performance by the updating data in the software systems.

Kaiser (2009) uses a conceptual framework to model the time and cost for drilling an offshore well. The model considers physical characteristics of the drilled well, but does not consider variability associated with the human aspects in decision making.

2.2 Project scheduling with resource

A project is a unique undertaking consisting of a set of activities related to each other by technological precedence relations. Each activity in the project is characterized by its precedence relations, duration and resource requirements (Dodin & Elimam, 2008). In oil/gas industry, project scheduling is generally classified into two categories, project scheduling with renewable resource and project scheduling with non-renewable resource.

Renewable resources are constrained on a period-by-period basis. Labor can be considered as a renewable resource if it is used every day and limited on a daily basis. Non-renewable resources are constrained on a project basis. The project budget or raw materials become non-renewable resources if the total consumption over the whole project duration is limited to a certain value (Özdamar & Ulusoy, 1995).

2.2.1 Project scheduling with renewable resource

Project scheduling with renewable resource has been studied widely in the literature (Davis, 1973; Icmeli, Erenguc, & Zappe, 1993; Özdamar & Ulusoy, 1995).

There are some research papers to describe integrated project scheduling with equipment planning. Dodin and Eliman (2008) employ a mixed integer model to control cost when expensive and specialized equipment is used in the project. Topal and Ramazan (2010) describe a model, which is based on mixed integer programming technique, for annually scheduling a fixed fleet of mining trucks in a given operation over a multi-year time horizon to minimize maintenance cost.

The approaches which are used to solve this type scheduling problem are various. Böttcher (1999) and Liu (2005) use genetic algorithm solving the problem. Zhenyuan and Hongwei

(2006) use heuristic algorithm approach to minimize the total cost of drilling activities under the resource constraints.

2.2.2 Project scheduling with non-renewable resource

Integration of project scheduling and ordering of non-renewable resource was initially investigated by Aquilano (1980). Since then, many papers considered integrated project scheduling and material planning and Smith Daniels (1987) develop a mixed integer 0-1 programming formulation for optimal project scheduling and material ordering problem. In a subsequent paper, Dodin and Eliman (2001) consider rewards (or penalties) for early (or late) completion and materials quantity discounts to control project schedule and cost.

In the literature, the other approaches for solving the project scheduling with non-renewable resources, such as genetic algorithm (Fu, 2014; Sajadieh, Shadrokh, & Hassanzadeh, 2009; Zoraghi, Najafi, & Niaki, 2012), heuristic algorithms(Hartmann & Kolisch, 2000; Kolisch & Hartmann, 1999), and iterative scheduling technique (Li & Willis, 1992).

2.3 Supplier selection techniques

When companies' outsourcing become a significant part of their business, supplier selection process is involved(Araz, Mizrak Ozfirat, & Ozkarahan, 2007). Supplier selection is the vital such for drilling projects. As Bhutta (2002) presented, in generally, supplier selection is a lengthy evaluation process. It takes into consideration of several criteria like price, delivery, product quality, and service. But however sometime, evaluation criteria involve trade-offs. For instance, a supplier may offer services with a lower price but an

uncertain delivery time. Because of this reason, it is necessary to find a method to cope with each criterion in order to get an optimally result. Adapted from Degraeve (2000), the supplier selection models could be generally classified into four categories which are mathematical programming, total cost approach, rating/linear weighting, and statistical approach.

2.3.1 Mathematical programming

There is an extensive amount of literature related to the supplier selection using the mathematical programming models, since mathematical model can provide a computable and convincible result. For the different cases, these models include linear models, integer models, nonlinear models, mix integer models, and fuzzy models.

From literature review, it could be found that linear programming models are popularly used to solve the problem. Ghodsypour and O'brien (1998) develop a model which can be applied to supplier selection with and without capacity constraints. In their paper an integration of an analytical hierarchy process and linear programming is proposed to consider both tangible and intangible factors in choosing the best suppliers (for different supplies) and placing the optimum order quantities among them such that the total value of purchasing becomes maximum. Ng (2008) proposes a linear programming model for the multi-criteria supplier selection problem and studies a transformation technique which can be solved without an optimizer. Qian (2014) develops a model including price, guaranteed delivery time, service level, and other quality-like performances and this model is also applied in investment decision on cost reduction and delivery time reduction. Results denote that operation characteristics of the supplier selection should match market

characteristics. Qian also implies that, with stochastic delivery time, the service level is not always binding at the minimal value reserved by the manager or the market.

Some authors use nonlinear and mix integer programming model to solve the problem. Kokangul and Susuz (2009) use analytical hierarchy process to match the ordering item characteristics with supplier's characteristics. Consequently they propose a non-linear integer programming model to analytically determine the best suppliers and the optimal order quantities among the available suppliers. Gheydar et al (2010) develop a coordination model, which is a nonlinear model, to coordinate the entire supply chain and align the decisions between its entities. In this nonlinear model, the buyer selects the right supplier and orders appropriate quantities. The suppliers split the buyer ordered quantities into small lot sizes and deliver them over multiple periods. The objective function is to minimize the total cost of the supply chain. Hadi-Vencheh (2011) proposes a weighted nonlinear model to solve the multiple criteria supplier-selection problem. The model not only incorporates multiple criteria for supplier selection but also maintains the effects of weights in the final solution. Patel (2012) uses a mixed-integer nonlinear programming model to consider competition in supply chain. The competition in a one-buyer vs. multiple suppliers system for the supplier selection process has been taken into consideration. Ware (2014) develops a mixed-integer non-linear programming model to address the dynamic supplier selection problem since a supplier identified for one period may not necessarily be same for the next period to supply the same set of goods or parts.

Besides these nonlinear programming models, the integer programming method is also widely employed to solve this project scheduling problem. Gupta and Krishnan (1999) use integer programming technique to build a the decision support system to assist selection of

components and suppliers that minimizes the design cost and lead time. Choudhary and Shankar (2014) consider the problem that a buyer procures a single product in multiple periods from multiple suppliers under constraint of the storage space. From their research, a multi-objective integer linear programming model is proposed for joint decision making of inventory lot-sizing, supplier selection and carrier selection.

Furthermore, some other mathematical programming techniques, such as dynamic programming model (Degraeve & Roodhooft, 1999) and fuzzy model, have been employed to solve this problem. Chen et al. (2006) present a fuzzy decision-making approach to deal with the supplier selection problem in a supply chain. The paper considers factors such as quality, price, flexibility, delivery performance and linguistic values to determine suitable suppliers. Wang (2009) proposes a fuzzy hierarchical model, viz. TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), which is not only well suited for evaluating fuzziness and uncertainty problems, but also can provide more objective and accurate criterion weights. Jazemi (2011) identifies the nondeterministic conditions in the environment of a business and the coordination between buyers and suppliers in a supplier selection problem. Consequently, a fuzzy model with cost, quality, and timely delivery has been developed. Mukherjee (2013) introduces a fuzzy preference degree between two triangular fuzzy numbers. The weights of the decision makers are considered and a methodology is proposed to determine the weights. Aghai (2014) presents a fuzzy multi-objective programming model with supplier selection taking quantitative, qualitative, and risk factors into consideration.

To negotiate with suppliers is a usual way to reduce the cost or price. Cakravastia and Nakamura (2002) studies the trade-off between the price and due-date and the negotiations

between a manufacture and its multiple suppliers for a single order. Ebadian and Rabbani (2008) consider a structure in make-to-order environment to determine whether a new order is accepted or rejected. They also suggest a mix integer programming model to determine the price and delivery time of an accepted order as well as how to select the optimal combination of subcontractors and suppliers.

In the papers as mentioned above, the computer software packages are often used to solve these developed models, such as Lingo and CPlus. Lingo a software package which has been developed to effectively solve linear, integer and nonlinear programming models. It can handle tens of thousands of variables and constraints, and even several thousand integer variables (Schrage, 2006).

2.3.2 Total cost approach

The total cost approach aims at quantifying all costs associated with the purchasing process throughout the entire value chain of a firm (Degraeve et al., 2000). The approach considers all costs over a product entire life cycle. It needs the extensive information of a selecting supplier and hence it could be very complicated when integrating a project management system with all the information. Roodhooft (1997) proposes an activity based costing approach for supplier selection and evaluation. He computes the total cost by a supplier's production process. There are also some other researchers to adopt this approach in their research (L. Ellram, 1993; L. M. Ellram, 1995; Ramanathan, 2007; Timmerman, 1987).

2.3.3 Rating or linear weighting

In the literature, some authors employ linear weighting method to rate suppliers against several criteria in order to combine multi-criteria evaluation under a single optimization objective, e.g. to maximize the suppliers' performance value. Linear weighting models often place a weight on each criteria and provide a total score for each vendor by summing up the vendor's performance scores on the criteria multiplied by these weights(Weber, Current, & Benton, 1991). Analytic hierarchy process (AHP) is a typical linear weighting method. The AHP is a decision-making method for ranking alternative courses of action when multiple criteria must be considered(Nydick & Hill, 1992). Ghodsypour and O'Brien (1998) propose an integration of AHP with linear model to choose the best supplier. Kahraman (2003) develops a fuzzy AHP model to select the best supplier with the most satisfactory performance under the pre-determined evaluation criteria. The similar or improved models can be found from other research papers, such as Chan and Kumar (2007), Wang (2008), Chan (2008), and Ertuğrul (2009).

Bhutta and Huq (2002) provide a comparison between the total cost approaches and AHP, and the comparison result is summarized in Table 2-1. Quinn and Strategy (2013) propose a methodology to integrate the total cost ownership (TCO) and the AHP approaches for selecting appropriate suppliers for a firm. They suggest a way of combining the objective and subjective information provided by the results of the TCO and AHP approaches.

Salient features	AHP	TCO
Procedure	Hierarchical and using ratio scales to integrate and then use pair-wise comparison and eventual synthesis to find “best” decision	Looks beyond purchase price to include all other purchase-related costs Based on the economists’ “transaction cost” view
Decision-making situations	Prioritizing decision making with intangible factors, along with intuitive, qualitative, quantitative and rational aspects	Supplier selection as well as supplier evaluation
Advantages	Use in both criterion comparison and individual aspects within each criterion can be tackled Forces managers to make trade-offs Simple	Provides a clear quantitative evaluation and selection rule Changes focus from purchase cost to total cost Help identify costs that otherwise may remain hidden Provides consistent message to supplier as regards the requirements and evaluation criteria

Salient features	AHP	TCO
Disadvantages	Requires enumerations of all issues Require intense management involvement Forces trade-offs	Complex Requires extensive tracking and maintenance of cost data Requires culture change Often situation-specific
Categories of supplier evaluation	Performance, capability, business, structure, quality system	
Applications	Multiple goal conflicts, supplier selection based on numerous factors, when price along is not the determining factor of supplier selection	Supplier evaluation as well as selection, when cost is of high priority

Table 2-1 Comparison of the total cost approaches and analytic hierarchy process (Bhutta & Huq, 2002)

2.3.4 Statistical approach

Statistical model in supplier selection is not very popular compared with the other three methods. Statistical model deals with the stochastic uncertainty related to the vendor choice

(De Boer, Labro, & Morlacchi, 2001). Ronen and Trietsch (1988) describe a model for purchasing materials and components for large projects under lead time uncertainty.

2.4 Outsourcing

Outsourcing occurs when an organization contracts with another organization to provide services or products of a major function or activity. In other words, a company pays another company to do some work for it (Belcourt, 2006). Outsourcing is a strategic tool for improving performance and managing cash flow in rapidly growing operating companies. The upstream petroleum industry routinely achieves effective outsourcing in operation project, like drilling project. McGowen (2003) divides upstream petroleum industry organizations into two basic types: staff augmentation and project outsource. He gives a good explanation for these two concepts. Staff augmentation involves locating an individual with the appropriate skill set and qualifications to fill a temporary position within an existing organizational hierarchy. Project outsources selectively to outsource a part of or the entire engineering project to a contractor. The outsourcing organization has the following merits:

1) Bring new perspective and ideas to the organization.
2) Transfer specialized expertise to the organization.
3) Accelerate the development process.
4) Free the internal technical and management resources to concentrate on ongoing operations and core competencies.
5) Allow operations managers to accomplish more with less effort and to shorten the time required to get a new development opportunity.

6) Draw on unique contractor resource.
7) The contractor has primary responsibility for the project outcome and cost.
8) Once properly initiated, it absorbs fewer company resources and detracts less from ongoing operations.
9) Allow access to highly specialized experts for short-term engagements.

Through the literature review, it could be found that outsource seems often link with the applications of information technology/information system (IT/IS) (Kern & Willcocks, 2000; Klepper & Jones, 1998; Levina & Ross, 2003; Loh & Venkatraman, 1992). Dhar and Balakrishnan (2006) indicate that IT/IS outsourcing is a way to transfer some or all of IS/IT-related decision-making rights, business processes, internal activities, and services to external providers, which can more effectively manage time and costs as well as improve productivity, quality, and customer satisfaction. Papers, which consider human resource (HR) outsourcing, are also found from the literature (Gilley, Greer, & Rasheed, 2004; Greer, Youngblood, & Gray, 1999; Hall, 2000; Lever, 1997). As Csoka (1995) indicate HR outsourcing can reduce costs, and increase service quality by producing greater economies of scale, incentives and accountability for service providers, and access to experts in specialized areas.

2.5 Summary

The scholars believe using the way of supply chain management could control the drilling cost. Supplier selection is very mature in the manufacturing industry but it is somehow not widely applied in drilling project. As to my best knowledge, no paper has been found to meaningfully consider supplier selection in drilling project through applications of

mathematic modeling technique. Some authors indicate that reducing total drilling time to control the whole project cost is an effective way. However, none of these authors provide a mathematical model to guide and optimize this lead time reducing process. On the other hand, well service is a large part of drilling project, but only a few publications consider well service into drilling project. Furthermore, none of the papers considers controlling the whole drilling project cost through the integration of well services and drilling project schedule.

Chapter Three: A mix-integer non-linear model for decision making

3.1 Introduction

For an oil industry to have the benefit of competitive advantage in the business environment, it is important to make an integrated partnership relationship with its suppliers. So the supplier selection decision becomes crucial due to its significant effect on the successful building of an efficient supply chain. Supplier selection decisions are complicated by the fact that various criteria must be considered in the decision-making process(Choy, Lee, & Lo, 2002). In Chapter 2, an overview of the existing supplier selection techniques was provided. The existing techniques could suit different situations, but it still has lack of ability in drilling projects. A new method for solving drilling project decision support problem is needed to overcome the weakness of the existing methods. The basic idea is to combine the advantages of the project schedule and supplier selection models. As most of them are considered for manufacture industry, in this chapter, a mix-integer programming model for drilling project has been developed.

3.2 Project schedule and supplier selection in manufacture industry

In a make-to-order (MTO) manufacture company due to the limitation of capacity and scarcity of resources, customers fall into different priority classes and it is important to link the order entry stage of the system with the procurement stage(Rabbani, Ahmadi, & Kian, 2009).

The decision-making problem of planning in manufacture is the optimal selection of suppliers and subcontractors to supply the required raw material and workload of the orders.

The current set of suppliers and subcontractors are first selected by considering other major criteria such as quality. To find the best set of suppliers and subcontractors, Ebadian (2008) develops Equation (3-1). However in his model, price and delivery time are considered.

Indices

I order index (i = 1,...,I)

R resource index (r= 1,...,R)

T period index (t = 1,...,T)

S subcontractor index (s = 1,...,S)

L supplier index (l = 1,...L)

k material index

Parameters

LT_i lateness amount of order i

P_{irs} suggested price of subcontractor s for workload of order i on resource r

P_{kl} suggested price of supplier l for raw material k

MAD_{ikl} delivery time of raw material k of order i by supplier l

S_{irst} maximum workload of order i on resource r that can be supplied by subcontractor s at period t

β_I penalty cost of receiving raw material before ERD_i per each unit of earliness.

β'_i penalty cost of receiving raw material of order i after ERD_i per each unit of lateness. Since the lateness can cause some orders to be delivered late then the value of β'_i must be computed in a way that the raw material is supplied on time or earlier

NO(i) set of the new accepted orders

L(ki) set of suppliers that can supply raw material k of order i

$L'_{(ki)}$ set of suppliers that deliver raw material k of order i before its ERD

$S_{(ri)}$ set of subcontractors that can supply required workload of order i on resource r

ERD earliest release date

Decision variable

O_{irt} amount of resource r assigned to order i at period t during over time, typically in machine hours

Y_{irt} amount of resource r assigned to order i at period t including regular, overtime, and subcontracting work, typically in machine hours

$$X_{irs} = \begin{cases} 1 & \text{if subcontractor s supplies required workload of order i on resource r;} \\ 0 & \text{otherwise} \end{cases}$$

$$X_{ikl} = \begin{cases} 1 & \text{if supplier l supplies required workload raw material k of order i;} \\ 0 & \text{otherwise} \end{cases}$$

$$Min Z' = \sum_{i=1}^{I}\sum_{r=1}^{R}\sum_{s\in S(r_i)} P_{irs}X_{irs} + \sum_{i\in NO(i)}\sum_{k=1}^{K}\sum_{l\in L(k_i)} P_{kl}X_{ikl} + \sum_{i\in NO(i)}\sum_{k=1}^{K}\sum_{l\in L'(k_i)} \beta_i(ERD_i - MAD_{ikl})X_{ikl} +$$

$$\sum_{i\in NO(i)}\sum_{k=1}^{K}\sum_{l\notin L'(k_i)} \beta'_i(MAD_{ikl} - ERD_i)X_{ikl} + \sum_{i=1}^{n}\sum_{r=1}^{R}\sum_{t=1}^{T}\left[\left(Y_{irt} - O_{irt} - \sum_{s\in S(r_i)}(S_{irst}X_{irs})\right) + co_{irs}O_{irt}\right]$$

(3-1)

The objective is to minimize the total operating costs (i.e., regular time, overtime, subcontracting, and lateness penalty costs), purchase costs of raw material, purchase costs

of workload, and earliness or lateness costs of raw material. The constraints include the total workload of all orders over planning horizon within all kinds of production capacities, order delivery time, order maximum tardiness, specific supplier or subcontractor selection, etc.

The make-to-order (MTO) companies are in the business of supplying products in response to a customer order in competition with other companies on the basis of price, technical expertise, delivery time and reliability in meeting due dates. Dealing properly with enquiries is the major problem that the MTO companies face. An operator company is somehow like a MTO company. When they want drill a well, they will contact a lot of drilling contractors, services companies and suppliers to negotiate price quality and delivery time. However, the MTO companies have a lot of in-house workload, whereas for oil companies, all the processes are outsourced. For the managers of MTO companies, they should integrate in-house process, suppliers and subcontractors. For the managers of oil companies, they should integrate all the activities by contract with drilling contractors, suppliers and services companies.

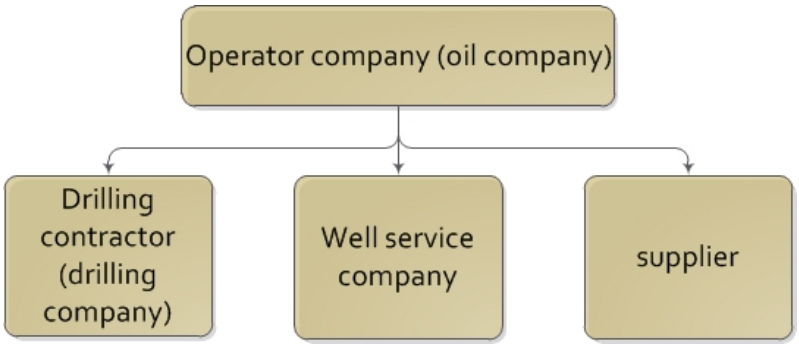


Figure 3-1 The relationship among the operator company, drilling contractor, well service companies and suppliers

3.3 Problem definition

A drilling project is usually complex (see Appendix 1). It needs to integrate all the equipment, activities, and crews, and it also requires making sure of crew safety. The relationship among the operator company, drilling contractor, well service companies and suppliers is shown in Figure 3-1. Decision makers are facing different contracting situation that could lead to different decisions. As the just-in-time completion is often a basic requirement in a drilling project, to select a valid supplier and outsourcing contractors which could stick to the scheduled delivery time is vitally important. The necessity of considering delivery date, lead time and cost all together rather than taking cost as the only criterion in supplier evaluation becomes obvious. Therefore this thesis work considers all these three factors as criteria to evaluate suppliers (Fig.3-2). As a drilling project normally works 24 hours per day and 7 days per week under nearly all kinds of weather conditions, the overtime concept does not exist. However, the total number of drilling days could be reduced if a faster service is employed. To employ a faster service increases the cost of the project, but it also brings the savings through crashing the project duration. The model as presented in this chapter aims at justifying the balance and trade-off between the cost and savings. This thesis uses an example of an open hole to valid the feasibility and effectiveness of model. The supplier selection procedure for an open hole project is shown Figure (3-3).

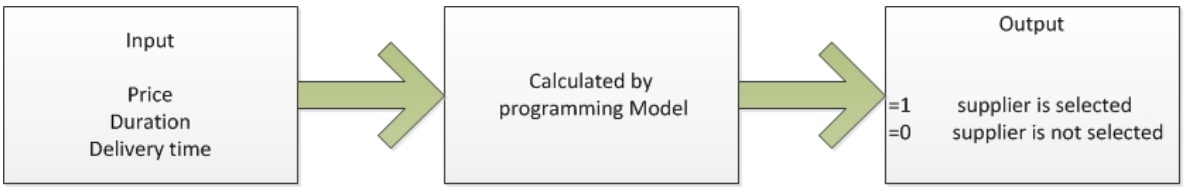


Figure 3-2 Supplier selection procedure

- ***Regular time.*** Activity's normal processing time and equipment install time.
- ***Crashing time***. The reduced time after changing to a faster service. Well service is charged by day. As a drilling project works 24 hours per day, it cannot work overtime any more. But the services could change to a faster service by changing software, engineer, technology, machine etc. For instance, the duration of one activity is 27 hours and it normally completes in two days. If it is crashed by 3 hours, the activity could finish in 24 hours.
- ***Crashing cost.*** The cost for crashing activities.
- ***Duration***. The time duration between starting and ending an activity. And it could be a regular time or crashing time. The drilling project is normally carried out 24 hours per day and 7 days per week in all over the world.
- ***Delivery time***. The day when services, such as equipment, crew, etc., are arrived at the platform.
- ***Total cost.*** The total expenditure for drilling a well.

Figure 3-3 The structure of an open hole

3.4 Notation and model

Indices

j well service activity index (j =1, … , J)

t time index (t=1 ,…, T)

i well service company index (i= 1 ,…, I)

Parameters

a) Project

cr_j unit operation cost per hourof activity j for regular working time

co_j unit operation cost per hour of activity j for crashing time

dd due date of drilling project

CR maximum available of regular working time

CO maximum available of crashing time

O set of activities to be processed

α_j cost of service j arriving at platform before SD_j per unit of time.

d_j duration of activity j

DC sub day rate which includes the cost of fuel, commutation, water, salary, transportation, environment, etc.

B_j set of activities preceding activity j

b) Supplier

I set of companies that can provide service activity j to the operator company

P_{ij} price offered by the service company i for well service j to the operator company

D_{ij} start time offered by Service Company i for well service j to the operator company

L'_i set of service company supply service before SD_j

Decision variables

SD_j start date of activity j

TR_j amount of working time for operating activity j

TO_j amount of crashed time for operating activity j

TT total time of drilling project

$$X_{ij} = \begin{cases} 1 & \text{if well service company i supplies service to activity j} \\ 0 & \text{otherwise} \end{cases}$$

Model

$$\text{MinZ} = \sum_{j\in o}\sum_{t=1}^{T} cr_j \times (d_j - TO_j) + co_j \times TO_j + \sum_{j\in o}\sum_{i\in L_i'} \alpha_j (SD_j - D_{ij}) X_{ij}$$

$$+\sum_{i\in I}\sum_{j=1}^{J} P_{ij}X_{ij} + DC \times TT \qquad (3\text{-}2)$$

Equation 3-2 is a mix integer programming (MIP) model for drilling project. The objective of the model is to minimize total cost of drilling project, and it consists of regular working cost, crashing working cost, earliness costs of service, purchase costs of service and sub cost (Equation 3-2).

s.t.

$$TR_j \le CR \qquad j \in o \qquad (1)$$

The regular working time cannot greater than maximum capacity of regular time

$$TO_j \le CO \qquad j \in o \qquad (2)$$

The crashing time of operation j cannot greater than maximum capacity of crashing time

$$TR_j \ge d_j - TO_j \qquad j \in o \qquad (3)$$

The total working time for activity j should be greater or equal to duration of activity j

$$\sum_{i\in I} X_{ij} = 1 \qquad j \in o \qquad (4)$$

Constraint (4) guarantees only one supplier should be chosen to one service.

$$SD_j \ge SD_k + d_k - TO_k \qquad j \in B_j \qquad (5)$$

If activity k precedes activity j, the completion time of activity k must be less than or equal to the start time of activity j.

$$TT \leq dd \tag{6}$$

Constraints (6) make sure that the due date of drilling operation should be greater than or equal to the total assignment time of the project. Hence, the project could finish on time.

$$TR_j, TO_j \geq 0 \qquad j \in o \tag{7}$$

$$X_{ij} = 0,1 \quad j \in o \tag{8}$$

Constraints (7) and (8) define non-negativity and type of the decision variables.

3.5 Data and result

In general, a drilling project could be discussed by the following two cases and will use the mix integer programming model to solve the two problems.

1. Service companies which cannot crash their project due to the limitation of the technology, equipment, staff skill, tools, etc. This case refers as C1.
2. Service companies can shorten its project duration or speed up the project progress according to the customer needs. This case refers as C2.

Furthermore, a typical project process flow is shown in Figure (3-4).

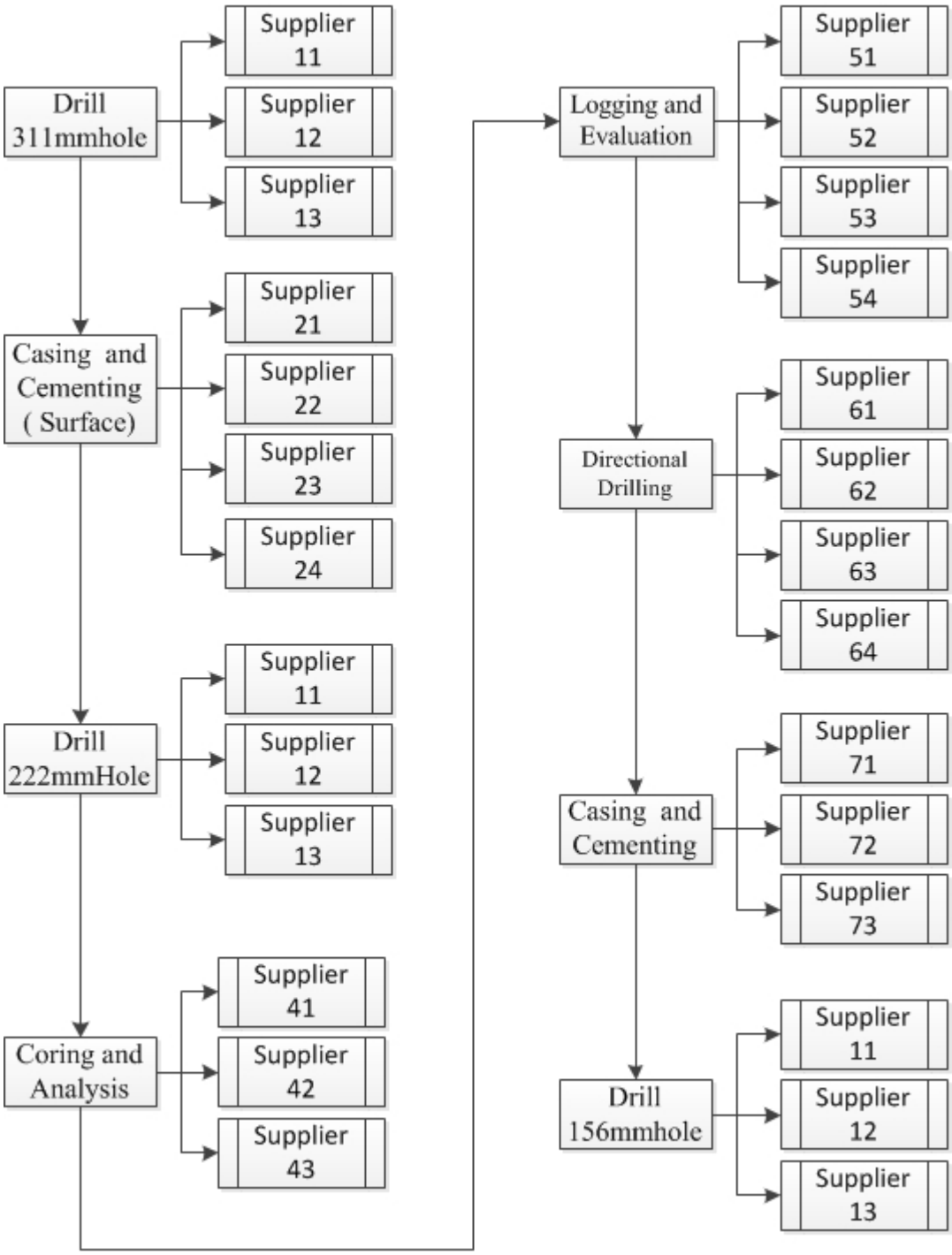


Figure 3-4 A typical drilling project process flow

The proposed MIP model was tested by 8 activities and for each activity it has three optional suppliers. The activities of Drill 311mm hole, Drill 222mm hole and Drill 156mm hole are provided by the same drilling contractor. The details of every supplier are shown in Table 3-1. The start time of project is assumed as time zero. The realizations are generated based on:

- Regular working time and crashing time of the activity
- Service duration, price and timely deliverance of suppliers
- Cost for earliness services
- Total drilling time
- Day rate of drilling operation

The extra cost of earliness services α_j = 18,000$/day. The costs per unit of regular time cr_j for the 8 activities are 832$/hour, 702$/hour, 861$/hour, 400$/hour, 716$/hour, 715$/hour, 702$/hour, 523$/hour respectively, and the costs per unit of crashing time co_j for 8 activities are 1,081$/hour, 912$/hour, 1,120$/hour, 800$/hour, 931$/hour, 932$/hour, 913$/hour, 680$/hour respectively. As drilling project is running 24 hours per day and 7 days per week, the maximum regular-time is 24hours/day. A daily rate of drilling operation is $76,000/day in normal. This data is from a local oil company

The mathematical programming computer software package, named LINGO, is used to solve the model and the solutions are obtained as shown in Tables 3-2 and 3-3. The codes for the two cases are shown in appendix.

Table 3-1 The parameters for the eight-activity project (under cases C1 and C2)

Activity	Optional supplier	Duration(hour)	Start time(day)	Price
Drill 311mm hole	Drilling contractor 11	67	1	$37,193.00
	Drilling contractor 12	80	0	$39,629.00
	Drilling contractor 13	64	0	$40,320.00
Casing and Cementing (Surface)	Supplier 21	43	4	$25,232.00
	Supplier 22	47	4	$28,764.00
	Supplier 23	41	3	$25,978.00
	Supplier 24	45	4	$24,080.00
Drill 222mm Hole	Drilling contractor 11	105	N/A	$58,287.00
	Drilling contractor 12	122	N/A	$60,434.00
	Drilling contractor 13	96	N/A	$60,480.00
Coring and Analysis	Supplier 41	115	9	$102,589.00
	Supplier 42	122	9	$104,442.00

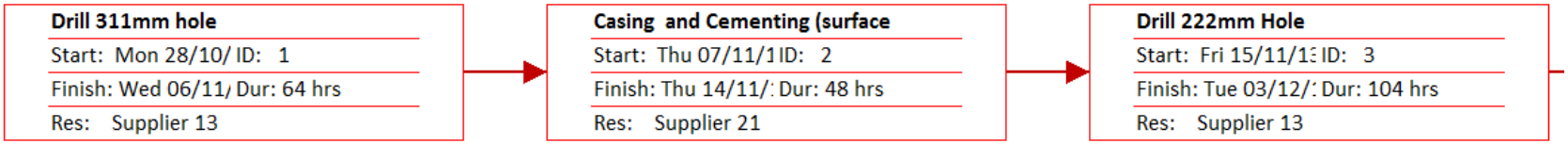
Activity	Optional supplier	Duration(hour)	Start time(day)	Price
	Supplier 43	108	11	$102,798.00
Logging and Evaluation	Supplier 51	41	13	$99,630.00
	Supplier 52	45	14	$102,222.00
	Supplier 53	38	13	$96,061.00
	Supplier 54	44	14	$96,000.00
Directional Drilling Services	Supplier 61	180	16	$166,925.00
	Supplier 62	188	15	$180,299.00
	Supplier 63	166	17	$169,121.00
	Supplier 64	167	17	$160,320.00
Casing and Cementing (Intermediate)	Supplier 71	48	22	$66,942.00
	Supplier 72	49	24	$65,444.00
	Supplier 73	45	26	$66,485.00
Drill 156mm hole	Drilling contractor 11	288	N/A	$159,874.00
	Drilling contractor 12	296	N/A	$146,626.00
	Drilling contractor 13	260	N/A	$163,800.00

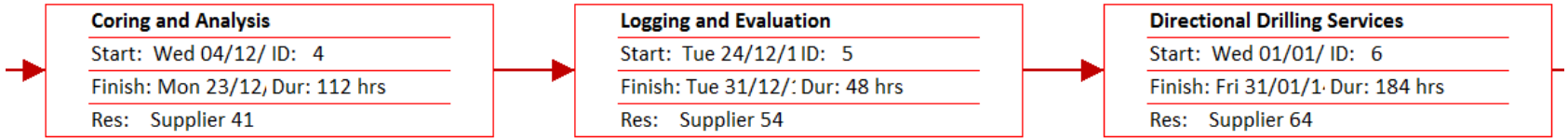
By running the model for C1, the results are obtained as follows as Figure (3-5):

$X_{13} = X_{21} = X_{41} = X_{54} = X_{64} = X_{73} = 1$, TT = 36day ➡ Z= 4,364,378.00$

Table 3-2 Solution of case C1

Activity	Supplier	TR(hour)	Duration(day)
Drill 311mm hole	Supplier13	63	3
Casing and Cementing (Surface)	Supplier21	41	2
Drill 222mm Hole	Supplier13	97	5
Coring and Analysis	Supplier41	108	5
Logging and Evaluation	Supplier54	39	2
Directional Drilling Services	Supplier64	169	8
Casing and Cementing (Intermediate)	Supplier73	45	2
Drill 156mm hole	Supplier13	260	11


Drill 311mm hole
Start: Mon 28/10/ ID: 1
Finish: Wed 06/11/ Dur: 64 hrs
Res: Supplier 13
Casing and Cementing (surface
Start: Thu 07/11/1 ID: 2
Finish: Thu 14/11/ Dur: 48 hrs
Res: Supplier 21
Drill 222mm Hole
Start: Fri 15/11/1 ID: 3
Finish: Tue 03/12/ Dur: 104 hrs
Res: Supplier 13


Coring and Analysis
Start: Wed 04/12/ ID: 4
Finish: Mon 23/12, Dur: 112 hrs
Res: Supplier 41
Logging and Evaluation
Start: Tue 24/12/1 ID: 5
Finish: Tue 31/12/: Dur: 48 hrs
Res: Supplier 54
Directional Drilling Services
Start: Wed 01/01/ ID: 6
Finish: Fri 31/01/1 Dur: 184 hrs
Res: Supplier 64

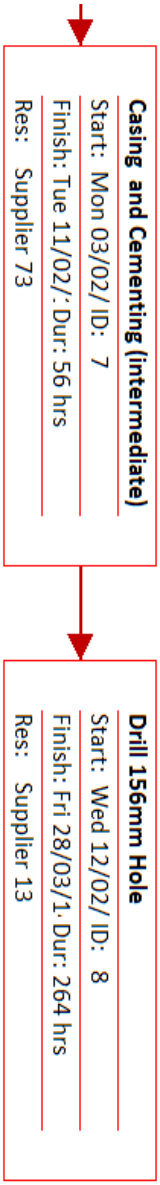


Figure 3-5 Network for the solution of case 1

By running the model for C2, the result is below:

$X_{13} = X_{24} = X_{41} = X_{53} = X_{64} = X_{72} = 1$, TT = 33day ➡ Z= 4,197,270.00$

Table 3-3 Solution of case C2

Activity	Supplier	TR(hour)	TO(hour)
Drill 311mm hole	Supplier13	67	0
Casing and Cementing (Surface)	Supplier24	44	0
Drill 222mm Hole	Supplier13	96	0
Coring and Analysis	Supplier41	97	1
Logging and Evaluation	Supplier53	38	0
Directional Drilling Services	Supplier64	169	1
Casing and Cementing (Intermediate)	Supplier72	49	1
Drill 156mm hole	Supplier13	260	0

The different results in Tables 3-2 and 3-3 show the flexibility and capability of optimally selecting suppliers based on changed situations. This gives the capability for an oil company to quickly select alterative suppliers to meet its drilling project requirements.

3.6 Analysis result

After analyzing the two results under cases C1 and C2, it could be found that to reduce the total drilling time is vital important. With the rise of days, the total cost will increase. For case C2, the drilling time is 33 days and the drilling cost is $4,197,270.00. For case C1, the drilling time is 36 days, but the total cost increases to $4,364,378.00.

For the supplier selection, a low price is important, but this is not the only criterion. Sometime, delivery time, duration and services level are more important. In case C2, for example, to select Drilling contractor 13 for drilling hole has the highest price (or the highest level), but the duration is the shortest. For this example, Supplier 24 is selected for the activities of Casing and Cementing (surface). After comparing the three alterative selections, it could be found that all the three selections finish activities of Casing and Cementing in two days and it cannot crash these activities time from two days to one day. This means the sub costs of these services provided by these three selected suppliers are the same. Therefore, the model selects the lowest price supplier which is Supplier24. When a drilling manager makes a decision, he/she should consider all the three factors and make a balance among these factors.

3.6.1 Sensitivity to test the quality of delivery time of Services Casing and Cementing

Casing is inserted a pipe into a recently drilled section of a borehole and typically held into place with cement. Cement is used to hold casing in place and to prevent fluid migration between subsurface formations. Changing the delivery time of the activities of Services Casing and Cementing from 2nd day to 10th day, it could get Figure (3-6). At first, the total cost decreases as delivery time increases, this indicates that if an earlier well service is required, it could cause an extra cost. The lowest cost is at the 4th day, which is the next day to the completion of the last activity. After that, the cost starts rising. There is a fluctuation around 7th day. This is because the delivery time could relatively suit the latter activities after choosing a suitable supplier. However, this is still not the best. After 7th day, the total cost keeps rising. If there is no supplier selection in latter activity, the sub cost will drive the total cost to keep growing after 4th day.

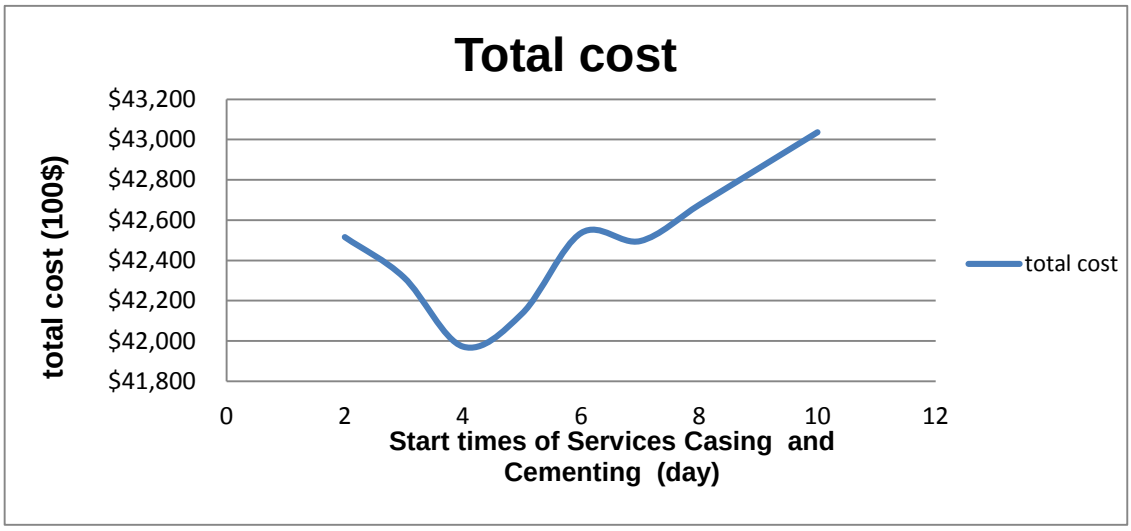


Figure 3-6 The start times of Services Casing and Cementing with the total costs

For the drilling operation, some services or equipment are extremely expensive and could affect drilling activities significantly. If this kind of services or equipment arrives earlier, it will cause unnecessary cost, such as inventory holding cost, and needs an extra space on platform which is normally very limited. However if it arrives late, it will extend the total drilling project time, hence increase the total expenditure. Therefore to ensure the start time from supplier is very important.

3.6.2 Sensitivity test of duration of Services Casing and Cementing (surface)

As shown in Figure (3-7), the crashing time of the activities of Casing and Cementing is assumed for 4 hours, and the duration of the activity is changing from 29 hours to 72 hours. In general, the total cost increases as the duration increases. From Figure (3-7), it can be seen that from 29 hours to 48 hours, the cost does not increase, because the activity could finish in two days and it does not need crashing the work. After that it goes up slowly between 49 hours and 52 hours, since the duration after 48 hours should be crashed to avoid total drilling time mount (Fig 3-8). Between 53 hours and 72 hours, the cost keeps stable. This is because even reducing the processing time the activity still cannot finish in one day. Therefore a regular work is simply needed.

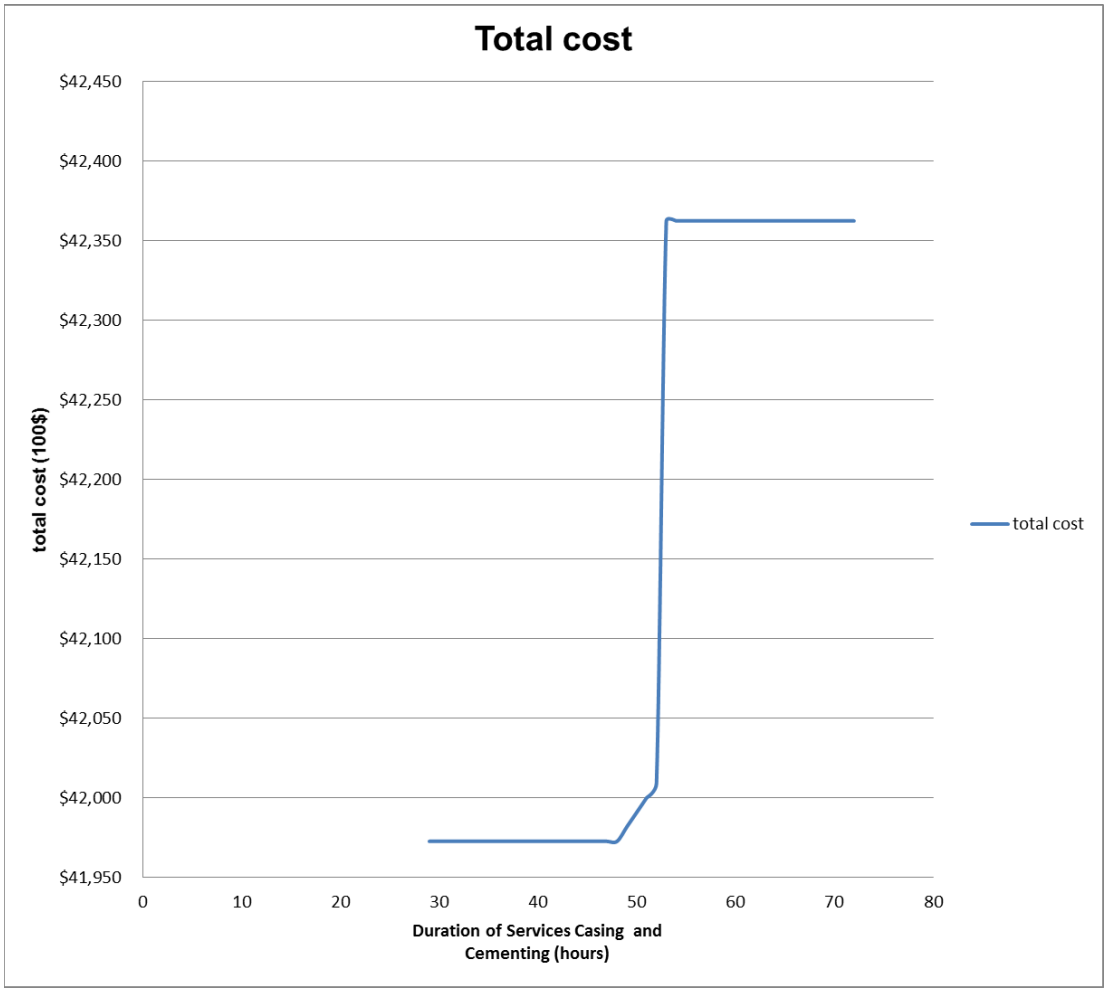


Figure 3-7 duration of activity Services Casing and Cementing with total cost

For the well services activities, if they can be finished more efficiently, it could save the cost along the whole drilling project. The project duration could be varied due to the software technology, worker skills, drilling technology, and equipment changing to different levels. For the same activity, the project duration will be reduced if the price ascends when the oil company changes to a higher quality service level. It is worth to note that to change to higher service level may not reduce the project duration if the higher service is not applied to a critical activity of the project.

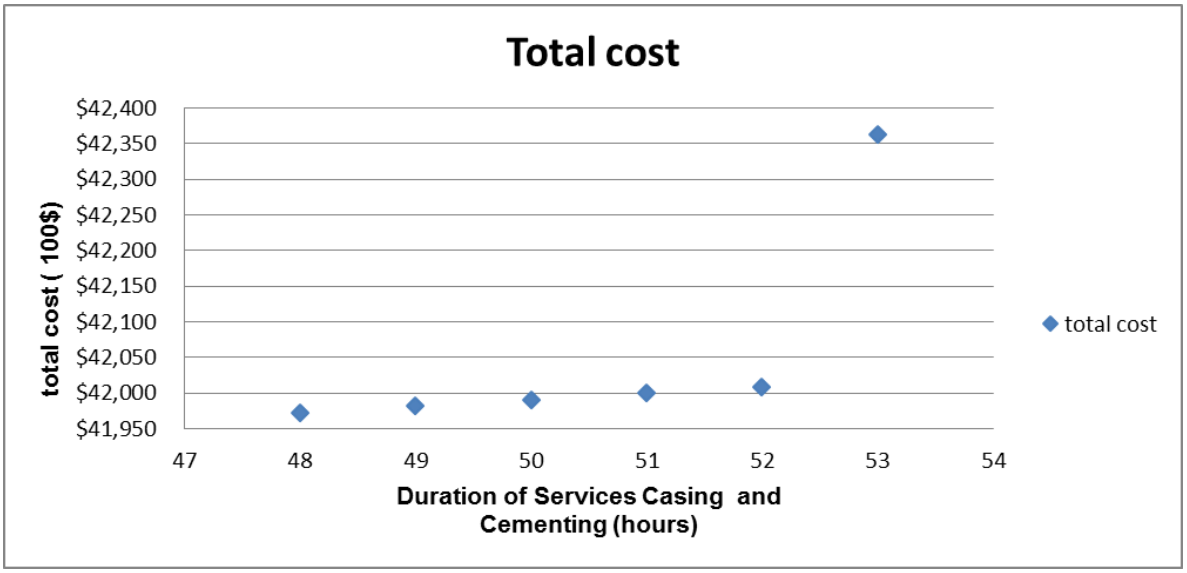


Figure 3-8 Part of Figure (3-7)

3.7 Summary

In this chapter, the data from a local oil company are collected and studied using the MIP model as presented. In section 3.2, the lack of ability of manufacture MIP model for drilling project has been shown. Through the case studies, the feasibility and effectiveness of the presented model are validated and tested. Through a series of sensitivity test, the results show that the model could help oil industry to synchronize its production schedule and control with its suppliers, and hence to provide useful decision support for integrated drilling project and supply chain management. When a drilling manager makes a decision, he/she could use the model to make validate various choices of delivery time, activity duration and price.

The work as reported in this chapter makes three novel contributions. First of all, this study suggests integrated drilling operation schedule and Well Services selection, which has not

been found in the literature. Secondly, this thesis work develops the model to select Well Services Company in terms of delivery time, duration and price to integrate drilling project schedule and supply chain management. Finally, through the case studies from an oil company, the feasibility and effectiveness of the proposed method and model are validated. The result indicates that the reduced drilling days is the most effective way to reduce the total drilling cost in a drilling project.

Chapter Four: Divergence of Operator Company and suppliers

4.1 Introduction

In Chapter 3, the model about project schedule and well services selection has been presented. This method can be used to flexibly and intuitively model the decision maker's preferences based on predetermined criteria. More specifically, the supplier(s) will be selected through the MIP model under considerations of operator company satisfaction and technical requirements. This model is used during project planning. After the project starts process, a lot of issues will happen as the divergent benefit of the Operator Company and suppliers. This chapter will talk about the benefit from the perspectives of both Operator Company and supplier. Then a useful method to solve this issue will be discussed.

4.2 Problem description

As well service is one type of outsourcing, the problems related to outsource will happen in a drilling process. A reliable and cooperative subcontract is a strong requirement in this situation. For the both operator company and outsource, it is natural for each party to try to maximize its individual benefit. For example, from the point of view of contractor, this could mean trying to obtain higher prices for services and/or longer delivery times than what had been expected. On the other hand, from an operator company's point of view, they will try to get the possible lowest expenditure and the highest service (Fig. 4-1).

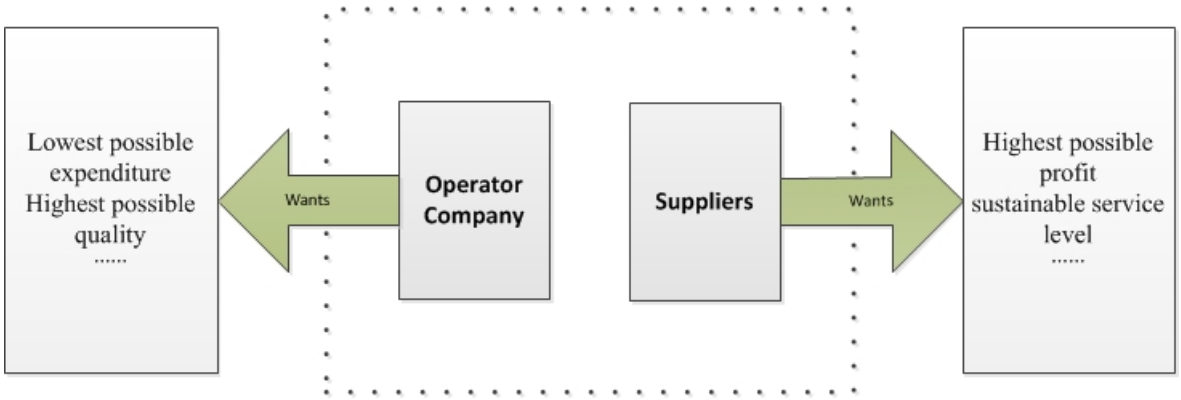


Figure 4-1 Divergent benefit Operator Company and well service company

4.3 Divergent of Supplier and Operator Company

From Usher (2003), the objectives of operator company and supplier could be classified in Table (4-1).

Table 4-1 The divergent of Supplier and Oil Company

Factor	Oil industry wants	Supplier wants
Cost	Lowest possible expenditure	Highest possible profit
Services quality	Highest possible quality	sustainable service level
Risk and liabilities	Transfer risk, and retain contract flexibility	Accept as little risk as possible, and try to clear and reliability limited contract
Flexibility	Cope with all kinds of changing needs	Limited flexibility and all changes subject to cost

Factor	Oil industry wants	Supplier wants
Specialisation and diversity	Get specialisation that is neither unavailable nor too costly for the limited time required	Add extra charges to every additional service
Information	Ability to obtain, process and utilise data for the service delivery in respect of identifying need and monitoring performance	All bespoke data reporting at extra cost to the standard suite
Responsibilities	Shared accountability	Shared accountability

Moomjian (1993; 1992) has thoroughly studied the relationship between operators and contractors. In terms of Moomjian (1992, 1993), the requirements from both Operator Company and supplier are analyzed in the following sections.

4.3.1 From Operator Company's perspective

From the operator's perspective, scheduling a commencement date is important for many reasons. The operator must plan for execution of the drilling program and arrange logistics for provision of required supplies and services. In some situations, such as where the drilling deadline is imposed under the operator's agreement, timing of the commencement of operations is crucial. The requirements of Operator Company are analyzed by Marinescu and Buchner (2007), which are summarized below:

- Increased ROP (rate of penetration) and drilling performance

- Minimized total well cost
- Eliminating unscheduled events
- Better formation evaluation
- Lower HES (Health, Safety and Environment) risks
- Reduced maintenance costs and waste generation

4.3.2 From supplier's perspective

The supplier wishes to deliver the minimum level of service which just meets the operator's requirements in order to maximize the profit and minimized the risk.

The contractor is also confronted with a number of considerations regarding timing of commencement for a future contract. If the rig is operating, the contractor must fulfill its existing contractual obligations. It may not be ab1e to predict when ongoing operations will be completed with a degree of accuracy. This is due to the uncertainties associated with drilling activities and potentially.

For the service company, what they want and what they can offer are summarized below:

- Sustainable service level (what they want)
- Maximized profit (what they want)
- Cope with the schedule conflicts when multi-projects are carried out and only a single source service is available (what they can offer)
- Integrated fluids data (what they can offer)
- Comprehensive HSE (what they can offer)
- All additional services is charged at an extra cost (what they want)

4.3.3 Resolving divergent needs between supplier and Operator Company

As mentioned in previous section, the divergent requirements or wishes from an operator company and its oil service enterprises are difficult to meet. However, Usher (2003) gives two critical and complementary solutions which as to the author's belief are able to cope with the conflict requirements, i.e. the development of the relationship and the formulation of the contract (Figure 4-2). Some authors indicate that the relationship is the qualitative aspect of the solution and it relies very much on people. The concept includes openness, commitment, communication and accessibility. At meanwhile, some other scholars consider reducing the divergence through making a formulation contract. . For a contract point of view, most companies tend to choose an incentive contract.

Sharing risk is considered by some scholars as a good way to avoid divergence. Oeffner (1988) presents the concept of "Shared Risk" contracts, where the total well drilling time is negotiated between operator and suppliers under considerations of responsibility for the potentially influencing risks. An example, in which the time overrunning up to a certain upper limit is reflected in zero day rates for the contractor, is used to demonstrate how risk is shared between the operator and its service suppliers.

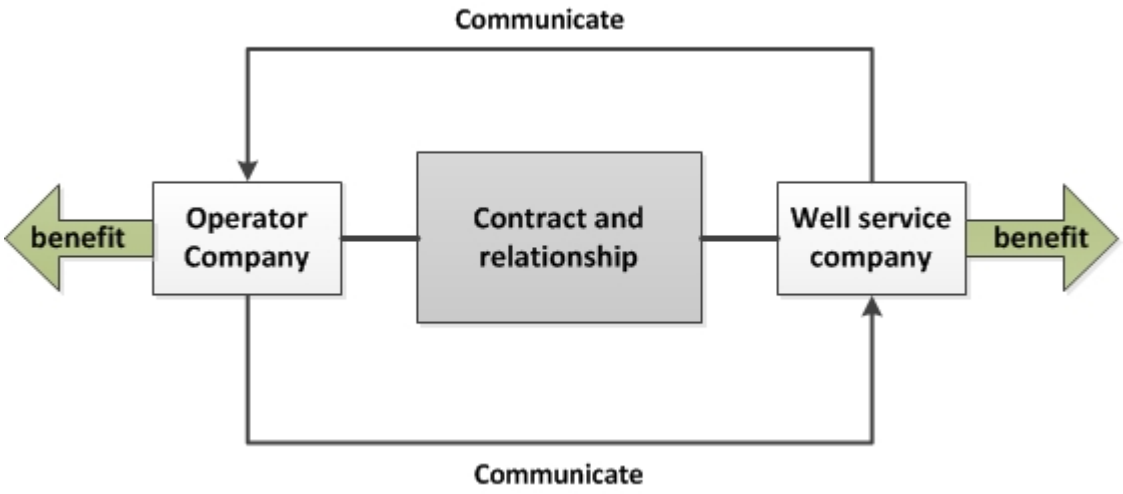


Figure 4-2 Resolving divergent needs and conflicts between an operator company and its suppliers

4.4 Simulation and analysis during project processing

Most of time, the subcontractor is physically located at a different place from the platform. The transportation may be delayed due to some uncertainties. Figure (4-3) is the relationship between the delay delivery of service and the corresponding total cost changes for case 2. From Figure (4-3), it can be found that the total cost increases rapidly as delay increases.

Figure 4-3 Simulation of testing delivery time of logging and evaluation during processing

If the service company finishes the activity later than it is originally planned, which could be caused by longer operation (Fig. 4-4) or bad weather, the total cost will also increase. If the completion time of a project is delayed just for one day, the cost of the project increases a lot.

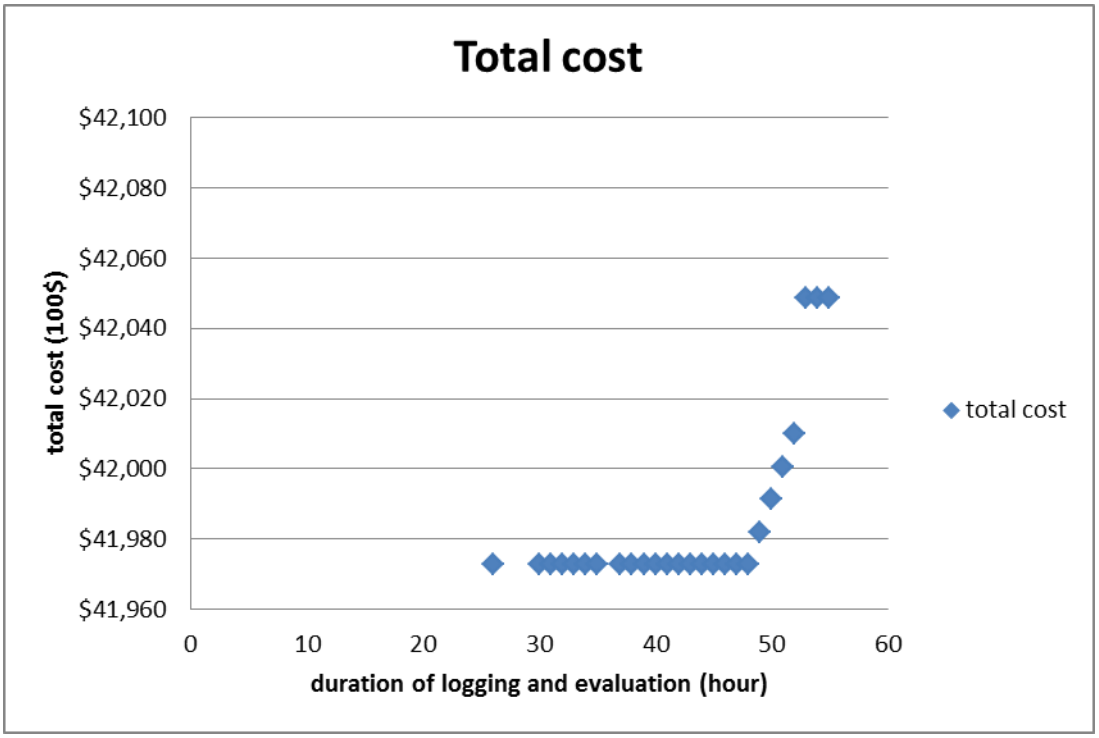


Figure 4-4 Simulation of testing duration of logging and evaluation during processing

However in most of the time, the increase of total cost of a drilling project and the increase of the project completion time do not have a linear relationship. For instance, if one activity cannot be finished on time, the next activity cannot start until this previous activity completes. Likewise, all the other succeeding activities will be delayed. These delays need to be negotiated and handled with all the service suppliers. This may not be feasible since these suppliers may not have flexibility to re-schedule these delay activities due to their extremely busy businesses. Obviously, this is a complex project management and re-schedule problem. One way to handle this problem is to pay extra costs to all the affected suppliers to let them crash the delayed activities. Another way is to hire new service contractors and pay them to finish the delayed activity. However, the price for hiring these

new contractors is normally quite high because of the short lead time. As mentioned before, the day rate of drilling operation is very high. Therefore, such a delay normally causes a significant increase of the total project cost.

To solve this problem, it is suggested that a penalty should be added into the contract to require the service providers to pay the operator when the project is not commenced by a scheduled starting date. This penalty can be calculated by the programming model as presented by 4-1 or based on the past experience of the operator. This penalty is reasonable under consideration of significant increase of the total cost due to an activity delay. In practice, this penalty is either ignored or under estimated, which often results in financial problem if an unexpected delay happens.

Notation

Tn_{ij} lateness time of service company i supply service j to the operator company

C_{ij} penalty cost for supplier of deliver service j after SD_j per each unit of lateness.

β_j cost of receiving service j after SD_j per each unit of lateness.

$$Y_{ij} = \begin{cases} 1 & \text{if well service company i did not supplies service j on time} \\ 0 & \text{otherwise} \end{cases}$$

$$\text{MinZ} = \sum_{j \in o} \sum_{t=1}^{T} \left[cr_j \times (d_j - TO_j) + co_j \times TO_j \right] + \sum_{j \in o} \sum_{i \in L_i^{'}} \alpha_j (SD_j - D_{ij}) X_{ij}$$

$$+ \sum_{i \in I} \sum_{j=1}^{J} P_{ij} X_{ij} + DC \times TT \; - \left[\sum_{i \in I} \sum_{j=1}^{J} C_{ij} Tn_{ij} X_{ij} - \sum_{j \in o} \sum_{i \in L_i} \beta_j Tn_{ij} X_{ij} \right] Y_{ij}$$

(4-1)

The objective of the model is to minimize total cost of drilling project, and it consists of regular working cost, crashing working cost, earliness costs of service, purchase costs of service and sub cost. The last part is the penalty for lateness Service Company.

s.t.

$$TR_j \leq CR \qquad j \in o \tag{1}$$

The regular working time cannot greater than maximum capacity of regular time

$$TO_j \leq CO \qquad j \in o \tag{2}$$

The crashing time of operation j cannot greater than maximum capacity of crashing time

$$TR_j \geq d_j - TO_j \qquad j \in o \tag{3}$$

The total working time for activity j should be greater or equal to duration of activity j

$$\sum_{i \in I} X_{ij} = 1 \qquad j \in o \tag{4}$$

Constraint (4) guarantees only one supplier should be chosen to one service.

$$SD_j \geq SD_k + d_k - TO_k + Tn_{ik} Y_{ik} X_{ik} \qquad j \in B_j \tag{5}$$

If activity k precedes activity j, the completion time of activity k must be less than or equal to the start time of activity j.

$$\sum_{i \in I} \sum_{1}^{J} (d_j - TO_j + Tn_{ji} Y_{ij} X_{ij}) \leq dd \tag{6}$$

$$TT \leq dd \tag{7}$$

Constraints (6) and (7) make sure that the due date of drilling operation should be greater than or equal to the total assignment time of the project. Hence, the project could finish on time.

$$TR_j, TO_j \geq 0 \qquad j \in o \tag{8}$$

$$X_{ij} = 0,1 \quad j \in o \tag{9}$$

$$Y_{ij} = 0,1 \quad j \in o \tag{10}$$

Constraints (8), (9) and (10) define non-negativity and type of the decision variables.

As the delay problem will happen in drilling project and it will influence drilling cost a lot. It is necessary to protect the profile of Oil Company. This model could help decision maker in Oil Company calculate loss. When the decision maker using the model to calculate loss, they already have the start time, price and duration for every supplier. So they could use the delay time to calculate loss.

4.4.1 Shared risk

The “shared risk" concept can be applied in either planned or unplanned situation, which happening would cause the drilling contractor suffering a financial loss (Moy & Kent, 1993). Moomjian (1999) argues that a clear allocation of the responsibility of the parties must be made from an insurance perspective, regardless of fault. The parties will have problems calculating their risk exposure and will be forced in practice to insure the same risk, since the risk is unclarified until an incident occurred. However, in most drilling contracts, the risk is mainly borne by the oil companies(Osmundsen et al., 2006). If the oil companies assumed all the risks, normally the well service companies would be assured of receiving the same payment regardless of their own performance, i.e. the contracts would

not give those incentives or penalty to do a good or poor job. Therefore, it is necessary to allocate some risk and give incentive to the suppliers. Risks and incentives are closely linked. To ensure incentives, the suppliers also need to share some risks from the oil company. For allocating risks between an oil company and its contractors, Herbert (1991) suggests that the operator (or oil company) assumes the risks of geology, location dependent factors and weather, while the contractors are charged with the responsibility of drilling the well. The operator would retain control over the well, while the contractors would be rewarded for above-average performance and penalized for sub-par performance.

4.4.2 Incentive contract

From the sensitivity test, it is found that to get a higher performance of the project, an incentive drilling contract is important. By definition, an incentive is something that encourages one to take action or work harder(C. A. Moomjian Jr, 1992). So incentive contracts are a question not only of efficiency, but to a great extent also of the allocation of input factors. This can influence the level of rates. The concept of including service companies and contractors into the overall project risk and awarding exceptional performance with additional bonus payment in general manufacturing businesses is not new. Within the drilling industry, however, the incentives are just recently introduced as a means of bringing drilling costs closer in line with the operators' target. Through negotiations with different oil companies over additional incentives after contracts have been signed, the contractors can also succeed in creating competition during its duration and thereby push up rates. Incentive contracts can serve as a selection mechanism, where contracts which

reward efficient operation attract efficient companies since they are the ones who can potentially gain more from such an agreement.

However there are a few things need to be paid attention when making the incentive contract(Spoerker & Ringhofer, 2002).

- The first requirement is strong commitment from all parties.
- Incentive crew
- Bonus payments to service companies and contractors can never increase total project cost, as they are paid out of the saving generated from increased performance.
- An incentive-type environment requires openness and trust among the parties
- Responsibilities and decision-making process have to be clear and communicated to everybody on location (Figure 4-5)
- Incentives are no static environment. As project occurs, incentive benchmarks and targets need to be constantly adapted.
- Require feedback from both operator's and contractor's crews on location.

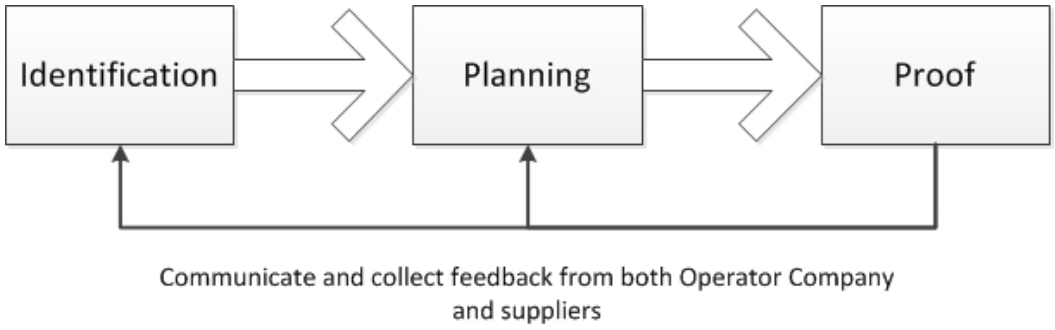


Figure 4-5 Process map

For example, if drilling contractor finish a well under the budget, the drilling contract could get 30% of the saving money. If a lost time accident or a serious safety incident occurs, 100% of the incentive award is lost. When the operator and suppliers share the common objective of reducing drilling time, a team spirit is created that permits the suppliers to provide a better-quality service and to implement efficiency measures. When working on an incentive basis, the contractor becomes a proactive participant in the drilling process because contract revenues will increase as a result of good performance.

The best incentive programs are based on trust and understanding between the operator and the suppliers. An innovative incentive contract should promote participative problem solving and provide an equitable sharing of savings achieved through good performance and efficiencies. Successful programs involve operators and suppliers who are mutually dedicated to reducing drilling time while conducting safe and efficient operations. This could improve and motive to maximize efficiency and address potential problems in each phase of well operations.

4.5 Summary

Drilling contractors, service companies and supply companies interacts among them and influence drilling project a lot. If they could work efficiently together, it will save time and money. Therefore to generate an “ownership” within Service Company’s and contractor’s staff is reflected by both the increased quality of the wells drilled and enhances safety record of the rigs. Significant divergence of opinion exists between Operator Company and suppliers, and hence it is hereby suggested that the parties approach this issue on

development of the relationship, share risk and the formulation of the contract. When addressed in this way, the principal contract terms can be resolved in a fair and equitable result.

Chapter Five: Conclusions and future work

5.1 Conclusions

This thesis develops a mix integer programming model (MIP) to select suppliers in oil/gas well drilling operation for integrated drilling project and supply chain management. The MIP model makes oil company quickly select alterative suppliers to meet its drilling project management requirements, such as price, delivery time and project duration. The solution aims at providing the optimal or rational solutions for the decisions on: supplier selection, regular working time vs. overtime for each activity, and the total project duration with the minimum total project cost.

The thesis work suggests the integrated consideration of the drilling operation schedule and well services selection. As to my best knowledge, this integrated project and supply chain management idea has not been meaningfully addressed in the current literature. The model as presented in this thesis is able to select a well services company under considerations of delivery time, lead-time and the cost to integrate drilling project schedule. This is a novel quantitative model to support decision making in drilling project management and supplier selection. The two typical drilling project cases from an oil/gas industry are collected and conducted to validate the feasibility and efficiency of the model. The first case assumes the service companies which cannot crash their projects due to the limitation of the technology, equipment, staff skill, tools, etc. The second case assumes the service companies can speed up the project progress according to the customer needs. Through the case studies, the feasibility and effectiveness of the presented model are validated and tested. Through a series of sensitivity test, the results show that the model could help an oil company to

synchronize the drilling project schedule with its supplier selection and control. Therefore, the model could be used for developing a decision support system for integrated drilling project and supply chain management. It is expected that this decision support system could provide convenience for an oil company to quickly select heterogeneous suppliers to meet its drilling project management requirements. In short, it would be concluded that the methods and model for integrated drill project and supply chain management as presented in this thesis are novel and such integration can effectively improve the performance of drilling operations and well service operations. .

Since the drilling contractors and service companies are interrelated involved in a drilling project, the collaboration and integration between these two types of companies are important for reducing the total cost and project duration. However, due to the divergent positions of the suppliers and the operator company, there are conflicts and trade-offs on the business profits and project time control. Therefore, an effective method or management mechanism is needed to deal with the problems resulted from the divergences between the two types of the companies. In this thesis, the sharing risk and making an incentive contract are adopted from other research to solve the problems. When the operator and suppliers share the common objective of reducing drilling time and consequently the two parties could share the common risk, a team spirit could be developed through this practice, which leads the suppliers to provide a better-quality service and to implement efficient measures.

5.2 Future work

New frontiers in drilling operation have been leading oil industries to face more complex challenges in terms of drilling project and supporting supply chain. A few things could be considered in the future work.

1. This thesis work only considers the delivery time, duration and price of the well services selection. However, there may be some other factors that impact on the drilling operation satisfaction which are not considered. To identify these factors could be ones of the interesting future researches.
2. There are some other factors could affect the drilling cost. For example, weather could influence drilling operation as bad weather may lead supply services delay. Hence, the influences caused by the uncertain issues and how to model these uncertainties could be another interesting topic.
3. In this thesis, the research considers the drilling projects on land. If the offshore environment is considered, the method and model may not be applicable. Because of the limited platform space for the offshore drilling operation, special vessels and helicopters are needed. This would certainty make the situation much more complex than an on-land drilling project.

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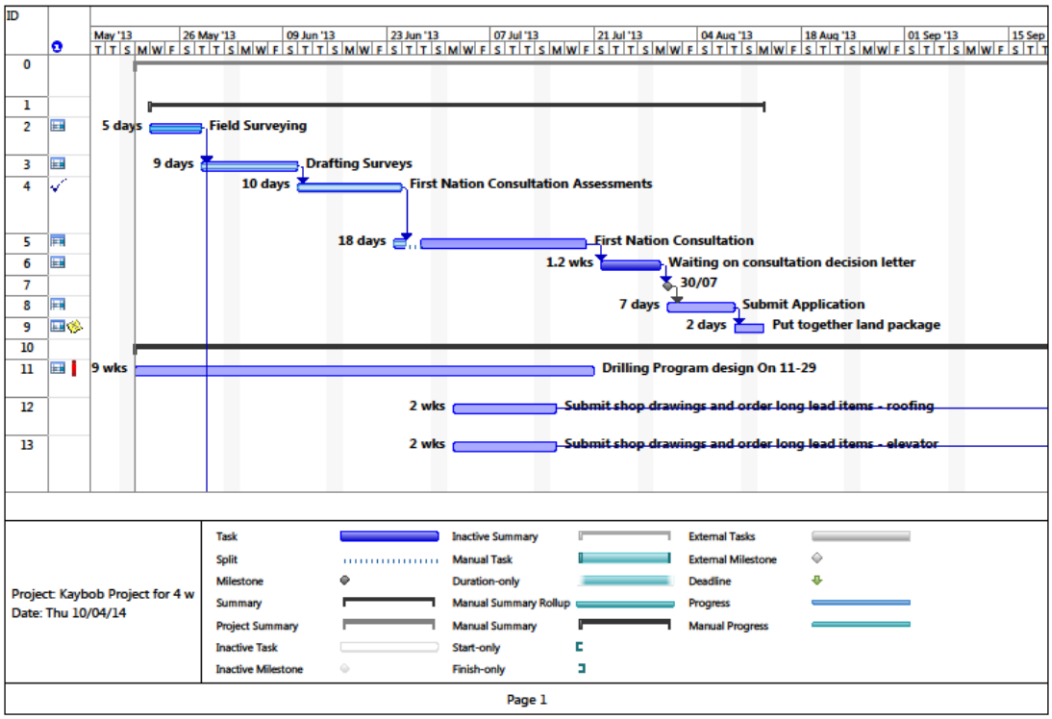
Appendix 1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May '13
26 May '13
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5 days
Field Surveying
9 days
Drafting Surveys
10 days
First Nation Consultation Assessments
18 days
First Nation Consultation
1.2 wks
Waiting on consultation decision letter
30/07
7 days
Submit Application
2 days
Put together land package
9 wks
Drilling Program design On 11-29
2 wks
Submit shop drawings and order long lead items - roofing
2 wks
Submit shop drawings and order long lead items - elevator
Project: Kaybob Project for 4 w
Date: Thu 10/04/14
Task
Split
Milestone
Summary
Project Summary
Inactive Task
Inactive Milestone
Inactive Summary
Manual Task
Duration-only
Manual Summary Rollup
Manual Summary
Start-only
Finish-only
External Tasks
External Milestone
Deadline
Progress
Manual Progress
Page 1

Appendix 2: Code for Case 1

```
sets:
supplier1/supplier11 supplier12 supplier13/;
activity1/1/;
links(supplier1,activity1):duration1,deliverytime1,price1,duration13,price13,duration18,pri
ce18;
TXS1(supplier1,activity1):x1;

endsets

data:
duration1=67 80 63;
deliverytime1=1 0 0;
price1=37193 39629 40320;
duration13=105 122 96;
price13=58287 60434 60480;
duration18=289 296 260;
price18=159874 146626 163800;
enddata

@FOR(activity1(k):@sum(supplier1(i):x1(i,k))=1);

@FOR(txs1:@bin(x1));

@FOR(activity1:@sum(TXS1(m,n):(duration1*x1))=D1);


@FOR(activity1:@sum(TXS1(m,n):(deliverytime1*x1))= I1);

fa1=@if(sd1 #gt# I1, 18000,0);
fb1=@if(sd1 #gt# I1, sd1,I1);

@for(activity1:
@sum(links:(832*nr1*TR1+@abs(fa1*(sd1-deliverytime1))+price1)*x1)=cost1);
sd1=0;

nr1*TR1>=D1;

TR1<=24;

sets:
supplier2/supplier21 supplier22 supplier23 supplier24/;
```

```
activity2/2/;
links2(supplier2,activity2):duration2,deliverytime2,price2;
TXS2(supplier2,activity2):x2;

endsets

data:
duration2=41 45 38 44;

deliverytime2=4 4 3 4;
price2=25232 28764 25978 24080;

enddata

@FOR(activity2(k):@sum(supplier2(i):x2(i,k))=1);

@FOR(txs2:@bin(x2));

@FOR(activity2:@sum(TXS2(m,n):(duration2*x2))=D2);

@FOR(activity2:@sum(TXS2(m,n):(deliverytime2*x2))= I2);

fa2=@if(sd2 #gt# I2,18000,0);
fb2=@if(sd2 #gt# I2, sd2,I2);

@for(activity2:
@sum(links2:(702*nr2*TR2+@abs(fa2*(sd2-deliverytime2))+price2)*x2)=cost2);

nr2*TR2>=D2;

sd2=fb1+nr1+1;

TR2<=24;

@FOR(activity1:@sum(TXS1(m,n):(duration13*x1))=D13);

@for(activity1:
@sum(links:(861*nr3*TR3+price13)*x1)=cost3);

nr3*TR3>=D13;

TR3<=24;
sets:
supplier4/supplier41 supplier42 supplier43/;
```

```
activity4/4/;
links4(supplier4,activity4):duration4,deliverytime4,price4;
TXS4(supplier4,activity4):x4;

endsets

data:
duration4=97 118 108;

deliverytime4=9 9 11;
price4=102589 104442 102798;
enddata

@FOR(activity4(k):@sum(supplier4(i):x4(i,k))=1);

@FOR(txs4:@bin(x4));

@FOR(activity4:@sum(TXS4(m,n):(duration4*x4))=D4);

@FOR(activity4:@sum(TXS4(m,n):(deliverytime4*x4))= I4);

fa4=@if(sd4 #gt# I4, 18000,0);
fb4=@if(sd1 #gt# I4, sd4,I4);

@for(activity4:
@sum(links4:(400*nr4*TR4+@abs(fa4*(sd4-deliverytime4))+price4)*x4)=cost4);
nr4*TR4>=D4;
sd4=fb2+nr2+nr3+1;
TR4<=24;
sets:
supplier5/supplier51 supplier52 supplier53 supplier54/;
activity5/5/;
links5(supplier5,activity5):duration5,deliverytime5,price5;
TXS5(supplier5,activity5):x5;
endsets

data:
duration5=41 45 38 39;

deliverytime5=13 14 13 14;

price5=99630 102222 96061 96000;

enddata
```

```
@FOR(activity5(k):@sum(supplier5(i):x5(i,k))=1);

@FOR(txs5:@bin(x5));

@FOR(activity5:@sum(TXS5(m,n):(duration5*x5))=D5);


@FOR(activity5:@sum(TXS5(m,n):(deliverytime5*x5))= I5);

fa5=@if(sd5 #gt# I5, 18000,0);
fb5=@if(sd5 #gt# I5, sd5,I5);

@for(activity5:
@sum(links5:(716*nr5*TR5+@abs(fa5*(sd5-deliverytime5))+price5)*x5)=cost5);
nr5*TR5>=D5;

sd5=fb4+nr4+1;
TR5<=24;

sets:
supplier6/supplier61 supplier62 supplier63 supplier64/;
activity6/6/;
links6(supplier6,activity6):duration6,deliverytime6,price6;
TXS6(supplier6,activity6):x6;

endsets

data:
duration6=180 188 170 169;

deliverytime6=16 15 17 17;

price6=166925 180299 169121 160320;

enddata

@FOR(activity6(k):@sum(supplier6(i):x6(i,k))=1);

@FOR(txs6:@bin(x6));

@FOR(activity6:@sum(TXS6(m,n):(duration6*x6))=D6);

@FOR(activity6:@sum(TXS6(m,n):(deliverytime6*x6))= I6);
```

```
fa6=@if(sd6 #gt# I6, 18000,0);
fb6=@if(sd6 #gt# I6, sd6,I6);

@for(activity6:
@sum(links5:(716*nr6*TR6+@abs(fa6*(sd6-deliverytime6))+price6)*x6)=cost6);
nr6*TR6>=D6;
sd6=fb5+nr5+1;
TR6<=24;
sets:
supplier7/supplier71 supplier72 supplier73/;
activity7/7/;
links7(supplier7,activity7):duration7,deliverytime7,price7;
TXS7(supplier7,activity7):x7;

endsets

data:
duration7=48 49 45;

deliverytime7=22 24 26;

price7=66942 65444 66485;

enddata

@FOR(activity7(k):@sum(supplier7(i):x7(i,k))=1);

@FOR(txs7:@bin(x7));

@FOR(activity7:@sum(TXS7(m,n):(duration7*x7))=D7);


@FOR(activity7:@sum(TXS7(m,n):(deliverytime7*x7))= I7);

fa7=@if(sd7 #gt# I7, 18000,0);
fb7=@if(sd7 #gt# I7, sd7,I7);

@for(activity7:
@sum(links7:(702*nr7*TR7+@abs(fa7*(sd7-deliverytime7))+price7)*x7)=cost7);

nr7*TR7>=D7;
```

```
sd7=fb6+nr6+1;
TR7<=24;
@FOR(activity1:@sum(TXS1(m,n):(duration18*x1))=D18);

@for(activity1:
@sum(links:(523*nr8*TR8+price18)*x1)=cost8);
nr8*TR8>=D18;

TR8<=24;
MIN=cost1+cost2+cost3+cost4+cost5+cost6+cost7+cost8+(fb7+nr7+nr8)*76000;
@gin(nr1);
@gin(nr2);
@gin(nr3);
@gin(nr4);
@gin(nr5);
@gin(nr6);
@gin(nr7);
@gin(nr8);
end
```

Appendix 3: Code for Case2

```
sets:
supplier1/supplier11 supplier12 supplier13/;
activity1/1/;
links(supplier1,activity1):duration1,deliverytime1,price1,duration13,price13,duration18,pri
ce18;
TXS1(supplier1,activity1):x1;
endsets
data:
duration1=67 80 63;
deliverytime1=1 0 0;
price1=37193 39629 40320;
duration13=105 122 96;
price13=58287 60434 60480;
duration18=289 296 260;
price18=159874 146626 163800;
enddata
@FOR(activity1(k):@sum(supplier1(i):x1(i,k))=1);
@FOR(txs1:@bin(x1));
@FOR(activity1:@sum(TXS1(m,n):(duration1*x1))=D1);
@FOR(activity1:@sum(TXS1(m,n):(deliverytime1*x1))= I1);
```

```
fa1=@if(sd1 #gt# I1, 18000,0);
fb1=@if(sd1 #gt# I1, sd1,I1);

@for(activity1:
@sum(links:(832*nr1*TR1+1081*TO1+@abs(fa1*(sd1-
deliverytime1))+price1)*x1)=cost1);
sd1=0;
nr1*TR1>=D1-TO1;
@bnd(0,TO1,4);
TR1<=24;
sets:
supplier2/supplier21 supplier22 supplier23 supplier24/;
activity2/2/;
links2(supplier2,activity2):duration2,deliverytime2,price2;
TXS2(supplier2,activity2):x2;
endsets
data:
duration2=41 45 38 44;
deliverytime2=4 4 3 4;
price2=25232 28764 25978 24080;
enddata
@FOR(activity2(k):@sum(supplier2(i):x2(i,k))=1);
@FOR(txs2:@bin(x2));
```

```
@FOR(activity2:@sum(TXS2(m,n):(duration2*x2))=D2);



@FOR(activity2:@sum(TXS2(m,n):(deliverytime2*x2))= I2);
fa2=@if(sd2 #gt# I2,18000,0);
fb2=@if(sd2 #gt# I2, sd2,I2);
@for(activity2:
@sum(links2:(702*nr2*TR2+912*TO2+@abs(fa2*(sd2-
deliverytime2))+price2)*x2)=cost2);
nr2*TR2>=D2-TO2;
@bnd(0,TO2,4);
sd2=fb1+nr1+1;
TR2<=24;
@FOR(activity1:@sum(TXS1(m,n):(duration13*x1))=D13);
@for(activity1:
@sum(links:(861*nr3*TR3+1120*TO3+price13)*x1)=cost3);
nr3*TR3>=D13-TO3;
@bnd(0,TO3,7);
TR3<=24;
sets:
supplier4/supplier41 supplier42 supplier43/;
activity4/4/;
links4(supplier4,activity4):duration4,deliverytime4,price4;
```

```
TXS4(supplier4,activity4):x4;
endsets

data:
duration4=115 122 108;
deliverytime4=9 9 11;
price4=102589 104442 102798;
enddata
@FOR(activity4(k):@sum(supplier4(i):x4(i,k))=1);
@FOR(txs4:@bin(x4));
@FOR(activity4:@sum(TXS4(m,n):(duration4*x4))=D4);
@FOR(activity4:@sum(TXS4(m,n):(deliverytime4*x4))= I4);
fa4=@if(sd4 #gt# I4, 18000,0);
fb4=@if(sd1 #gt# I4, sd4,I4);
@for(activity4:
@sum(links4:(400*nr4*TR4+800*TO4+@abs(fa4*(sd4-
deliverytime4))+price4)*x4)=cost4);
nr4*TR4>=D4-TO4;
@bnd(0,TO4,7);
sd4=fb2+nr2+nr3+1;
TR4<=24;
sets:
supplier5/supplier51 supplier52 supplier53 supplier54/;
```

```
activity5/5/;
links5(supplier5,activity5):duration5,deliverytime5,price5;
TXS5(supplier5,activity5):x5;

endsets
data:
duration5=41 45 38 44;
deliverytime5=13 14 13 14;
price5=99630 10222 96061 96000;
enddata
@FOR(activity5(k):@sum(supplier5(i):x5(i,k))=1);
@FOR(txs5:@bin(x5));
@FOR(activity5:@sum(TXS5(m,n):(duration5*x5))=D5);
@FOR(activity5:@sum(TXS5(m,n):(deliverytime5*x5))= I5);
fa5=@if(sd5 #gt# I5, 18000,0);
fb5=@if(sd5 #gt# I5, sd5,I5);
@for(activity5:
@sum(links5:(716*nr5*TR5+931*TO5+@abs(fa5*(sd5-
deliverytime5))+price5)*x5)=cost5);
nr5*TR5>=D5-TO5;
@bnd(0,TO5,4);
sd5=fb4+nr4+1;
TR5<=24;
```

```
sets:
supplier6/supplier61 supplier62 supplier63 supplier64/;
activity6/6/;
links6(supplier6,activity6):duration6,deliverytime6,price6;
TXS6(supplier6,activity6):x6;
endsets
data:
duration6=180 188 166 167;
deliverytime6=16 15 17 17;
price6=166925 180299 169121 160320;
enddata
@FOR(activity6(k):@sum(supplier6(i):x6(i,k))=1);
@FOR(txs6:@bin(x6));
@FOR(activity6:@sum(TXS6(m,n):(duration6*x6))=D6);
@FOR(activity6:@sum(TXS6(m,n):(deliverytime6*x6))= I6);
fa6=@if(sd6 #gt# I6, 18000,0);
fb6=@if(sd6 #gt# I6, sd6,I6);
@for(activity6:
@sum(links5:(716*nr6*TR6+931*TO6+@abs(fa6*(sd6-
deliverytime6))+price6)*x6)=cost6);
nr6*TR6>=D6-TO6;
@bnd(0,TO6,7);
sd6=fb5+nr5+1;
```

```
TR6<=24;
sets:
supplier7/supplier71 supplier72 supplier73/;
activity7/7/;
links7(supplier7,activity7):duration7,deliverytime7,price7;
TXS7(supplier7,activity7):x7;
endsets
data:
duration7=48 49 45;
deliverytime7=22 24 26;
price7=66942 65444 66485;
enddata
@FOR(activity7(k):@sum(supplier7(i):x7(i,k))=1);
@FOR(txs7:@bin(x7));
@FOR(activity7:@sum(TXS7(m,n):(duration7*x7))=D7);
@FOR(activity7:@sum(TXS7(m,n):(deliverytime7*x7))= I7);
fa7=@if(sd7 #gt# I7, 18000,0);
fb7=@if(sd7 #gt# I7, sd7,I7);
@for(activity7:
@sum(links7:(702*nr7*TR7+913*TO7+@abs(fa7*(sd7-
deliverytime7))+price7)*x7)=cost7);
nr7*TR7>=D7-TO7;
@bnd(0,TO7,4);
```

```
sd7=fb6+nr6+1;
TR7<=24;




@FOR(activity1:@sum(TXS1(m,n):(duration18*x1))=D18);
@for(activity1:
@sum(links:(523*nr8*TR8+680*TO8+price18)*x1)=cost8);
nr8*TR8>=D18-TO8;
@bnd(0,TO8,7);
TR8<=24;
MIN=cost1+cost2+cost3+cost4+cost5+cost6+cost7+cost8+(fb7+nr7+nr8)*76000;
@gin(nr1);
@gin(nr2);
@gin(nr3);
@gin(nr4);
@gin(nr5);
@gin(nr6);
@gin(nr7);
@gin(nr8);
end
```