Comparative Study of Crude Oil Transportation

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การศึกษาเชิงเปรียบเทียบของการขนส่งน้ำมันดิบ

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ณฐวรรณ สิทธิผลกุล : การศึกษาเชิงเปรียบเทียบของการขนส่งน้ำมันดิบ (Comparative Study of Crude Oil Transportation) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ศ. ดร. ปารเมศ ชุติมา, หน้า.

การศึกษาเชิงเปรียบเทียบนี้ใช้กระบวนการลำดับชั้นเชิงวิเคราะห์ (Analytic Hierarchy Process) เพื่อเลือกวิธีการขนส่งน้ำมันดิบที่เหมาะสมและตอบสนองกับนโยบายของบริษัท โดยกระบวนการวิเคราะห์นี้จะช่วยในการนำปัจจัยทั้งหมดที่ต้องการใช้เพื่อเปรียบเทียบ ทั้งปัจจัยเชิงคุณภาพและเชิงปริมาณ เข้ามาเกี่ยวข้องในการตัดสินใจเลือกทางเลือกที่เหมาะสมต่อไป ซึ่งปัจจัยทั้งหมดจะถูกนำมาเปรียบเทียบในเกณฑ์เดียวกัน โดยมีสี่ปัจจัยหลักคือ ค่าใช้จ่าย ความเสี่ยงในเรื่องของความปลอดภัยและความต่อเนื่องในการขนส่งน้ำมันดิบ ผลกระทบกับสิ่งแวดล้อม และการยอมรับจากชุมชน ปัจจัยข้างต้นจะถูกนำมาเปรียบเทียบเพื่อหาค่าความสำคัญสุดท้ายในการเลือกระหว่างการใช้รถบรรทุกน้ำมันดิบ ซึ่งเป็นวิธีดำเนินการปัจจุบันของบริษัท หรือ การสร้างท่อขนส่งน้ำมันจากสถานีผลิตลานกระบือ จังหวัดกำแพงเพชรไปจนถึงคลังน้ำมันดิบบึงพระ ในจังหวัดพิษณุโลก โดยปัญหาที่พบเจอในการดำเนินงานปัจจุบันของบริษัทคือ ความไม่ต่อเนื่องในการขนส่งน้ำมันดิบในหน้าฝนที่เกิดน้ำท่วมในหลายจุด ทำให้การขนส่งชะงัก รวมทั้งนโยบายความปลอดภัยของบริษัทที่ต้องการป้องกันอุบัติเหตุทางรถยนต์ ทำให้รถบรรทุกไม่สามารถวิ่งในตอนกลางคืนได้ รวมทั้งมีการจำกัดความเร็วในการวิ่งของรถบรรทุก เป็นผลให้ได้รับการร้องเรียนจากชาวบ้านในเรื่องของการกีดขวางถนนในเวลาเร่งด่วน รวมทั้งสร้างเสียงรบกวนกับชุมชน อย่างไรก็ตามข้อจำกัดหนึ่งคือ การลงทุนที่ต้องใช้ในการสร้างท่อขนส่งน้ำมัน ซึ่งจะมีผลในการตัดสินใจเลือกทางเลือกที่เหมาะสมเมื่อเทียบกับปัจจัยอื่นๆที่กล่าวมาข้างต้น

ผลการศึกษาพบว่าการสร้างท่อขนส่งน้ำมันดิบเป็นทางเลือกที่เหมาะสมที่สุดเพื่อตอบสนองความต้องการและนโยบายของบริษัท โดยค่าความสำคัญของท่อขนส่งน้ำมันเป็น 59% ในขณะที่ค่าความสำคัญของรถบรรทุกน้ำมันเป็น 41% เนื่องมาจากบริษัทให้ความสำคัญในเรื่องของความปลอดภัยและความต่อเนื่องในการขนส่งน้ำมันเป็นอันดับแรก ตัวแปรสำคัญที่จะทำให้ผลการศึกษาเปลี่ยนแปลงคือ ค่าความสำคัญของ มูลค่าการลงทุน โดยหากเพิ่มค่าความสำคัญของปัจจัยนี้อีก 17.5% การขนส่งทางรถบรรทุกจะเป็นทางเลือกที่เหมาะสมกว่าการขนส่งโดยท่อขนส่งน้ำมัน

ภาควิชา	ศูนย์ระดับภูมิภาคทางวิศวกรรมระบบการผลิต	ลายมือชื่อนิสิต	....
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This comparative study applied the Analytic Hierarchy Process (AHP) to select the most suitable crude oil transportation methods that will align with the company's policy. The model enabled comparison of both quantitative and qualitative parameters involved in this decision making, which include cost factor, safety and reliability issue, environmental impact, and community acceptance survey. There are two transportation options to transfer crude oil from production station to the depot. First is the current practice using road tankers to carry crude oil using public highway. Current operation has many difficulties such as not reliable during flooding period, not being able to run at night time and also receiving complaints from nearby neighborhood. Hence, there was a proposal to install pipeline instead. However, high investment cost is required for pipeline installation and the company requires a reasonable judgment in order to sanction the project.

From this thesis study, it was determined that pipeline installation is the most suitable transportation option based on the associated criterions stated above. The overall priority of pipeline installation option from Expert Choice program is 59% over that of 41% from road tanker method. The result was related to the company's safety policy to consider safety and reliability as first priority. The most critical parameter is the cost factor importance level since if varied more than +17.5%, the decision outcome will prefer the other option.

Department:	Regional Centre for Manufacturing Systems Engineering	Student's Signature	....
		Advisor's Signature	....
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1. CHAPTER I Introduction

1.1 Background of the Research

There are several ways to transport crude oil from the processing facilities to targeted consumers over long distances. The options include tanker trucks, tanker rail cars, tanker ships, and crude pipeline. Tanker transportation was claimed to have "inextricable links with oil trading" since the early years of oil trading in the late 19th century (Kumar). Moreover, demand on tanker transportation for both crude and refined oil transportation has been increasing over years (Kumar). Meanwhile, crude pipelines were claimed to be "the most energy-efficient, safe, environmental friendly and economic way to ship hydrocarbons over long distances" (Dey). Consequently, there is no exact answer for the petroleum production company on ways to transfer crude oil.

In recent years, crude production is getting more difficult and complicated. All the large hydrocarbon reservoirs have been drilled and brought to production. What's left is the more challenging and complex reservoir or reservoirs in deep water. Furthermore, world energy demand is increasing with the growing world population. Energy consumption is projected to grow by 1.6% p.a. from 2011 to 2030 (BP). Hence, petroleum production companies have to find ways to maintain energy supply in every way. One of the difficulties nowadays is production from marginal oil field. It is a discovery of potential oil field from small size reservoirs, which might be too small to be economically feasible. The development of this type depends mainly on the cost; both capital and operating expenditure. This includes crude transportation to the profitable consumers, which could be a challenging decision making. Therefore, whether to use tanker transportation or pipeline network for marginal crude oil field is crucial.

In addition to cost optimization, environmental issue and community concerns are the two major issues regarding the image of the company. Acceptance from the community and corporate social responsibility are the keys to company sustainable development. Reliability of the national oil company also plays an important role in maintaining the energy security of that country. Therefore, field development has to involve all aspects, and not just cost optimization.

1.2 Introduction to Sirikit Oil Field, PTTEP

Sirikit oil field, or S1 for short, is a marginal crude oil production located in the northern part of Thailand which having the production license covering 4 provinces. It started producing first oil from well LKU-A01 in 1982 under Thai Shell Exploration and Production Company. In 1985, PTTEP jointed 25% with Thai Shell and PTTEP owned the entire asset in early of 2004.

Currently, the gross production rate is about 70,000 BPD with crude oil production rate ranging between 27-33,000 BPD. Graph of crude production is predicted until end of concession which is at year 2031. The production trend is declining, which is a nature of oil producer field as seen in Figure 1. If flowline is proven to be better than road carriage, then the expected flowline commissioning target will be at end of Q2 2017.

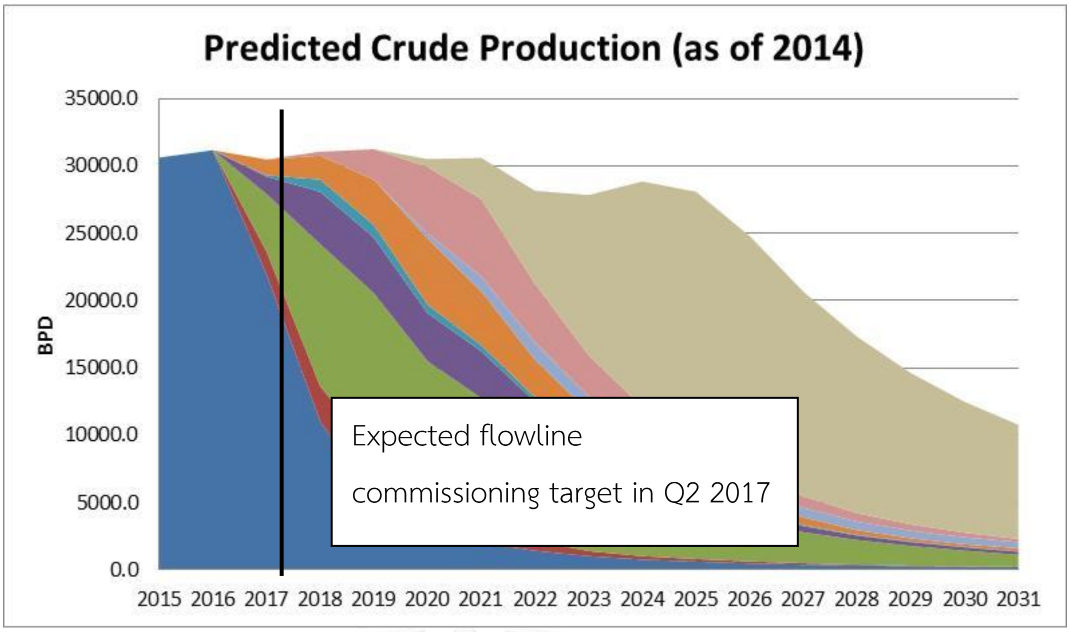


Figure 1: High Case Predicted Crude Production

Produced crude oil from well sites is routed to main production station (LKU) for liquid-gas separation in two-phase separators. This main production station (LKU) is located in Lan Krabu area in Kamphaeng Phet province. Liquid streams go directly to storage tank for further oil-water separation treatment. Crude oil is daily trucked by road tankers to the depot in BungPhra (BPR) area situated in the city of Phitsanulok. Then, it will be transferred to Bangchak and Thai Oil refineries by trains. The company outsourced road tankers operation to Sri Thai company, who is responsible for taking care of finding competent drivers as per PTTEP specification, filling up fuel, and all the tankers maintenance issues. The current transportation system can be seen in Figure 2 below.

My position in this company during this project was an asset planning engineer responsible for new project development. My role and responsibilities were to develop asset business plan and justify the sanction of any new projects that require high investment. Therefore, being able to give justification and way forward on the transportation options was under my responsibility.

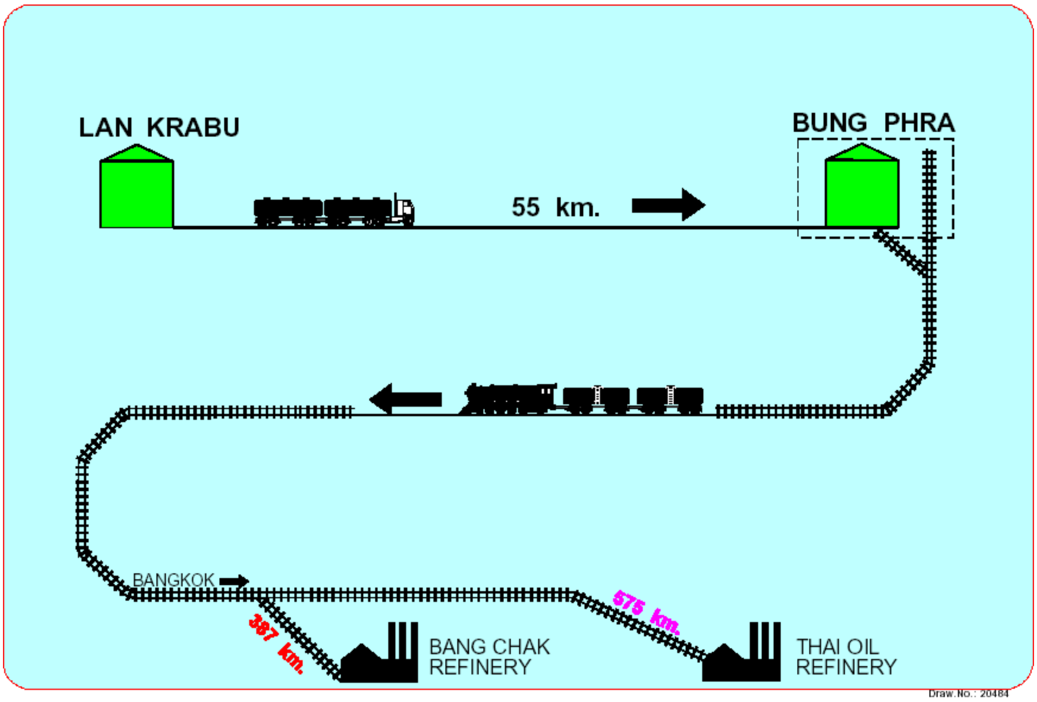


Figure 2: S1 Crude Oil Transportation System as of 2014.

1.3 Statement of the Problem

Current Road Tanker Capacity:

There are 43 units available right now with the capacity of 215 bbls/unit. They are making about 150 trips from LKU to the city of Phitsanulok per day, so each road tanker makes approximately 3 trips/day. It operates only during day time for 12 hours.

Problems and limitations of the current system using road tankers for transportation of crude oil had been observed. Those include roads blockage from flooding events and safety concern on road accidents.

Flooding is a major problem in road transportation. Roads blockage from flood may last for several days, weeks or months. The consequences are the production loss and deferment since there are only limited numbers of storage tanks to keep crude oil. Figure 3 shows the direction of flooding from heavy rain and excess water from Ping River. It can be seen that Lan Krabu (LKU) district, Kamphaeng

Phet where S1 onshore production station is located is directly receiving excess water from Ping River. Thus, there is high risk of severe flooding according to Royal Irrigation Department report in Figure 4.

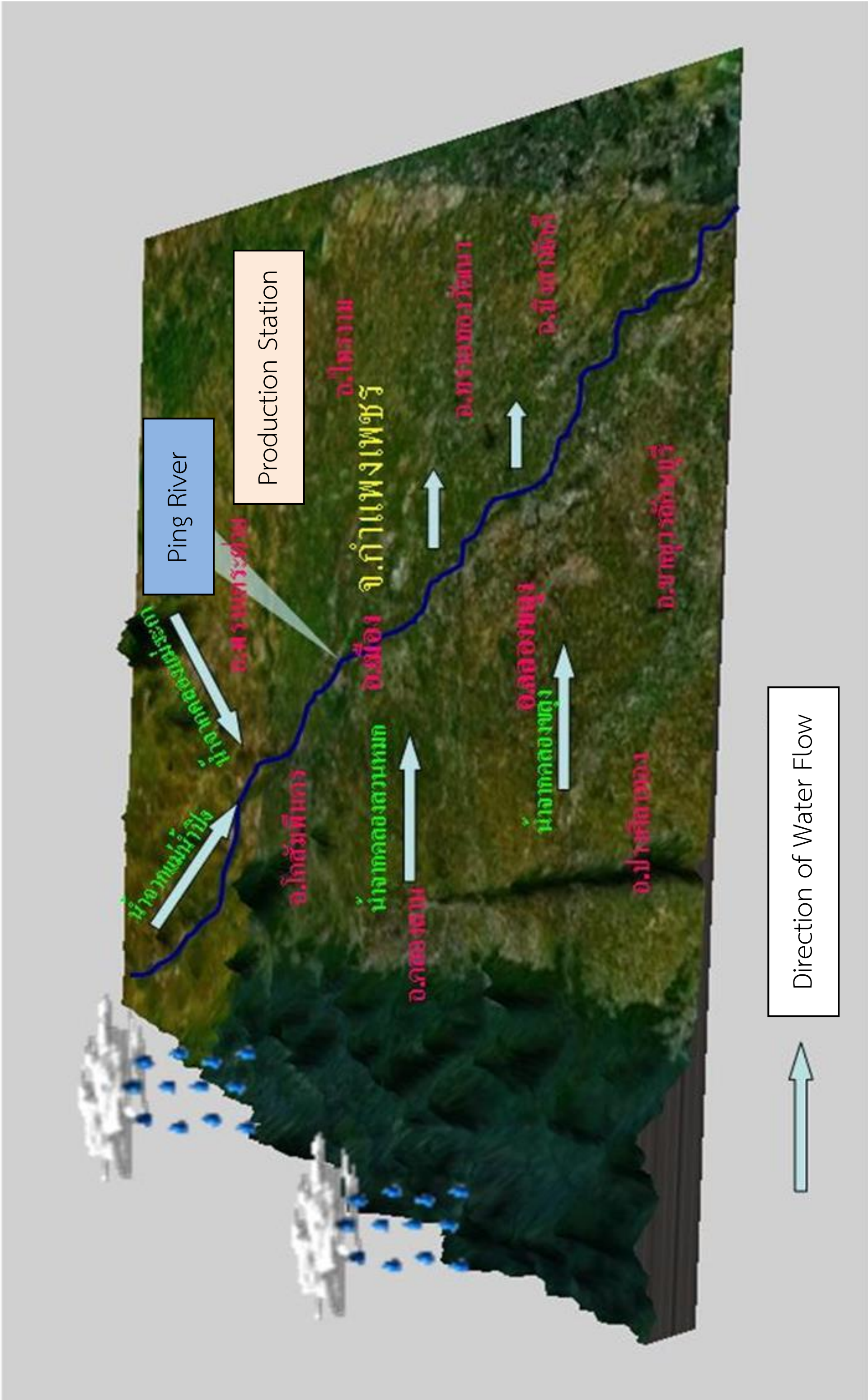


Figure 3: Direction of Water Flow from Ping River (Thailand Royal Irrigation Department)

Areas in Kamphaeng Phet province that have high risk of flooding (during rainy season) contain 17,251 rai or about 6,821 acre. Top four areas include the followings.

1. Klongkum Area consisting of
   Tha Puttra sub district 7,730 rai (3,056 acre)
   Wangkhen sub district 2,819 rai (1,114 acre)
   Wangyang sub district 575 rai (227 acre)
   Hua Thanon sub district 3,090 rai (1,222 acre)

   Total area = 14,214 rai (5,619 acre)

2. Pran Kratai Area consisting of
   Bann Kui Ong sub district 405 rai (160 acre)
   Wang Tabake sub district 357 rai (141 acre)

3. Kamphaeng Phet City Area consisting of
   Tammarong sub district 407 rai (161 acre)
   Lan Dokmai sub district 282 rai (111 acre)

4. Lan Krabu Area consisting of
   Non Plung sub district 1,038 rai (410 acre)
   Bung Thap Raet sub district 548 rai (217 acre)

Figure 4: Lan Krabu District is classified as a High Risk Area for Flooding according to the Royal Irrigation Department Report (Thailand Royal Irrigation Department).

Moreover, the highway road leading from Lan Krabu district, Kamphaeng Phet province to the city of Phitsanulok has to pass Bangrakam district, which is another area having high risk from flooding events. Long duration of flooding around rainy season caused transportation problems due to some roads blockage and other non-effect roads have heavy traffic congestion problem. Diagram below shows the highway that crude oil is transported from the production facility to the city. Historical data of flooding frequency and duration of the S1 onshore plant, near-by areas, and crude oil transportation route are also shown in the below table. It can be seen that crude oil transportation has suffered from flooding event every year. Especially the severe flooding in 2011, S1 suffered from flooding for the total duration of 5 months at production station and the highway road blockage for more than 6 months. After that year, there are several cases of flooding event that caused transportation problems both at production station and along the transportation route. Figure 5 showed the transportation route in blue. It could be seen that there will be river crossing for the pipeline installation. Also, Table 1 summarized the flooding events that occurred at the main production station area and along the delivery route to crude oil depot.

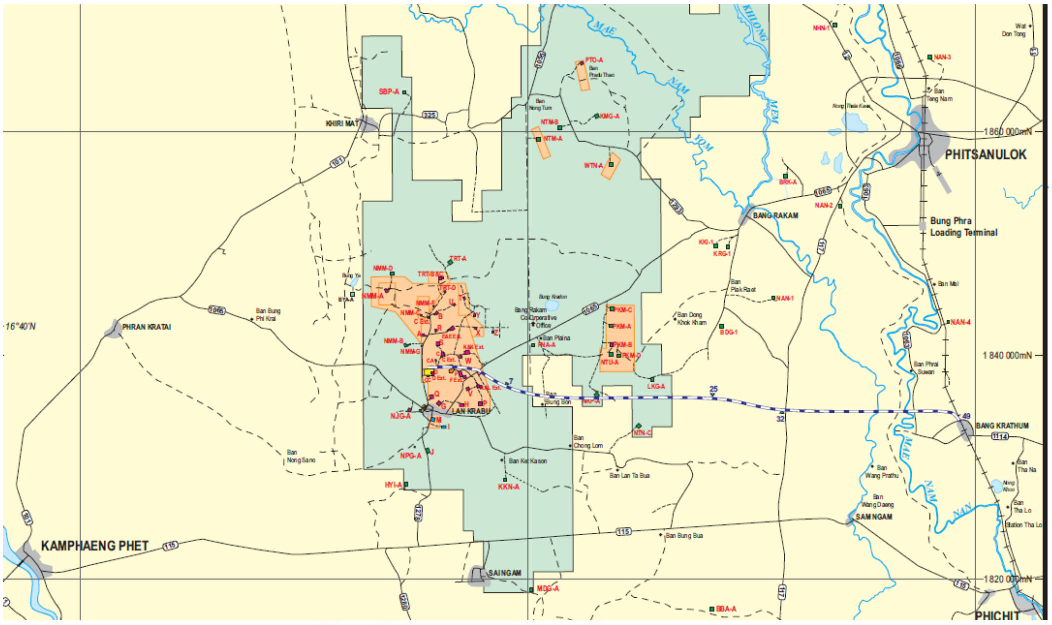


Figure 5: Crude Oil Transportation Route.

Table 1: Flooding Event Occurred along Road Tankers Delivery Route (4 years historical record from 2011-2014)

Year	Location	Date	Duration	Causes
2011 (Thaiwater)	Lan Krabu	July - Nov	4-5 Months	1. Heavy rain 2. Bad water management
	Bang Rakam Phitsanulok	Jan - Oct	10 Months	
2012 (Thaiwater)	Bang Rakam Phitsanulok	June	1 Month	Excess water from Yom River
	Kamphangphet	Sep	A few weeks	1. Heavy rain 2. Flash flood
2014 (Phitsanulok Hot News)	Bang Rakam Phitsanulok	Sep	2 Months	Excess water from Yom River
2014 (KPP News)	Lan Krabu	Aug	Several days	Heavy Rain

2. Number of road accidents during working hours is one of the main safety factors that are included into the key performance indicator of the company. As a result, the tankers are prohibited to transport crude oil at night time due to high risk of accidents from bad vision at night when driving. As a result, the transportation is not continuous (only day time allowed) and crude oil inventory is very high during night time.

3. Other problems include poor road conditions such as the lanes are non-uniform route. Some part of the road has 4 lanes, but some part has only 2 lanes. The road surface conditions are poor and rough, so the speed is limited. Moreover, there are public concerns on the rush hours that road tankers sometimes block the traffic because of the size of the truck and the limit speed. Several complaints were

received from groups of local residents who got suffered from tankers transportation. The locals united together to appeal to the company to find a solution for the difficulties they faced from tankers running. Records of complaints are shown in below table.

Table 2: Serious Complaints Historical Record (Last 4 years)

Year	Number of Serious Complaints
2011	2 complaints were received. - First call was about the speed of the road tankers that is too slow and usually block the road during peak hours - Second was about the noise of the road tankers at early morning (about 9 am)
2012	4 complaints were received. - Three complaints were about the road blockage during peak hours. - One was about the smell of the crude oil at off-loading station
2013	3 complaints were received All about the road blockage during peak hours.
2014	4 complaints were received - Two complaints were about the road blockage during peak hours. - The other two complaints were about the smell of the crude oil at off-loading station

This also related to the political issue of the company as we were considered as a national oil and gas company. Hence, being responsible for the well-being of the people living around our facilities was critical to company’s image. Being accepted by the community could provide a sustainable development in terms of solving political issues and company’s good recognition.

From the above stated problems, alternative transportation using pipeline plays an important role in reducing the inventory of crude oil and allow for continuous transportation during night time and flooding event. Nevertheless, there are many factors for the company to be aware of in terms of pipeline construction including environmental aspects and community agreement.

Initiated alternatives:

There was some brainstorming sessions to figure out the other transportation alternatives. All level of employee in the company including operation teams, engineers, and management teams were involved in bringing up some solutions. However, it was concluded from the management level that only one alternative needed further study, which was the option to install crude flowline. Other alternatives could not be done due to many reasons, which can be seen in the following examples.

Install additional storage tanks to increase the storage capacity of crude oil. This initiative was not approved because it would require too many storage tanks if flooding lasts for weeks and those tanks would not be in use at all during normal operation.

Level up roads elevation on the section that got flooding problem. The frequently flooded road section is approximately 10 kilometers. This initiative was not approved because all the roads connected to the main plant are under government owned. Private party cannot modify or reconstruct any parts of the roads. Moreover, all pieces of land near-by main plant are privately owned by local people and they would not agree to sell the land. Thus, building new roads could not be done either.

1.4 Objectives

The objective of this research is to compare the logistics of crude oil between road tankers transportation versus pipeline.

1.5 Scope of Research

This research will cover onshore crude oil production field located in the Northern part of Thailand. Road tankers transportation route will refer to the map in Figure 5. Crude pipeline will refer to the map in Figure 6 represented as red line. Parameters used for developing a scoring system include:

1. Cost for both initial investment and operating and maintenance cost (capital and operating expenditures). Capital expenditure will include detail cost break down of material, installation, construction, tariff, and decommissioning cost.

2. Safety and reliability concern

3. Environmental issue

4. Community acceptance

Study will be conducted under marginal field basis. Crude oil production of 27,000 – 33,000 BOPD is the target amount to be transferred. The routing for crude pipeline is from main production station (LKU) to crude oil depot (BPR) in the city of Phitsanulok with the total distance of about 53 km. The route path will be along the highway that mainly runs through rice fields. However, there are some areas near the crude depot that the pipeline has to cut through small villages.

Selection of pipeline route will mostly utilize public infrastructure such as highways and power transmission area to avoid the cost of private land acquisition. The pipeline route should be on the shortest distance; however, it should detour populated and city areas to keep the construction away from disturbing the community.

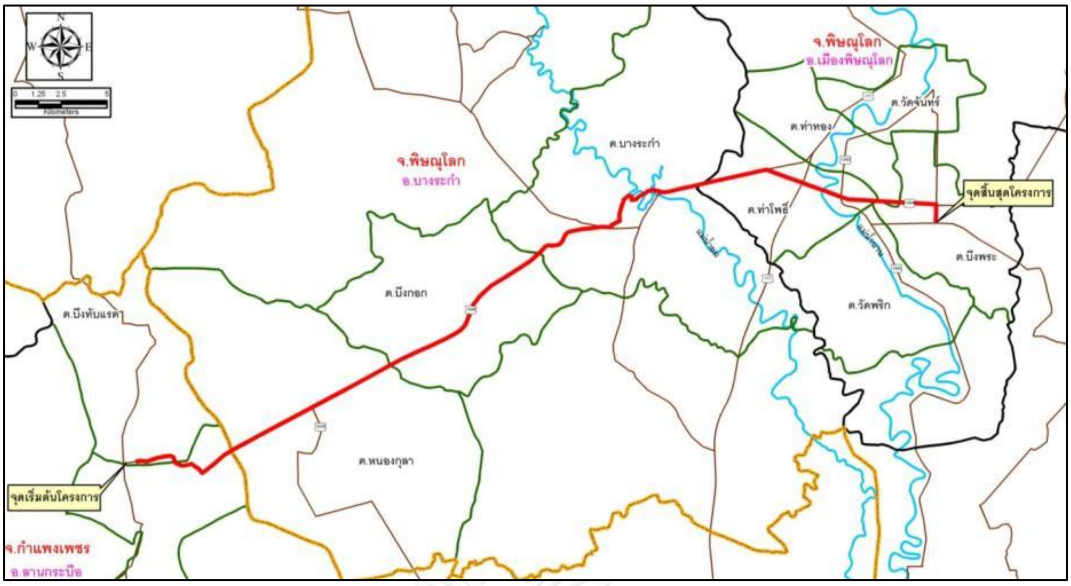


Figure 6 : Crude Oil Pipeline Construction Route in Red

1.6 Expected Benefits

This study will include the effect of the pipeline construction to the environment and community, which are major concerns to the company. The possibility of community acceptance, foreseen problems and risk issues for pipeline construction will be shown in this report. All concerned factors will be weighed and scored to conclude if pipeline construction is feasible or not for the company.

The result from the study on of pipeline construction consequences will allow the onshore oil company to be able to decide which of the two logistic methods between road transportation and pipeline is more suitable for the company in all aspects. Capital investment and operating expenditures are the two terms that can be directly compared in quantitative. However, there are some other indirect factors to be concerned of including safety concerns, reliability level, environmental, and community. With the use of this scoring system, company can easily determine whether they should build a pipeline to replace the road transportation or not.

1.7 Methodology

1. Study the effect of each parameter on the decision making of the two options.
2. Survey, collect and analyze data based on these four parameters;

2.1 Cost parameter

Cost estimation will be based on the historical data of previous pipeline construction project. Engineering study on the technical feasibility of the pipeline delivery will be done so as to include all the additional equipment required in order to deliver crude oil from main production station to the depot. Cost will be divided into capital investment and operating expenditure. For capital cost, this will include the procurement of pipeline itself and other additional equipment that might be required. Additionally, engineering, construction, and installation cost shall be considered with 30% contingency at this feasibility stage. For operating cost, it will be compared between road tankers contract versus pipeline operating and maintenance cost.

2.2 Safety and deliverable reliability factor

This parameter will refer to statistic of past incidents using risk assessment matrix by inputting the frequency, and seriousness of the incident to determine the impact to the company.

2.3 Environmental impact of the pipeline

The initial environmental examination shall be performed to determine whether there are any harmful environmental effects or not. Also, mitigation plan shall be proposed to reduce down the effects if any.

2.4 Community Survey to be conducted.

This research work will include doing public hearing on the two proposed options. The surveys will focus on the topics of serious complaints from the locals when road tankers are running versus the conditions when oil pipeline are under construction.

3. Develop a scoring system using AHP model in determining which of the two transportation methods is most suitable for the oil company based on the asserted parameters and their consequences.
4. Thesis conclusion, suggestions and examination

2. CHAPTER II Literature Review

Logistics and crude oil transportation has been a popular subject to further study as can be seen in these literatures below. Both the tankers transportation and optimized crude pipeline installation have been studied and provided information that can be useful to the organization.

In June 2004, Cheng and Duran from chemical engineering department made a study on the logistics and world-wide crude oil transportation using simulation. They believed that crude oil transportation plays an important role in the oil industry. They integrated the discrete event simulation and stochastic optimal control for the crude oil inventory/ transportation system. Markov decision was considered as it can take into account the uncertainties such as crude demand. They claimed that this integrated simulation framework and controller can be used to measure and evaluate the design and operation of the system. Additionally, they proposed an approximate architecture claimed to be able to solve optimal control problem.

Marcoulaki, Papazoglou and Pixopoulou wrote a paper in 2011 about the approach to optimal pipeline design, operation and maintenance. They talked about the initial investment cost for pipeline installation, operation and maintenance cost. They also included the information on the environmental impact and system availability and with those parameters; they created an optimization framework for pipeline construction.

Benjamin Sovacool made a paper about the oil and gas pipelines in Southeast Asia and Captain Sea. It focused on the interpretive flexibility of the TGAP (Trans-ASEAN Gas Pipeline) network that connects gas reserves from, Indonesia, Myanmar, Thailand, and Singapore. The paper concentrates on the interpretive frames for this pipeline network and claimed that the pipeline not only distribute energy fuels, but also linked with political power and have effect on economic and social development.

Economic limit for marginal field development is also another popular issue for research study. Several examples of marginal field production have been modeled to explain how factors such as increase of operating cost can affect the field production.

Marginal field production in Gulf of Mexico (Part I and II) has been modeled and described by Kaiser and Yu from the Center for Energy Studies. They created economic model, identified the economic limits and did sensitivity analysis on several small oilfields that are expected to be marginal over the 60-year time. They also forecasted that total oil production will contribute up to 4.1% of total oil production.

Not only did they study the marginal fields in Gulf of Mexico, Kaiser and Yu also wrote a paper on the "Economic Limit of Field Production in Texas." They stated that all oilfields at some point will have to terminate themselves due to the revenue from oil selling is less than operating cost. They gathered information on the 16,405 fields that are no longer producing in Texas and get the statistics of the production rate and gross revenue. They concluded that the offshore fields' revenue thresholds is greater than onshore fields. Also, the found that gas field turned into marginal field faster than oilfield.

Al-Othman et al., published a paper in September 2008 about the supply chain optimization under uncertainty petroleum market demands and prices. They created the model based on all crude oil related activities such as processing and distribution. After that, they did the impact on the uncertainties using sensitivity analysis with ±20% deviations. The stochastic formulation was then proposed. They claimed in their study that the economic uncertainties can be tolerated by balancing the crude export and process capacities.

Apart from comparison of capital and operating cost, Treccani Encyclopedia of Hydrocarbon compared the two transportation methods in other aspects including flexibility, implementation time, security and environment. Wessel Pienaar also published a paper comparing the advantages and disadvantages of pipeline construction comparing to other transportation methods. The study concluded that pipeline is substantially safer, more reliable and cheaper than road transportation (Pienaar).

Several papers discussed about the safety and reliability of each transportation method comparing the risks and their impact on each one. According to Cardi Report issued in November 2014, the paper discussed about the associated risks to be considered for each transportation system. For pipeline, the associated risks are the quality of pipeline from material deterioration, cracks from corrosion, erosion and defective welding (Christopherson). Moreover, flooding or land slide can severely damage the pipeline and hence routine monitoring should be performed to prevent pipeline spills. Impacts include ecological damage to animals and land resource, human health, economic loss from clean-up activities and from rebuilding reputation. On the other hand, tanker transportation also posts several risks including en route collision which increase accident rate by sharing the same public transportation system with the community. Moreover, inadequate infrastructure and truck design can be issued during loading and unloading of crude oil which can cause spill (Christopherson). Lastly, regulatory regime can be one risk if too many tankers use the public transport causing problems to the community. Heavy use of tankers lead to traffic congestions and caused damage to the paved roads resulting in limit of numbers of tankers and also speed limit (Crude Oil Transport: Risks and Impacts). The impact of road accidents was the highest of all transportation methods causing high fatality rate (Christopherson). Additionally, the oil spill from accident during loading and unloading also caused high impact from fire and explosion (Christopherson).

Summary in Table 3 shows the comparison of both transportation methods in various aspects and the advantages and disadvantages of them of several studies and papers.

Table 3: Factors to Consider in Transportation Methods Comparison.

	Tankers	Pipelines
Capital Investment	Limited (Treccani Encyclopaedia of Hydrocarbons)	Major (Marcoulaki)
Operating Cost	Based on negotiation (Treccani Encyclopaedia of Hydrocarbons)	Low once constructed (Pienaar). However, maintenance cost needed to be considered (Marcoulaki).
Flexibility	High (Christopherson)	Low (Christopherson)
Capacity	Can increase (Treccani Encyclopaedia of Hydrocarbons)	Fixed (Treccani Encyclopaedia of Hydrocarbons)
Implementation Time	2-3 years (Treccani Encyclopaedia of Hydrocarbons)	Very long (Treccani Encyclopaedia of Hydrocarbons)
Safety and Security	Low (Christopherson)	High (Christopherson)
Reliability	Based on negotiation (Treccani Encyclopaedia of Hydrocarbons)	Excellent (Treccani Encyclopaedia of Hydrocarbons)
Environment	Poor (Treccani Encyclopaedia of Hydrocarbons)	Very good (Treccani Encyclopaedia of Hydrocarbons)

Decision making between the alternatives can be complicated if it involved several level of criteria and sub criteria. AHP model is a tool to help describe the decision making process with mathematics. Hence, the chosen alternative will be more reasonable than using just desirable. Moreover, decision making cannot be done in one meeting where everyone agreed on some points. This tool helped to point out which way to go for when there is disagreement between different parties. That is the reason it is called Analytical Hierarchy Process as they provided a decision making process with reasonable mathematical method used on alternatives with complicated criterion (Golden). With several criterion which is difficult to quantify e.g. environmental impact, safety issue. Saaty proposed an eigenvector approach for estimation of weight in pairwise comparison (Golden). With this tool, each criteria and sub criteria can be directly compared against each other and put into the whole process for choosing the best option. The importance level for pairwise comparison can be divided into level 1 to 9 as per Table 4. Matrix will be used for calculating the weight importance of each criteria using eigenvector. Then, the sub criteria will be weighted by its upper level criteria in hierarchical order and result in option with the highest score.

Table 4: Scale of Measurement of AHP (Golden)

Numerical Values	Definition
1	Equally important or preferred
3	Slightly more important or preferred
5	Strongly more important or preferred
7	Very strongly more important or preferred
9	Extremely strongly more important or preferred
2,4,6,8	Intermediate values to reflect compromise
Reciprocals	Used to reflect dominance of the second alternative as compared with the first.

The hierarchy diagram to describe the weighting process of decision making can be seen in below figure. First, the objective needs to be identified. Then, the criteria and sub criteria will be weight in hierarchy orders. Finally, all criterions will be weight and link with all the stated alternatives to find the best option.

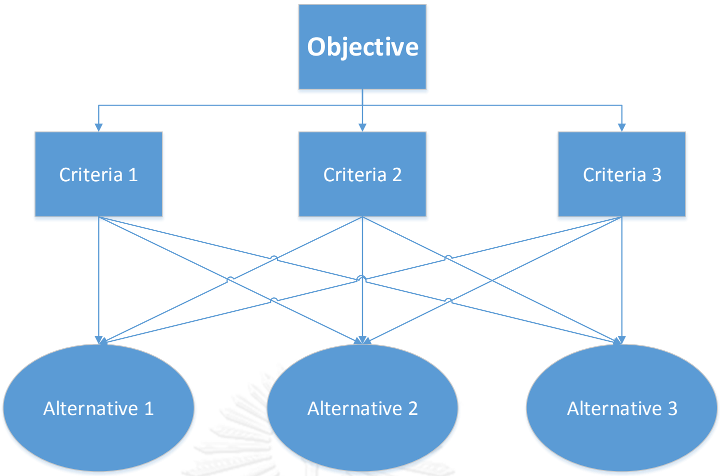


Figure 7: AHP Model Diagram

Sample matrix for calculating the overall priority of each alternative with criteria is shown below. The weight of each criterion shall be computed first, and then followed by the calculated weight of each alternative according to the related criteria. Hence, the overall priority is the product of the calculated weight of alternative and each criterion (Golden).

Criteria	C1	C2	C3	Weight
C1	a_{11}	a_{12}	a_{13}	W1
C2	a_{21}	a_{22}	a_{23}	W2
C3	a_{31}	a_{32}	a_{33}	W3

Criteria	C1	C2	C3	Overall Priority
Alternatives	W1	W2	W3	

B1	w_{11}	w_{12}	w_{13}	W1·w_{11} + W2·w_{12} + W3·w_{13}
B2	w_{21}	w_{22}	w_{23}	W1·w_{21} + W2·w_{22} + W3·w_{23}
B3	w_{31}	w_{32}	w_{33}	W1·w_{31} + W2·w_{32} + W3·w_{33}

Apart from being able to compute the overall priority, in order to tell if a matrix of size n is acceptable or not, the consistency ratio or C.I. should be calculated and should be ≤ 0.1 or else the judgement should be revised (Golden). This ratio is computed from the consistency index of the matrix divided by the random index (R.I.) of a random matrix of the same size (Golden).

$$C.I. = \frac{\lambda_{max} - n}{n - 1}, where\ n\ is\ the\ size\ of\ matrix.$$

$$C.R. = \frac{C.I.}{R.I.}, where\ R.I.\ can\ be\ found\ in\ \text{Table 5.}$$

Table 5: Random Inconsistency Index (R.I.) for computing C.R. (Golden)

n	1	2	3	4	5	6	7	8
R.I.	0	0	0.58	0.9	1.12	1.24	1.32	1.41

3. CHAPTER III Evaluation of the Alternatives

3.1 Analysis on the Associated Parameters

From several studies summarized in

Table 3, there are mainly 7 parameters to be considered for transportation method comparison, which are capital and operating expenditure, flexibility, implementation time, safety and security, reliability, and environmental issue. Although they are all relevant and contribute to decision making step, these parameters are based on green field development mostly situated in USA and Canada which is not quite suitable for S1 oil field. Therefore, some of them can be omitted from this study as S1 is marginal brown field development.

One factor that all business must take into account is cost as this is the main driver for business to survive. Capital and operating expenditure will be included in the considering parameter, but if the cost associated with both methods are not differing much from each other, other factors will also play an important role in the decision making process. Next is the safety and security of the system. Since PTTEP operates with LTI (loss time injury) target zero meaning that safety is considered significantly important to the company and incorporated into company's KPI, the safety strategy was implemented into all practices. Hence, this factor must also be included in the parameters. Next is the reliability of the system. This factor, in one way or another, links with both cost and safety. If the system is not reliable, it means that the company will lose money over not being able to deliver product. For pipeline, the reason for not being able to deliver can be from pipeline damage, which corresponds to safety issue. Last but not least, environmental impact should be considered as per government regulatory. Before any project construction and EIA is required to be approved from ONEP (Office of Natural Resources and Environmental Policy and Planning). Thus, if the project caused too much impact to the environment, it will not pass the EIA regulation and company will not be able to continue on the project.

Other factors that cannot be implemented with S1 oil field include flexibility, capacity and implementation time. Flexibility is not to be considered because S1 is a brown field type of business and already had its own crude depot with 10 crude oil tanks and loading/unloading facilities. Consequently, end destination or the depot is already fixed since it will require very high investment to move all those already in place facilities. Moreover, it is a marginal field development with known reserve or amount of crude oil production, so expansion of the capacity will not be an issue. Lastly, implementation time depends on how fast the pipeline can be installed which determines the different in cost comparison between transportation by tankers and pipeline. As pipeline takes longer to be installed, cost comparison between tankers operating and capital investment in pipeline construction will favor tankers operation. Hence, implementation time will be incorporated and reflected in the operating and capital cost comparison factors.

The selected parameters were brought into discussion meeting with S1 field planning and development team lead senior engineers and manager. They were agreed on the parameters selection with minor comments. First was that safety and reliability factors shall be grouped into one parameter because they claimed that the method used to quantify them will be the same which is the risk assessment. Second was to add community acceptance as one of the main parameters as it is critical to the project if company cannot get right of way from the land owners. Third point was about the environmental impact assessment should be based on EIA guideline. This is to be certain that all points have already been taken before asking for approval from ONEP. In conclusion, as agreed by asset senior engineers and managers from the meeting, there will be a total of 4 factors to be considered in this study; cost (both capital and operating), safety and reliability using risk assessment, environmental aspect using EIA guideline, and community acceptance.

Apart from selecting the associated parameters, the importance level of each parameter was surveyed from interview among the senior engineers and managers.

The result was to be used in weighting the factors in AHP model. Details of each participant were listed below.

Title: S1 Asset Planning Manager
Work Experience related to Oil and Gas Business: 15 years
Education Background: Chemical Engineering, PhD.

Title: S1 Crude Evacuation and Transportation Manager
Work Experience related to Oil and Gas Business: 20 years
Education Background: Industrial Engineering, M.S.

Title: Reservoir Engineer (Team Leader)
Work Experience related to Oil and Gas Business: 10 years
Education Background: Reservoir Engineering, M.S.

Title: Asset Reliability Engineer (Team Leader)
Work Experience related to Oil and Gas Business: 12 years
Education Background: Chemical Engineering, M.S.

Title: Operation and Maintenance Supervisor (Team Leader)
Work Experience related to Oil and Gas Business: 18 years
Education Background: Mechanical Engineering, B.Eng.

Title: Senior Process and Pipeline Engineer (Team Leader)
Work Experience related to Oil and Gas Business: 11 years
Education Background: Chemical Engineering, M.S.

Title: Construction Engineer (Team Leader)
Work Experience related to Oil and Gas Business: 13 years
Education Background: Civil Engineering, M.S.

Title: Senior Environmental Engineer (Team Leader)

Work Experience related to Oil and Gas Business: 14 years

Education Background: Environmental Engineering, M.S.

Survey results indicating the importance level of each associated criterion were as following table. These outcomes were to be used as weighting factors in AHP model.

Table 6: Importance Level of Each Associated Parameter as Decision Making Criteria

Criteria / Survey	Risk-Cost	Risk-Community	Risk-Envi	Cost-Community	Cost-Envi	Community-Envi
#1	2-1	7-1	8-1	4-1	4-1	2-1
#2	4-1	5-1	8-1	2-1	3-1	3-1
#3	2-1	8-1	9-1	4-1	5-1	2-1
#4	3-1	7-1	8-1	3-1	4-1	2-1
#5	4-1	6-1	8-1	3-1	4-1	2-1
#6	3-1	7-1	9-1	3-1	5-1	2-1
#7	3-1	8-1	8-1	3-1	4-1	2-1
#8	3-1	7-1	5-1	3-1	2-1	1-2

Remark: Envi = Environmental Impacts, Scores were based on important level from Table 4.

From the management interview results, it was definite that risk parameter (safety and reliability) came as number one priority compared to other aspects. Cost parameter was slightly less preferred with regards to risk factor at 1-3 ratios on average. Cost factor was not ranked as first priority since additional investment on the pipeline was considered an acceptable investment compared to company's overall asset. This also aligned with the company's policy to put safety first to achieve zero incidents record. Moreover, delivery reliability will decrease production deferment and bring good relationship with customers. Lastly, environmental and community were two least preferred; however, community factor was agreed to be slightly more important. This was because there had been some political issues going on with the company. There were protests going on in Thailand about the high gas price and PTTEP should be more responsible for society as a national oil and gas company. To be able to gain good recognition from Thai people, it is a good practice to gain good relationship with the community and not being seen as profit-making company that showed no accountable for the surroundings.

For the importance level of sub criterion, those under cost and risk criteria were voted against each other to find the different in importance level between them. Importance levels of capital and operating expenditure, and safety and reliability were surveyed with results shown in table below. As for the importance level of environmental sub criterion, the importance level of soil loss, air pollution, and noise emission were based on the severity of the impact which will be discussed in environmental impact session.

Table 7: Importance Level of Sub Criterion under Risk Parameters

Criteria / Survey	Willingness to pay CAPEX-OPEX	Safety-Reliability
#1	8-1	8-1
#2	7-1	7-1
#3	8-1	6-1
#4	7-1	9-1
#5	6-1	8-1
#6	7-1	8-1
#7	7-1	8-1
#8	7-1	9-1

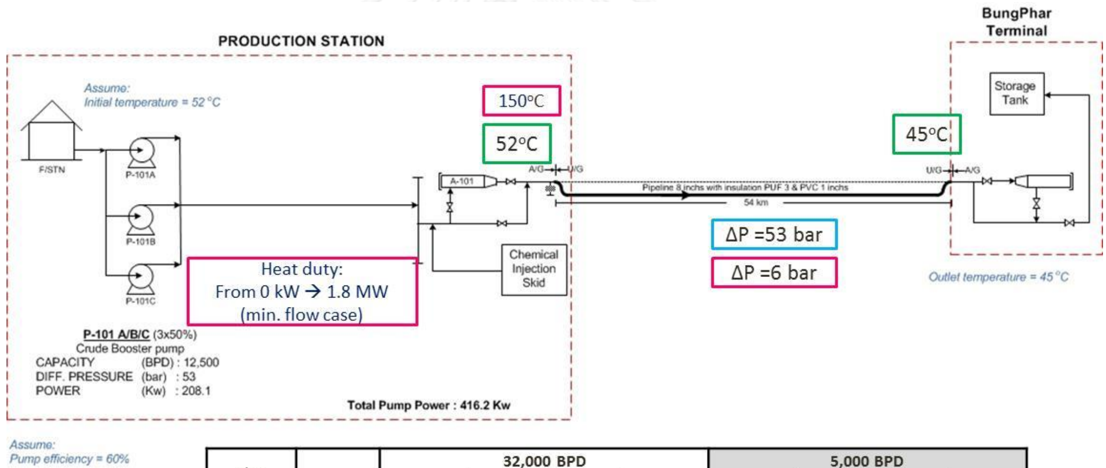
It could be seen from Table 7 that capital expenditure was the main concern for most interviewees because of the current downturn in crude oil price. They would prefer to hold any major investment and wait for when the price bounce back. Hence, the importance level of willingness to pay for CAPEX is higher than OPEX. The transportation alternative with lower capital cost will get higher score than the other. As for safety and reliability, all agreed that safety came as first priority and was highly more important compared to reliability factor.

3.2 Comparison of Capital and Operating Expenditures

Before making decision to sanction any project, cost estimation and comparison on each option are required as first priority. From the prediction of crude oil production, there will be crude production continue until 2031. As a result, the economic evaluation will be from 2016-2031. There are two aspects of cost estimate, capital and operating expenditure. As for tankers transportation, only operating cost will be considered since there is no major investment to the facilities or equipment. For pipeline delivery, there will be both capital expenditure for pipeline construction and installation, and also operating expenditure for pipeline maintenance during its lifetime.

From pipeline design study on the technical aspect, there are two main concerns in delivering crude oil underground for 54 km which are the pressure drop in pipeline and the heating of pipeline to keep crude flowing. From crude properties data, its pour point is at 36 degC and thus the temperature inside pipeline should not drop below that number otherwise there will be wax deposition problem inside pipeline causing high pressure drop and eventually no flow. Therefore, two technologies were compared to keep the right range of temperature along the pipeline; first is the heat tracing and second is heat insulation. Also, pour point depressant (PPD) will be used as a main chemical injection to lower down the pour point temperature of crude oil to lower down risk of wax formation inside pipeline.

After detail engineering study, it was concluded that the optimum pipeline size is 8" for 5,000 – 32,000 BPD of crude oil production. Existing booster pumps can provide enough pressure driving force to deliver crude oil for 54 km with the help of PPD injection along the way. As for the heating technologies, it was concluded that the best way is to use heat insulation of 3" PUF and 1" PVC instead of heat tracing. This is because heat tracing system requires power line along the pipeline. Having heating station along the way and power line buried together with pipeline require a lot of maintenance for safety issue. As a result, the option of using heat tracing and heating stations was discarded. The cost estimation for pipeline will be based on 8" buried pipeline of 54 km with heat insulation and PPD injection. Figure 8 showed simple crude transfer diagram and main equipment to deliver crude oil from main production station to terminal.



Pipe diameter (inches)	Distance (km)	32,000 BPD				5,000 BPD			
		ΔP (barg)	Inlet Temp. (°C)	Outlet Temp. (°C)	Velocity (m/s)	ΔP (barg)	Inlet Temp. (°C)	Outlet Temp. (°C)	Velocity (m/s)
F/STN to BPR	**54**	**53**	**52**	**45**	**1.5**	**6**	**52**	**21**	**0.3**
*MIN FLOW case	•Additional heater required at F/STN (if flow lower than 10,000 BPD) •Require higher pipeline inlet temp thus higher heat duty								

Figure 8: Schematic and Simulation Results for Pipeline Technical Design according to Engineering Study

As for tankers operating cost, it was estimated using predicted crude production and current price contract agreement with Srithai Tanker Company. The price is per trip and each trip can deliver about 215-240 bbl of oil depends on the type of road tanker. The price is also varied with the market diesel price. For average estimation, diesel price of 30 THB/liter will be used as baseline. From current contract, there is 2 pricing range. First 25,000 bbls will be the base price at cheaper rate. After 25,000 bbls and above, the tanker company will charge the company at higher price due to they will need to allocate more tankers and drivers from other services. Cost estimation comparison of both options can be seen in below tables and figure.

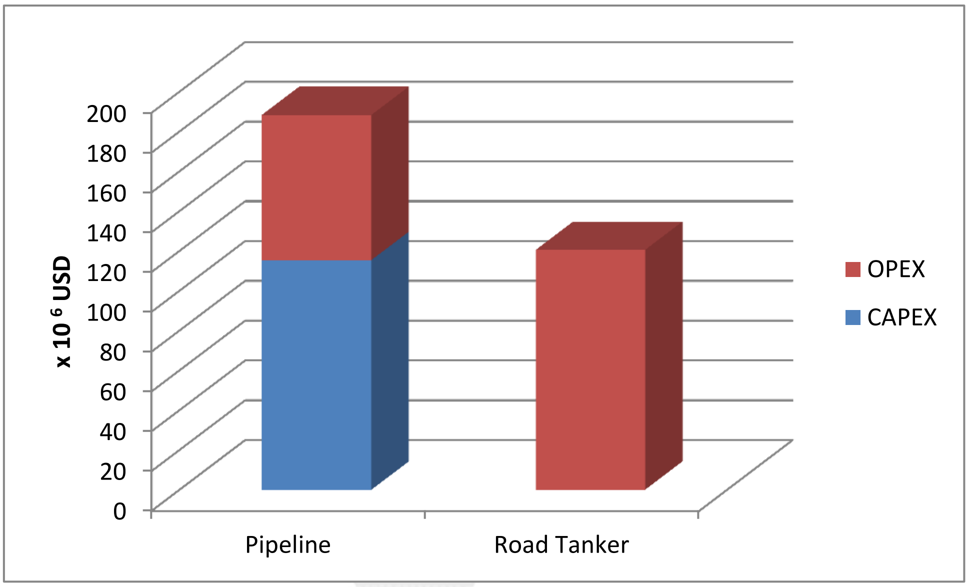


Figure 9: Capital and operating expenditure comparison in USD for transportation by pipeline versus road tankers from 2016 until end concession in 2031.

It could be seen that the overall capital cost for pipeline construction almost equals to the operating cost of road tankers. In addition to the investment, there is also operating cost for pipeline, which comes hugely from the heating system and chemical usage to prevent wax formation inside. The difference in overall cost is about 68 million USD or 36% higher for flow line construction. Details of cost estimation are shown in Table 8. From routing survey, there will be 6 road crossing points and 3 river crossing points which were included in the construction cost. The total EPCI cost was estimated to be about 83 million USD with 10% owner cost. Heating and insulation cost were 5.8 million USD in total contributed to 88.7 million USD for overall capital cost. With 30% contingency added, the CAPEX for pipeline construction would be 115.4 million USD. As for operating cost, it included PPD injection, pigging operation, and 5Y/10Y pipeline maintenance and inspection. Total OPEX was estimated to be 5.23 million USD per year.

Table 9 and Table 10 showed the cost breakdown of procurement and construction/installation cost which were the main contributions. This included material and land purchase and the transportation of all materials. Engineering cost was estimated to be 20% of the procurement and construction cost.

Major capital investment cost items were listed below.

1. Material and procurement of pipeline 40.5 million USD
2. Pipeline construction and installation 14 million USD
3. Engineering cost 10.9 million USD
4. Heating equipment – total engineering, procurement, construction and installation cost was 5.8 million USD

Operating cost items were listed below.

1. Chemical injection (PPD) 3.4 million USD
2. Others e.g. labor, electricity, utility, maintenance cost 1.8 million USD

Note that government policy still not requires company to pay for yearly rental fee for using the pipe route underground of the highway.

Table 8: Detailed Cost Estimation for 54 km Crude Pipeline (with Heat Tracing) Procurement, Construction and Operating Cost (in million USD)

S1 Crude Transport Pipeline CAPEX & OPEX Estimates		
Rev. 7/09/2015		
Export pipeline		
Assumptions		**Crude Pipeline**
Diameter	inch	8
Length	km	54
wt	mm	14.3
Coating		
3LPP - 3.5 mm	km	54
Concrete coating	km	none
Thermal insulation		
Material		PUF +PVC
wt		3" + 1"
Crossings		
Road crossing	nos	6
River	nos	3
ESTIMATES (in Million USD)		
Procurement/subcontracting		40.5
Pipelaying & construction		12.6
Mob/demob		1.5
Sub-total technical cost		**54.6**
Contractor's engineeering, management & supervision	20%	10.9
Estimated EPCI cost		**65.6**
PTTEP owner cost	10%	6.6
Contingency	15%	10.8
Accuracy ranges	-20%/+30%	
CAPEX P50		**82.9**
Heating		
Number of Heating stations		none
ME & materials		2.2
Construction/Installation		0.8
Direct cost		**3.1**
Technical allowance	15%	0.5
Freight &inland transport	8%	0.2
Construction indirect costs	15%	0.1
Total technical costs		**3.9**
Contractor's EMS	25%	1.0
EPC Cost		**4.8**
Company costs	20%	1.0
CAPEX P50		**5.8**
Total CAPEX Pipeline & Heating stations		**88.7**
Total CAPEX with 30% Contingency		**115.4**
OPEX with PPD MM USD/year (including 5Y and 10Y interval repair & maintenance)		**5.23**

Table 9: Procurement Cost Breakdown

Linepipe S1 Crude Transport Pipeline - Option 3	ND inch	QTY	LENGTH km	WT mm	UNIT WEIGHT kg/m	TOTAL WEIGHT t	COST USD
Linepipe	8	X65	54.0	14.3	72.22	3,900	7,799,760
Allowance for other materials (flanges,clamps,..)		8%				104	623,981
Linepipe for testing & qualification, spares,…							34,666
-- Welding WPQ/PQT			*0.12*	*14.3*	*72.22*	*9*	*17,333*
-- Pipe coating leading in/out + PQT			*0.06*	*14.3*	*72.22*	*4*	*8,666*
-- Damage spare			*0.06*	*14.3*	*72.22*	*4*	*8,666*
-- Offshore installation spares			*0*	*14.3*	*72.22*	*-*	*-*
Sub-total Linepipe						**4,021**	**8,458,406**
Coating & Insulation	**ND** inch	**QTY** m2	**LENGTH** km	**WT** mm	**UNIT WEIGHT** kg/m	**TOTAL WEIGHT** t	**COST** USD
3LPP coating	8	34,472	54	3.50			861,802
	Ext Dia mm	volume m3					
Concrete coating (2400 kg/m3)	219.1	-				-	-
	Ext Dia [mm]	volume [m3]	length [km]	wt [mm]	unit weight [kg/m]	total weight [t]	cost [USD]
Insulation PUF	219.1	3,742	54.0	75	29	1,572	11,225,900
	Ext Dia [mm]	surface area [m2]	length [km]	wt [mm]	unit weight [kg/m]	total weight [t]	cost [USD]
Insulation PVC OD =" Sch 80	14		54.0		68	3,693	16,932,672
Sub-total coating & insulation							**29,020,374**
Transportation						**TOTAL WEIGHT** t	**COST** USD
Transportation from pipe mill to coating yards						4,021	361,909
Transportation from coating yard to site						9,286	417,876
Custom clearance handling (excl. import duty & taxes) + inland transport							382,586
Sub-total transportation							**1,162,371**
Cathodic protection	**OD** mm	**QTY**	**LENGTH** km	**WT** mm	**UNIT WEIGHT** kg/m	**TOTAL WEIGHT** t	**COST** USD
Anodes	219.1	1.25 kg/m2	54			37.2	223,017
Sub-total cathodic protection						**37.2**	**223,017**
Pig L/R	**ND** inch	**QTY**	**LENGTH** km	**WT** mm	**UNIT WEIGHT** kg/m	**TOTAL WEIGHT** t	**COST** USD
Pig launcher 200/250, 5.6m						0.65	-
Pig receiver 200/250, 8.2m						0.65	-
Pig L/R installation material (incl. piping, inst & elec)							-
Sub-total Pig L/R							**Included in OPEX**
Pipeline T control & monitoring	**ND** inch	**QTY**	**LENGTH** km	**WT** mm	**UNIT WEIGHT** kg/m	**TOTAL WEIGHT** t	**COST** USD
Fiber optic based Distributed Temperature Sensing system			54		0.0	607.5	1,647,000
Total DTS system						**608**	**1,647,000**
Total procurement							**40,511,168**

Table 10: Construction Cost Breakdown

Onshore Pipelaying & Construction	ND inch	QTY	LENGTH km	Duration days			COST USD
Pipelaying & construction							
Working strip		20	m				
Total length		54	km				
Site area		1.1	km2				
Land purchase		675	rai				**4,500,000**
Method		**Lenth (km)**	**Width (m)**	**Surface Area (m2)**	**Burial Depth**		
Buried		54			1		
Working strip		54	20	1,080,000			
Track							
	Dia	**Lenth (km)**	**Width (m)**			**Volume**	
Pipe laying & construction	8	54					**7,977,099**
Fabrication & installation	8	54					3,121,200
Excavation & backfill	16	54	1.21			91,718	4,585,899
Hydrotest & inspection	8	54					270,000
Crossings		width m	total length m				**150,000**
Road crossings	6	20	120				60,000
Track crossings	0	25	0				0
Pipeline crossing	0	30	0				0
River crossing	3	30	90				90,000
Track re-routes (graded road)				0	m2		0
Provision for construction spread mob/demob + accommodation & logistic				1			1,500,000
Total onshore construction							**14,127,099**

3.3 Risk Assessment on Safety and Reliability of Pipeline versus Tanker Transportation

Risk assessment matrix was used for evaluating the risks on pipeline construction and operation compared to risks involving in road tankers for transportation. This method is a simple decision support ranking risk in two dimensions; likelihood and potential consequences (PTTEP). This is in accordance with the definition of risk, which is defined as the product of consequence multiply by the frequency of occurrence (Hyatt). First, the hazards of each transportation method need to be identified and then the risk measurement of each hazard will be performed. For processing plant, the risks measurement is usually measured in terms of death (lethality), property damage ($), lost production ($), environmental damage, and impact on the community/public relation (Hyatt). Hence, in this study, the consequences were divided into three categories; type, severity, and frequency. Each category had its conditions and terms to help in the judgement process of which category each item belongs to. After being ranked, the risk level of each hazard would turn out in green (low risk), yellow (medium risk), or red (high risk) corresponding to its ranking. After the assessment was done, mitigation plan to reduce the risk shall be set up to reduce the impacts for those hazards with high risk level.

In this study, the risk measurement were classified based on the affected parties which were people, asset or production loss grouping in one category, environmental impact, and reputation of the company. Severity ranged from minor, moderate, serious, major, and catastrophic. Lastly, the frequency of occurrence based on company historical records varied from rarely to frequent as can be seen in below risk assessment matrix table. This table, Table 11, was developed as a company standard to be used as simple decision making for any new projects.

Table 11: Risk Assessment Matrix for Evaluating the Hazards Involved in Pipeline Construction & Operation and Road Tankers Transportation.

Risk Assessment Matrix									
Consequences					Frequency of Occurrence				
Severity	People(*)	Asset / Production loss(**)	Environmemtal(***)	Reputation	Rare(1)	Unlikely(2)	Credible(3)	Likely(4)	Frequent(5)
Catastrophic(5)	Multiple fatalities	Loss > $50M	Spill > 100,000 bbl o	International TV Internat	1.00	2.00	3.00	4.00	5.00
Major(4)	Multiple LWDC or one or m	Loss between $5M - $50M	Spill > 10,000 bbl or	National TV National pape	0.80	1.60	2.40	3.20	4.00
Serious(3)	Single LWDC or multiple R	Loss between $100K - $5M	Spill > 1,000 bbl or	Local TV Local written me	0.60	1.20	1.80	2.40	3.00
Moderate(2)	MTC or Single RWDC	Loss between $10K - $100K	Spill > 1bbl or Moder	Local media interest	0.40	0.80	1.20	1.60	2.00
Minor(1)	Minor injury with First A	Loss < $10K	Spill < 1bbl or Spill	No Reaction	0.20	0.40	0.60	0.80	1.00

Hazards in Pipeline Construction & Operation

Loss of containment from pipe rupture. This can happen when the pressure inside pipeline is higher than design pressure of material, which will result in several impacts to people, asset, environment, and reputation. However, it is mandatory to have several safety protections during design phase including selecting design pressure of material to be higher than the shut-off pressure of booster pumps, pressure switch high to stop booster pumps and also safety relief valves to relieve all the fluid to safe areas. All safety equipment needs to fail at the same time for this to happen. Hence, the frequency is considered rare. Ranking table below concluded the risk level of this hazard in details.

Consequences	Severity	Frequency	Score
People	Major: Multiple LWDC (lost work day case) if there are operators around the pipe rupture area	Rare	0.8
Asset/ Production Loss	Catastrophic: A pipeline costs more than 50 million USD	Rare	1
Environment	Major: Spill > 10,000 BPD but not over 100,000 BPD (limit by production capacity per day)	Rare	0.8
Reputation	Catastrophic: International TV and loose trust to shareholders in other assets	Rare	1
Governing Case			1 (yellow)

Loss of containment from pipe leak caused by erosion or corrosion of pipeline. This case is less severe than pipeline rupture since the leak starts off small and no danger from high pressure fluid. On the other hand, the possibility of this hazard is higher than pipe rupture. Mitigation is to design pipeline wall thickness to cover the corrosion allowance and to do preventive maintenance yearly.

Consequences	Severity	Frequency	Score
People	None		
Asset/ Production Loss	Moderate: Pipeline corrective maintenance for pipe leakage is less than 100,000 USD.	Credible	0.8
Environment	Serious: Since the pipeline is underground, leakage can occur without noticing until maintenance campaign. Thus, leakage hole can be large enough for > 1,000 bbl by the time company notice there is leak.	Credible	1.2
Reputation	Major: If leak rate is high, it will be on national TV	Credible	2.4
Governing Case			2.4 (yellow)

Accident during construction phase e.g. car crash into the construction side as it is located on the highway. This is likely to happen and will need mitigation plan to reduce the risk since it falls into “red” category.

Consequences	Severity	Frequency	Score
People	Major	Likely	3.2
Asset/ Production Loss	Serious: Cost of damaged properties and medical cost for those injured	Likely	2.4
Environment	None: No spill as there is still no production through pipeline		
Reputation	Major: National TV	Likely	3.2
Governing Case			3.2 (red)

Hazards in Road Tankers Transportation

Spill can happen during loading and unloading the crude oil from tanks. This is a man operation, so the loss of containment is within control.

Consequences	Severity	Frequency	Score
People	None		
Asset/ Production Loss	Minor	Likely	0.8
Environment	Minor	Likely	0.8
Reputation	None		
Governing Case			0.8 (green)

Road accident is very serious and is likely to happen. On April 30th 2016, an empty crude tanker got into an accident with a motorcycle which caused one fatality. This caused company bad reputation and required more investigation into the real cause of accident. Moreover, the accident could have been worst if the tanker itself caused spill, which then will be the risk of fire case.

Consequences	Severity	Frequency	Score
People	Catastrophic	Likely	4.0
Asset/ Production Loss	Moderate: In case tanker capsize, loss will be over 10,000 USD	Likely	1.6
Environment	Moderate: 1 tanker = 250 bbl spill	Likely	1.6
Reputation	Major: National News	Likely	3.2
Governing Case			4 (red)

Noise, vibration, and traffic problems from community complaints. As stated above, this has become a huge problem to the community since the tanker is heavy which caused vibration and loud noise. Also, the road condition is not good in some sections which will make louder noise when large truck drives on them. Company made several attempts to upgrade the roads; however, the roads conditions became poor again after flood.

Consequences	Severity	Frequency	Score
People	None		
Asset/ Production Loss	Minor: Company has to pay for roads upgrading in some damaged parts	Frequent	1
Environment	None		
Reputation	Moderate: Local media interest	Frequent	2
Governing Case			2 (yellow)

Overall, pipeline transportation gave 2 yellow hazards and 1 red hazard while tanker transportation gave 1 green, 1 yellow, and 1 red hazard. As for pipeline option, the highest risk level was from the accident during construction phase. Mitigation plan could be to have big signs and barriers to caution all vehicle drivers prior to enter the construction zones. Although the risk was classified as high level, this was temporary only during a short construction phase period. After the pipeline was done with installation, this risk would be gone. The highest risk level from this risk assessment is 4.0 from road accident when transport crude oil by tankers. Mitigation plans to reduce this risk needs to be done such as well-trained tanker drivers to be more careful and giving out bonus to those who drive without accidents for consecutive period. Nevertheless, it is more difficult nowadays since the traffic is getting busier in Phitsanulok making accident harder to avoid.

3.4 Analysis on Environmental Impact

All human activities involving industrial or infrastructure projects will have environmental impact. As a result, environmental impact assessment is required to make certain that the project owners are aware of the impact and follow pollution control law and policy. Moreover, they will have to propose valid preventive actions and mitigation plan as there is possibility of things going unplanned. For pipeline construction, there are many environmental aspects to take into account depending on the type of pipeline and its route. Since PTTEP tried to minimize the effect of pipeline installation to the environment and community, the pipeline type is selected to be mostly underground along the public highway. This is to avoid the danger from loss of containment from pipeline rupture in any possible cases i.e. hit by vehicles. However, during pipeline construction, there will be some pollution that could affect the community. As a result, first priority in pipeline route selection is to avoid populated area and local community. There are several environmental aspects to be considered for both transportation alternatives as further described below.

Topography

Transportation by road tankers will have no concern on the topography because the tankers utilize existing roads and highways. On the other hand, pipeline installation will have minor effect. From survey report, the pipeline route is located on the plain with only 0-5% slope. It is about 40-70 meter above sea level and will be mostly along the public highway. During pipeline construction phase, there will be open cut work on the ground surface to lay down pipeline. The open cut maximum dimension is 3 m and 2 m in depth and width respectively. There will be no surface filling and after pipeline is in position, PTTEP will do surface cultivation to be as close to previous conditions as possible. For route sections that are required to cross the river, pipe bridges will be installed parallel to the existing bridges. Hence, there will be no effect to the topography along the pipeline route.

Soil Resources

Transportation by road tankers will have no concern on soil resource because all activities are on paved highways and roads. As for pipeline installation, there is high possibility of soil running off from rain and discharged water during open cut work to install pipeline into the ground. This can be calculated from universal soil loss equation (USLE) below (USDA National Institute of Food and Agriculture).

$$A = R \times K \times LS \times C \times P$$

A = Predicted soil loss (tons/acre/year)

R = Rainfall and runoff factor

K = Soil erodibility factor (depending on specific soil type)

LS = Slope factor (L= Length, S = Steepness)

C = Crop and cover management factor

P = Conservation practice factor

Assuming the construction will be done in 1 year, the predicted soil loss during pipeline installation will be calculated for the construction phase. The R parameter for South East Asia region shall refer to the following equation with rainfall rate of 1,317 mm/year according to Meteorological Department of Phitsanulok average 30-year historical data from 1981-2010 (Thailand Meteorological Department).

R = (0.4669 x rainfall) – 12.1415 (Thaiklar)

R = 602.77

K is classified by the type of and texture of soil. The soil mixture that contains high amount of clay will have low K value (0.05-0.15) because they are resistant to detachment. Sandy soils with coarse texture usually has low runoff rate resulting in low K value (0.05 – 0.2) as well. The highest K value comes from medium texture soils or soils mixture of high silt content because they can detach easily from the surface. The K value can go from 0.25 to more than 0.40 for soils with mostly silt content (Institute of Water Research, Michigan State University). For this study, the area of pipeline construction is mostly clay with some silt mixed in. Thus, the K value to be used in this study can range from 0.15 for mostly clay area and to 0.25 for those areas with mixed soils content of clay and silt.

L is the slope length whereas S is the steepness in percentage. These two factors are usually considered together to reflect the soil loss effect from the surface slope. They can be referenced through an LS table for construction site (Institute of Water Research, Michigan State University). For this pipeline construction, it will involve only small slopes as most of the pipeline route is within 0-8% slope with length of less than 1 m (3 feet). Hence, the LS factor to be used is within 0.05 – 0.32 for highest slope involved in the project.

As for C and P factors, the study will use 1.0 for both. This is considered for worst case scenario as all the crops will be removed from soil during open-cut pipeline construction. Thus, there will be no soil loss protection from cropping and the erosion rates will be highest without any crops. Moreover, the P factor will not be taken into account as there will be no soil loss protection from the pipeline installation.

From all the factors, soil loss rate from pipeline installation was predicted to be around 4.52 – 48.2 tons/acre/year. From database of Land Development Department in February 2000, the soil loss rate were classified into 5 categories ranging from very low at level 1 to highest as level 5 as per Table 12. From previous calculation, the soil loss is between 1.79 – 19.1 tons/rai/year which fall in to very low to high severity. Therefore, pipeline construction will have high impact on the soil loss during construction phase, which was estimated to be around 0.5 - 1 year.

Table 12 Soil Loss Rate and their Severity Level Classification from Land Development Department Database from Feb, 2000 (Thaiklar)

Level of Severity	Soil Loss Rate (tons/rai/year)
1: Very Low	0-2
2: Low	2-5
3: Medium	5-15
4: High	15-20
5: Very High	>20

Air Pollution

Both alternatives are engaged in air pollution, but on different levels. For road tankers transportation, the impact will be from emission of pollution such as carbon dioxide (CO_2) and carbon monoxide (CO) to the atmosphere. From Carbon Label report from Department of Environmental Quality Promotion (DEQP) under Ministry of Natural Resources and Environment, CO_2 emission factors from 16 tons 10 wheel road tankers are 0.6723 kg CO_2 eq./km on 0% load and 0.0549 kg CO_2 eg./ 1,000 kgkm. Hence, for one round trip from LKU production station to BPR crude oil depot (55 km), there will be approximately 90 kg CO_2 eq. emitted to the atmosphere. To transfer crude oil production for one day, it is required on average 110 road tanker trips per day. Thus, total CO_2 emission is about 9.9 tons/day.

During pipeline construction phase, there will also be air pollution from dust emission to the community. It can be calculated from the following Box Model equation (Hanson). This equation is the simplest one to describe the dust concentration emitted from the activity assuming the emission is homogenously distributed.

$$C = \frac{Q}{d \times w \times m}$$

C = Dust concentration in atmosphere (mg/cubic meter)

Q = Emitted dust to the atmosphere from the activity (mg/second)

d = Area length perpendicular to the wind direction (m)

w = Wind speed (m/s)

m = Mixing height (m)

The emitted dust rate could be used from historical data based on US EPA for the construction site, which stated that the emission was measured to be 1.2 tons/acre of construction site/month. When converting this number to Q, it equals to 0.114 mg/second/square meters. As for d, it can be calculated from the size of the open-cut pipeline bed which is 1.5 m in width. Considering 1 meter of both sides of the open-cut as worksite area, the whole length should be 3.5 meters. In a day, the maximum working open cut length is 100 m, so the whole construction site is 350 square meters. The wind speed is according to the Meteorological Department of Phitsanulok during 1982 – 2011 was 0.57 m/sec (Thailand Meteorological Department). Mixing height is about 2 km from surface based on the atmospheric aerosol area where particles can disperse into.

From given data, the dust concentration in atmosphere is calculated to be 0.01 mg/cubic meter. From the database of Pollution Control Department, the limit of small dust (less than 2.5 μm) emission in the atmosphere shall not exceed 0.025 mg/cubic meter in one year. As for medium (10 μm) and large (100 μm) size dust, the emission rate shall not exceed 0.05 and 0.1 mg/cubic meter respectively (Thailand Pollution Control Department, Ministry of Natural Resources and Environment). It can be seen that this activity will only generate 0.01 mg of dust/cubic meter which is within limit and the construction will only last for 1 year.

Noise Impact

There were two complaints reported in 2011 from the community that the road tankers made loud noise during morning time. Moreover, the community survey process also showed that road tankers making loud noise was an important issue to the neighborhood that live near the highway.

Pipeline installation will help reduce this problem in the long run. However, there will be loud noise during pipeline construction phase. The main activities include clearing and grading the right of way to remove obstacles during construction. Next is the ditching to provide the specified dimensions for pipeline cover. This activity will generally use backhoe and rock drilling for areas with rocky terrain. Both machines will create high noise impact to the community, which can be estimated using below Table 13. The noise 50 feet away from the area from backhoe and rock drill are estimated to be 80 dBA and 98 dBA respectively. After the ditching is done, pipe laying will be performed with internal lineup and welding if necessary. This process is not the main noise impact compared to the ditching part. It involves only the side-boom crane to lift the pipe parts and lay down into the bed creating 83 dBA noise. Afterwards, a water pump will be used for pipeline pressure test to detect any leakage at tie-in points, which create 76 dBA of noise. Lastly, protective coating on pipeline is required before backfilling using backhoe and compactor. This will emit about 80 - 82 dBA of noise.

Office of National Environmental Board defined a standard limit of noise during construction to not exceed 115 dBA as maximum limit. Moreover, for a longer period of 24 hours, the average noise emission shall not exceed 70 dBA (Office of Natural Resources and Environmental Policy Planning). From previous noise estimation during pipeline construction, each individual machine activity will exceed the limit of 70 dBA if working longer than 24 hours. Additionally, if two machines working at the same time, the noise emission will be higher, but not higher the maximum limit of 115 dBA. Mitigation plan is to limit working hours during ditching and open cut process to reduce high noise during off work hours.

Table 13: Construction Equipment Noise Emission Level (Hanson)

Equipment	Typical Noise Level (dBA) 50 ft from Source
Air Compressor	81
Backhoe	80
Ballast Equalizer	82
Ballast Tamper	83
Compactor	82
Concrete Mixer	85
Concrete Pump	82
Concrete Vibrator	76
Crane, Derrick	88
Crane, Mobile	83
Dozer	85
Generator	81
Grader	85
Impact Wrench	85
Jack Hammer	88
Loader	85
Paver	89
Pile Driver (Impact)	101
---"------ (Sonic)	96
Pneumatic Tool	85
Pump	76
Rail Saw	90
Rock Drill	98
Roller	74
Saw	76
Scarifier	83
Scraper	89
Shovel	82
Spike Driver	77
Tie Cutter	84
Tie Handler	80
Tie Inserter	85
Truck	88

3.5 Community Survey

A roadshow session to introduce the pipeline transportation project was conducted on August 26th last year for the three communities along the pipeline route which were Lan Kra Bue district, the city of Phitsanulok, and Bangrakam district. The information given to the community was about the background problems of current transportation method. Then, the participants were informed about the preliminary details of the project and pipeline routing. Pictures during construction phase of previous pipeline projects at Phitsanulok and Sukhothai were shown to the community, so they could have clearer ideas. The construction and installation methods were to bury pipeline with 1.5 m depth into the earth surface and using Pipe Bridge for the 3 river crossing points.

There were a total of 68 participants, all of which had one or more properties along the potential pipeline route. The participants also included the head of the communities, village headmen, and the head of the Phitsanulok highway. After the meeting presentation, they were given opportunity to ask questions and giving feedbacks/comments to the potential pipeline project. Also, they were asked to complete the survey at the end before leaving the meeting. Out of the 68 participants, only 52 agreed to complete the survey, which counted as 76.4% of the total participant lists. The rest claimed they needed more details in order to give opinions.

From the survey, 40 participants (58.8%) approved of the pipeline installation whereas the other 12 participants preferred current crude oil transportation. Their concerns were classified into three categories; the safety and reliability of the pipeline, environmental issue, and impact during construction phase. These 17.65% of participants said they would like to know in more details about the pipeline safety design to reassure them and involve them in the process. Company confirmed to give more details once EIA was approved and management confirmed to continue the project.

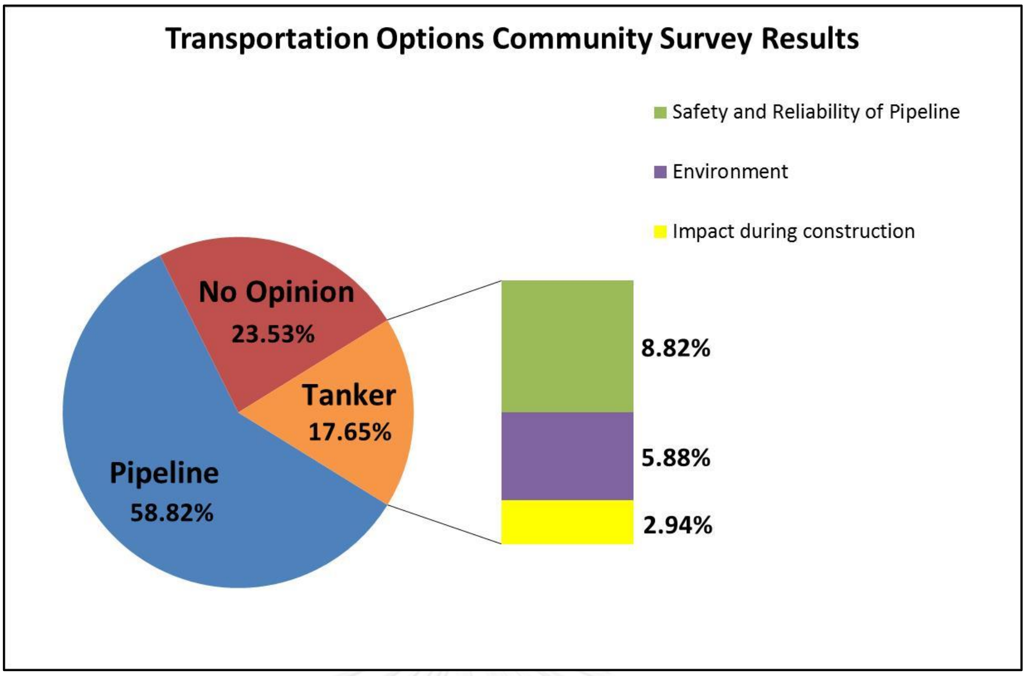


Figure 10: Community Survey Results from Road Show Session

4. CHAPTER IV Analytic Hierarchy Process (AHP) for Decision Making Model

Decision making process that involves many intangible parameters requires a model to justify which option gives a better solution. Analytic hierarchy process is a model to be used for giving out priority scales to intangibles by converting them in relative terms using a pairwise comparison method (Saaty). With AHP model, it can tell which option is relatively better than the other with the priority scale given to them. The model was used in evaluation of multi-criteria technology investment decision, manufacturing system, and other engineering problems (Triantaphyllou).

The criterion and their sub criterion are shown in below diagram. Each criterion will be compared in pairwise manner to weight out the final priority at the final stage. The scoring is based on fundamental scale from Table 14.

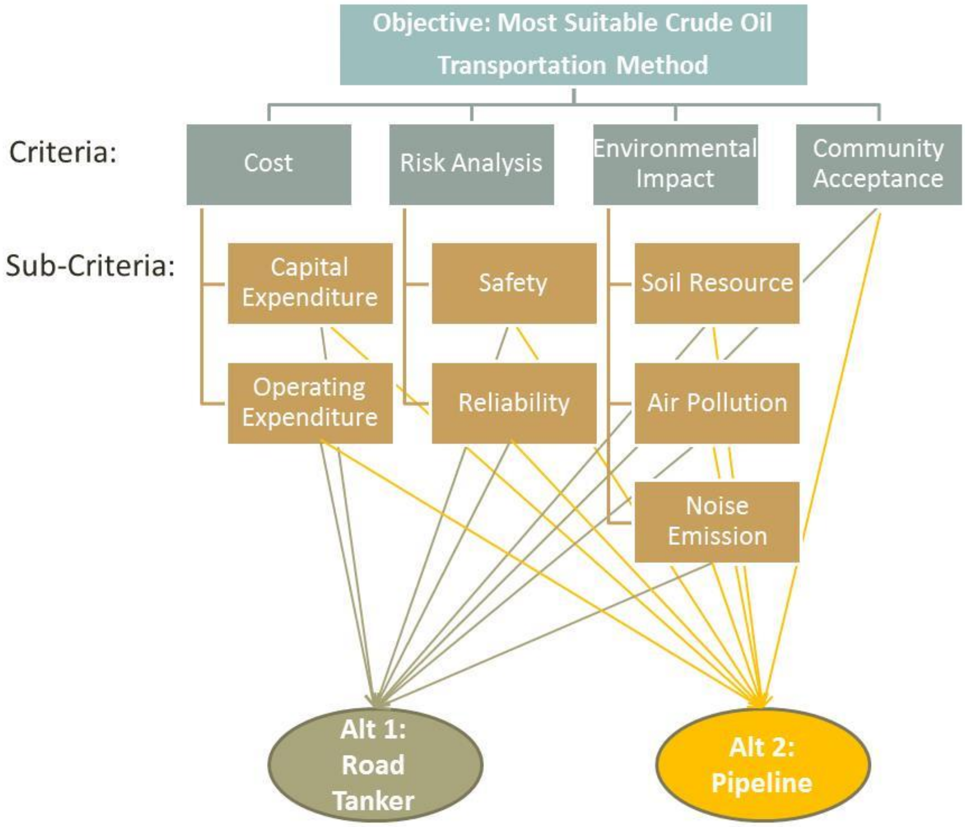


Figure 11: Criterion for Comparing the Transportation Choices.

Table 14: T.L. Saaty Fundamental Scale of Absolute Numbers (Saaty)

Intensity of Importance	*Definition*	*Explanation*
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
1.1–1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

4.1 Criterion and Sub criterion Pairwise Comparison

The four main criterions are cost comparison, risk of both transportation activities, environmental impact, and community acceptance. Most important of all is the risk which includes safety and reliability of both transportation methods. This is because safety involves the life of people around the operating area and safety of the community living in the area. Reliability also dictates whether the crude oil can be continuously transport or not. The second most important is the expense involved in the transportation activities. Company is doing a business to gain profit. Thus, bad judgement on investment can be harmful to the company’s cash flow and status. The relationship between cost and risk is a 1-3 ratio as risk (safety and reliability) has moderate importance compared to cost. Next is the acceptance from the community as company do not want people to suffer from company’s activities and without community approval, pipeline construction might not be possible. Thus, the ratio between cost and community is also a 3-1 with cost as slightly favorable. However, when compared to risk, it went down to 7-1 ratio as safety of people is strongly favorable. Last is the environmental impact, which is also important, but not as much as the other three criterions. The relationship between community and environmental impact is 2-1 with community acceptance has almost equaled important compared to environment impact. The scoring and overall priority of each main criterion can be seen in below table.

The Four Criteria	Cost	Risk	Environmental Impact	Community Acceptance	Overall Priority
Cost	1	1/3	4	3	0.2387464
Risk	3	1	8	7	0.6077839
Environ. Impact	1/4	1/8	1	1/2	0.0596866
Community	1/3	1/7	2	1	0.0937831
C.R.					0.0564362

The first criterion is the cost involved in both transportation methods. It can be classified as capital and operating cost. Capital cost is a one-time expense for investment in building up something until it reaches operable status. Then, afterwards, the operating cost will be the cost required to keep it running. Capital cost requires high cash flow as the company will have to spare budget for this investment. Due to the crude price crisis at the moment, company is trying to reduce or delay any unnecessary investment to keep high cash flow in case the crude price is lower than profitable margin. Hence, the company's concern to pay for investment capital cost is higher than operating cost giving a 7-1 importance level ratio.

Cost Criteria	CAPEX	OPEX	Overall Priority
CAPEX	1	7	0.8750
OPEX	1/7	1	0.1250

Second is the risk with two sub criterion; safety and reliability. The ratio is 8-1 as safety is very strong compared to reliability as it deals with the life and death of people. The ratio is slightly higher than the CAPEX-OPEX important ratio. However, it didn't get the 9-1 ratio as reliability can sometimes involve in danger of people as well. For example, if poor maintenance is done on the pipeline, it means the reliability will be lower consequences in high corrosion rate and pipeline leakage. If the petroleum is leaked into natural bodies of water, it can get contaminated and can directly affect the community in that area.

Risk	Safety	Reliability	Overall Priority
Safety	1	8	0.8889
Reliability	1/8	1	0.1111

Third are the environmental impact sub criterions. Major impacts are considered here consisting of soil resource, air pollution, and noise emission. Other environmental aspects such as Topography and water resource are not considered as there is no major impact involved. From environmental impact estimation in previous section with advice from senior environmental engineer, the two major impacts that are considered higher than limit are the soil loss from pipeline construction and the noise impact both from complaints about tankers running and estimated noise emission during pipeline construction. Noise emission is slightly more important than soil loss with at 1-2 ratio as it is a nuisance and will get complaints by the community easily. For air pollution, the impact is comparatively less important when compared to the other two. Thus, the scoring is 5-1 ratio as can be seen in below table with their overall priorities calculated.

Environment Criteria	Soil Resource	Air Pollution	Noise Emission	Overall Priority
Soil Resource	1	5	1/2	0.3522
Air Pollution	1/5	1	1/5	0.0887
Noise Emission	2	5	1	0.5591
C.R.				0.0462

4.2 Synthesizing for Final Priority

As the comparison of each criterion is performed, the next is the pairwise comparison of each alternative with each criterion. The scoring is based on the evaluation of the impact of each criterion on the transportation option in previous section of this study.

Cost Involved: Since lower cost is better to gain profit for the company, the option that cost less will gain higher score. There are two cost sub-criteria; capital and operating cost. Capital expenditure is only required in pipeline installation, so the ratio of pipeline to road tanker is 1-9 since road tanker is much more preferred in this case. As for operating cost, tankers' running cost is 120 million USD until end of concession versus pipeline overall operating and maintenance cost of 73 million USD. This is about 40% difference. Consequently, the importance level ratio according to the difference in running cost of road tanker is 1-4.2 as it is slightly more preferable to pay for pipeline operating and maintenance cost rather than road tankers.

CAPEX	Pipeline	Road Tanker	Overall Priority
Pipeline	1	1/9	0.1000
Road Tanker	9	1	0.9000

OPEX	Pipeline	Road Tanker	Overall Priority
Pipeline	1	4	0.8000
Road Tanker	1/4	1	0.2000

Risk Involved: Safety and reliability of pipeline is measured using risk assessment matrix. They both held high risk (red level) with pipeline at level 3.2 and road tanker at level 4. Both are from road accident, which is difficult for mitigation plan to reduce the severity and frequency of risk involved. Thus, for safety reason, the ratio is 2-1 as pipeline is slightly preferable as risk level is slightly lower. For reliability, road tanker is strongly less preferred since continuous operation cannot be achieved during flooding. Moreover, company needs to rely on the road tanker's company to continue on the transportation operation whereas if company has its own pipeline, it can take the whole responsibility to them.

Safety	Pipeline	Road Tanker	Overall Priority
Pipeline	1	2	0.6667
Road Tanker	1/2	1	0.3333

Reliability	Pipeline	Road Tanker	Overall Priority
Pipeline	1	7	0.8750
Road Tanker	1/7	1	0.1250

Environmental Impact Involved: From primary environmental impact evaluation, it can be concluded that pipeline construction will cause high soil loss rate and high noise during construction phase. However, it can reduce air pollution from CO_2 emission from tankers and the dust emission from construction is comparatively low. For noise impact, pipeline is slightly more preferred even though high noise during construction phase is expected. This is because it will be temporary compared to permanent loud noise from road tankers which caused nuisance to the community. Thus, the scoring is done the following manner.

Soil Resource	Pipeline	Road Tanker	Overall Priority
Pipeline	1	1/9	0.1000
Road Tanker	9	1	0.9000

Air Pollution	Pipeline	Road Tanker	Overall Priority
Pipeline	1	3	0.7500
Road Tanker	1/3	1	0.2500

Noise	Pipeline	Road Tanker	Overall Priority
Pipeline	1	2	0.6667
Road Tanker	1/2	1	0.3333

Community Involved: From survey, it was found that about 59% of the people were agreed on pipeline construction when the other 18% still chose tankers transportation and the rest remained no opinion. The majority of the people favored pipeline which is calculated to be at 5-1 ratio.

Community	Pipeline	Road Tanker	Overall Priority
Pipeline	1	5	0.8333
Road Tanker	1/5	1	0.1667

With all the pairwise comparisons done, the final priority of each alternative can be calculated from the weight of each criteria and the alternative individual priority and can be summarized in Table 15.

Table 15: Synthesize of Final Priority for Each Crude Oil Transportation Alternative

Criteria	Cost 0.2387464		Risk Assessment 0.6077839		Environmental Impact 0.0596866			Community Acceptance 0.0937831	Overall Priority
Subcriteria	CAPEX 0.8750	OPEX 0.1250	Safety 0.8889	Reliability 0.1111	Soil Resource 0.3522	Air Pollution 0.0887	Noise 0.5591		
Pipeline	0.1000	0.8000	0.6667	0.8750	0.1000	0.7500	0.6667	0.8333	0.5705
Road Tanker	0.9000	0.2000	0.3333	0.1250	0.9000	0.2500	0.3333	0.1667	0.4349

4.3 Comparing Model using Expert Choice Program

Expert Choice is a program for evaluating the objective priority using AHP model. It enables user to vary the weight priority of each parameter for sensitivity analysis. Nareerat Pothikun (2005) applied the AHP model to warehouse location selection using both manual calculation and Expert Choice program. The study showed small difference in both calculation modes with advantage on program which enable user to do sensitivity analysis on the nodes (Pothikun).

With the given model from previous section, a model was created in expert choice program with the results attached. It could be seen that the weight priority with respect to goal of the model is the same between excel and program method. The result was slightly difference between the two method; excel gave overall priority of pipeline at 0.5705 whereas program showed 0.590, which was about 3% difference. The overall inconsistency ratio was 0.02 which was under acceptable range of less than 0.1.

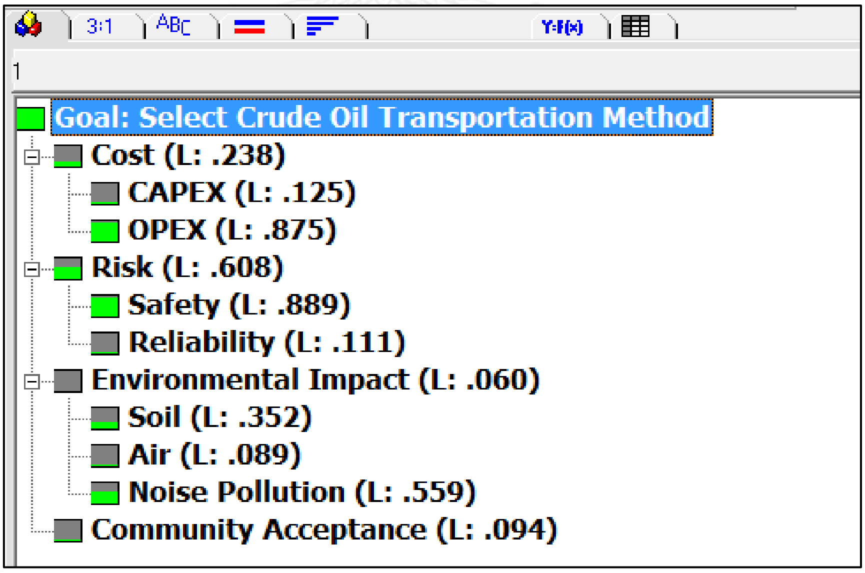


Figure 12: Importance Level of Each Criterion and Sub Criterion.

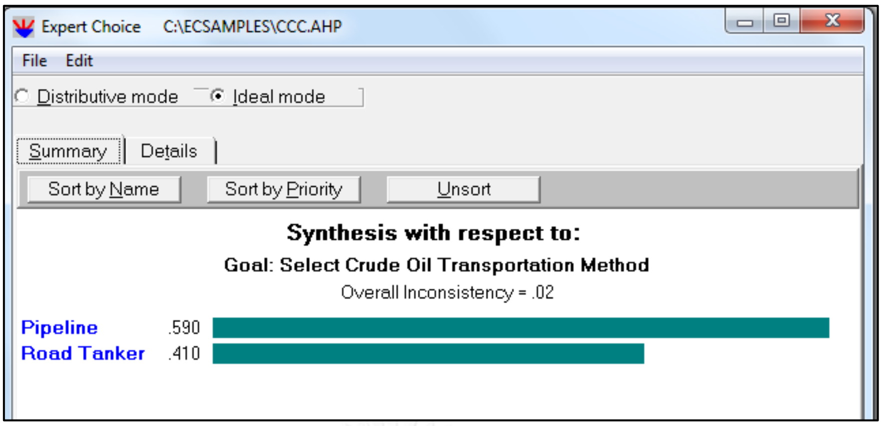
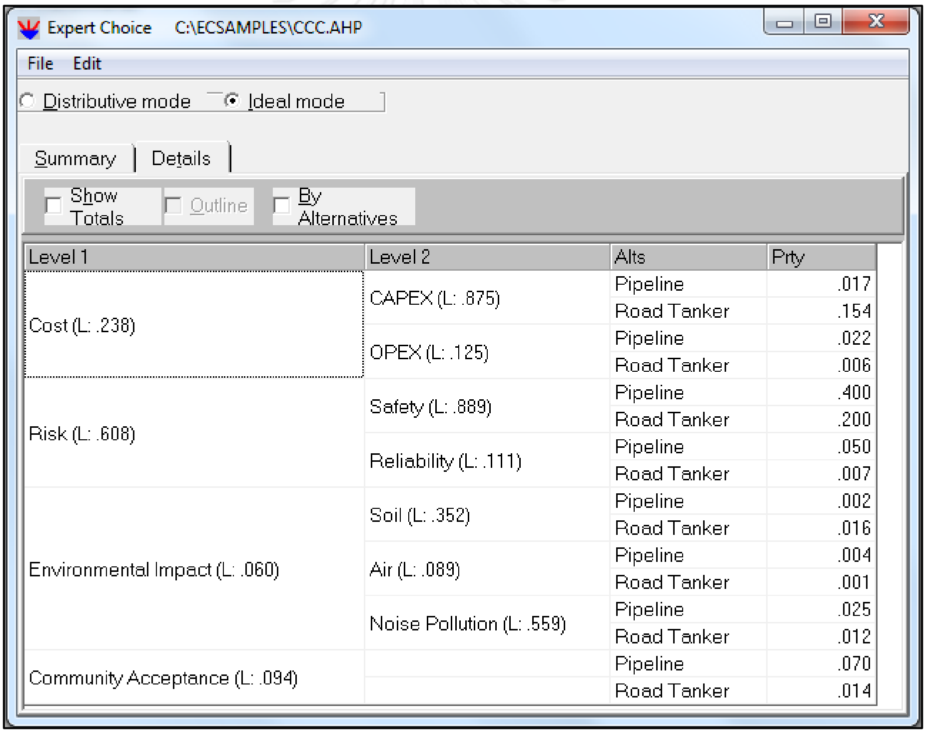


Figure 13: Analysis Results using Expert Choice Program.



Level 1	Level 2	Alts	Prty
Cost (L: .238)	CAPEX (L: .875)	Pipeline	.017
		Road Tanker	.154
	OPEX (L: .125)	Pipeline	.022
		Road Tanker	.006
Risk (L: .608)	Safety (L: .889)	Pipeline	.400
		Road Tanker	.200
	Reliability (L: .111)	Pipeline	.050
		Road Tanker	.007
Environmental Impact (L: .060)	Soil (L: .352)	Pipeline	.002
		Road Tanker	.016
	Air (L: .089)	Pipeline	.004
		Road Tanker	.001
	Noise Pollution (L: .559)	Pipeline	.025
		Road Tanker	.012
Community Acceptance (L: .094)		Pipeline	.070
		Road Tanker	.014

Figure 14: Detail Results of the Model using Expert Choice Program.

Further work was done on the sensitivity analysis of the model. Expert choice program gave the performance sensitivity of each parameter according to the final goal which was shown in next figure. It could be seen that the only parameter that would result in making road tanker overall priority higher than pipeline was the cost factor.

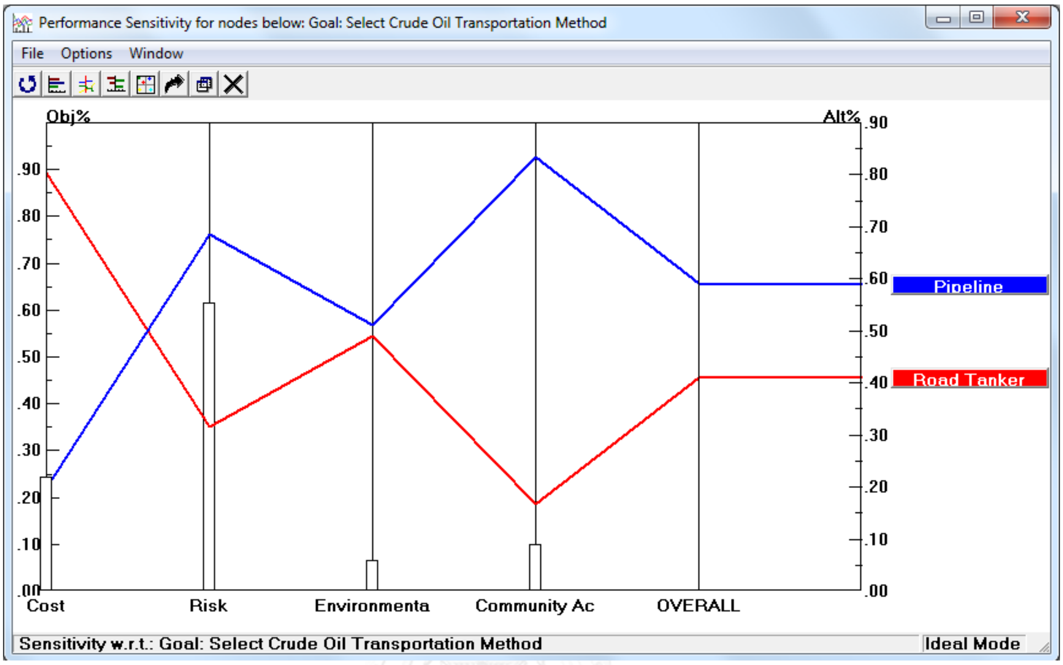


Figure 15: Performance Sensitivity on Each Associated Parameter with respect to Objective.

Consequently, sensitivity on cost parameter was done to explore the cut point where road tanker will be the preferred choice. It could be seen that increasing the importance level of cost factor by 10% will result in reduction of the overall priority of the pipeline by 5%. However, the final choice will still be pipeline with slightly higher overall priority compared to road tanker. The cut point where the two options will come to equal overall priority was when importance level of cost parameter was raised by 17.5%.

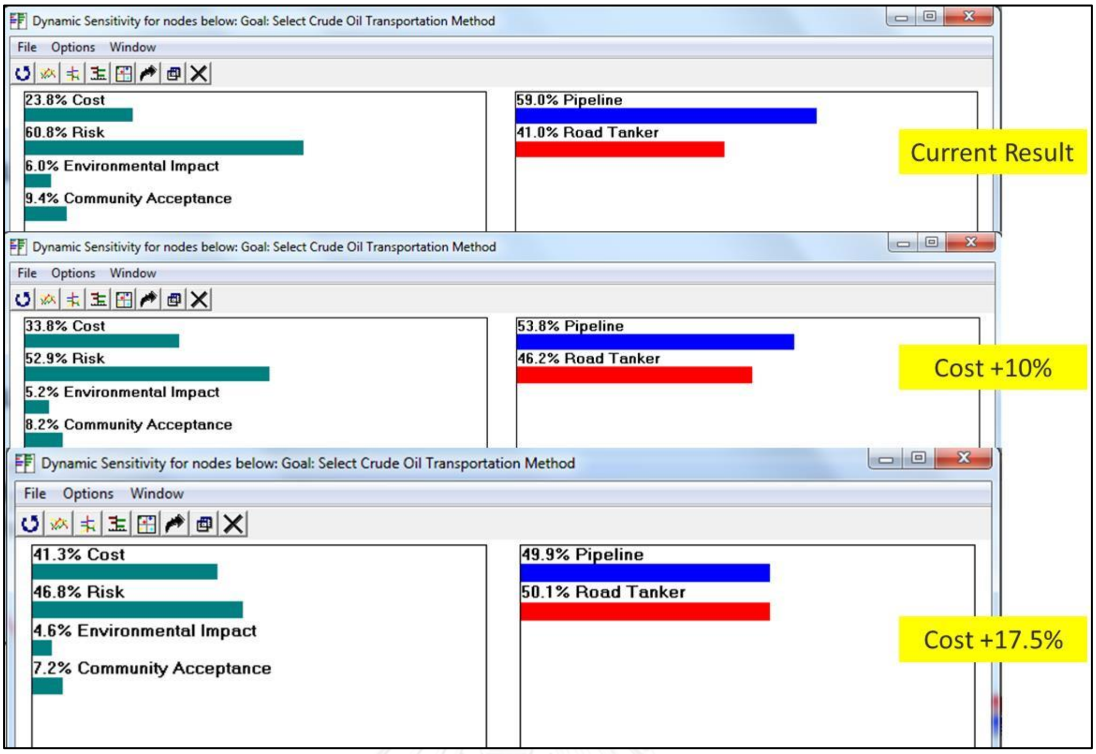


Figure 16: Sensitivity Analysis on the Cost Parameter.

5. CHAPTER V Conclusion and Recommendation

Current operation for crude oil delivery at S1 relied on the road tankers to transfer product from main production station to depot. There were several constraints and problems that company had including the safety issues, delivery reliability, and community complaints from tankers operation. Consequently, company had initiative to invest in pipeline installation in order to increase the safety measure, have a more reliable delivery system, and also receive fewer complaints from the neighborhood. In order to figure out if this investment should be sanctioned or not, a decision making model is required to be able to determine the most suitable option of crude oil delivery. Thus, an AHP model was developed in this study to compare and analyze the advantages and disadvantages of each delivery option based on company's required criterions.

Firstly, literature reviews were explored in order to determine which criterions to be included in the study. Then, a session with selected numbers of specialists from involved departments was held to agree on the final criterions usage in the study and their importance level in pair-wise comparison. From literature reviews, there were about 7-8 criterions used to compare the options; however, some of them were not included in this study due to they applied for green field development which was not the case for brown field S1 oil field. For example, flexibility criteria was not included because S1 already had facilities such as tanks farm and loading station installed at the beginning and final destination. Therefore, the transportation route was fixed as changing the locations would require very high investment. Moreover, capacity was also not an issue as flowline sizing was based on high case capacity and also can cover turn down ratio according to reservoir production profile. Since the asset was currently in operation for a long time, oil production capacity was easily predicted and would decline until end of concession. After all criterions were agreed upon all related parties, engineering study on the technical part of the pipeline installation was done based on topographic survey of the selected route. Pipeline was sized to match with pressure and temperature drop and additional chemical and equipment usage were determined. The line size was 8” with some additional heating system and pipeline insulation material required to prevent too low temperature drop which could cause waxing problem in pipeline. Cost estimation was done based on the technical results and separated into capital investment and operating expenditure. Cost profile included the whole EPCI cost with 30% contingency as this was feasibility level of estimation. Risk assessment session with the experts was done in order to compare the safety and reliability factors of each option. Initial environmental impacts based on government requirement was done and reviewed by company’s environmental department and the importance level of each criterion was decided accordingly. Lastly, community surveyed was done with the leaders from neighborhood along tanker and pipeline route invited to join the session. The details of pipeline installation were presented to them and technical authority engineers were at the session to answer all the questions the locals raised before company asked them to complete the survey. After all information was gathered, an AHP model was developed based on the selected criterions and importance level of them. Additional to the manual calculation, an Expert Choice program was used to compare the results and did performance sensitivity analysis.

Final priority showed that pipeline is a more preferred choice of transportation with its overall priority of 0.590 (0.5705 using excel) compared to road tanker at 0.410 (0.4349 using excel). The overall inconsistency level was in acceptable range. Hence, it is recommended to install a pipeline instead of current use of road tankers.

All associated parameters made pipeline a more preferable transportation choice except the cost parameter. This is because pipeline installation and construction require high investment cost and the operating and maintenance cost of pipeline is not that much different compared to road tankers operation. With sensitivity analysis, increasing the priority weight of cost parameter by 10% will still give the same result. The limit where both choice will come of a 50-50% overall priority is when the priority weight increases by 17.5%.

The final result was reasonable for further use as this study covered all associated parameters involved in comparing between the two transportation methods. The cost estimation was done by engineering and procurement study team. Risk assessment on the pipeline safety and integrity level was performed to cover major hazards that could happen for both choices. Preliminary environmental impact estimation was done based on advice from environmental engineer to also determine for the possibility of acquiring EIA approval. Community survey was done with the group of people lived along the proposed pipeline route. This could also determine the possibility of this project from community acceptance. All the importance level weighting were interviewed from all related parties with experience more than 10 years in oil and gas field. The sensitivity of the cost parameter was +17.5% in order to still provide the same result of pipeline installation preference.

Even though pipeline installation was not attractive in term of cost and investment at this period, the decision aligned with company's safety vision to be the leadership in safety by being an injury-free workplace and demonstrate environmental responsibility. Our safety missions are to eliminate all incidents and injuries by hazards management, create safety culture at the company, and achieve the best-in-class safety performance in exploration and production line of business. Additionally, our company is considered as a national oil and gas company, which owns several assets and petroleum concession in the country. We are responsible for sustainable development to be able to provide energy to Thai people. With that target, company is required to be accepted by the community and avoided any political issues. This reflected in one of the company's missions is to be responsible for society. As a result, in spite of high investment in pipeline, other factors including safety and delivery reliability, environmental impact, and community acceptance are the key indicators in making pipeline a more suitable transportation method. With current value of assets the company owned, more investment in pipeline can be traded off to achieve higher safety performance to avoid incidents and injuries, higher delivery reliability for our customers, less environmental impacts and being more accepted by the community around the area.

In conclusion, the study recommended installing pipeline instead of road tankers with regards to cost factor, safety and reliability, environmental impacts, and community acceptance. Nevertheless, with current oil price crisis, decision whether to install pipeline will need to be proposed to management team for further approval.

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APPENDIX

Appendix A Minute of meeting with project team

Minute of Meeting

PTT Exploration and Production Public Company Limited

Title	*Crude Evacuation Project Ways Forward*
Date	*Thursday November 26th, 2015*
Time	*9:30 AM – 12:00 PM*
Venue	*EnCo#2647-48*

Participants:

1. K. Benjapol Anusasamornkul	Manager, DSO/E
2. K. Thanongsak Sutthiruk	Supervisor, DSO/E
3. K. Rittichai Sukbanjongwatthana	Engineer, ECM/O (Team Leader)
4. K. Chin Lih Ching	Senior Engineer, EET/P
5. K. Surakit Kanokngam	Engineer, EET/P (Team Leader)
6. K. Pariyachat Oonkhanond	Manager, DSA/P
7. K. Sunisa Watcharasing	Engineer, DSP (Team Leader)
8. K. Artit Latthi	Senior Engineer, DSF/H
9. K. Natawan Sittipolkul (Minute)	Engineer, DSA/P

Objectives

To brainstorm and discuss on the ways forward of Crude Evacuation project after engineering team finished feasibility study.

Items of Business	Action Party
1. Crude Evacuation Project with Pipeline Installation was done with its feasibility study and concluded technically feasible by engineering team. Cost estimation was done to be compared with current tanker operation.	Info
2. Parameters to be included for evaluating project sanction were discussed and concluded to be cost factor, safety and reliability factor, environmental impact, and community survey shall be done. Interview with each party on the importance level of each parameter was done. Results of the interview will be analyzed and summarized by DSA/P to include in the decision making process.	DSA/P
3. DSF/H reviewed the preliminary environmental impacts and agreed on the results. The study was based on EIA requirement. Note that this is only initial environmental examination report. When the project gets approved, outsource to consulting team for EIA approval stage has to be done.	Info
4. Further study on safety records for road transportation is necessary for crude evacuation project justification. The study team should work out with safety and risk specialists to identify road transportation safety quantitatively and take this into account for economic justification to conclude whether or not to sanction the project.	EET/P and DSA/P

End of Meeting

Appendix B Community Survey Records and Signatures of Participants and PTTEP Representatives

การศึกษาผลกระทบสิ่งแวดล้อมเบื้องต้น ในการศึกษาความเป็นไปได้

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ลำดับ	ชื่อ-สกุล	ตำแหน่ง	ที่อยู่	เบอร์โทรศัพท์	ลายเซ็นต์
1	นาย [illegible] [illegible]	[illegible] 7	43 ม.7 [illegible]	083627771	[illegible]
2	[illegible] [illegible]	[illegible]	30/4 ม.6 [illegible]	0873157431	[illegible]
3.	[illegible] [illegible]	[illegible]	[illegible]	081-2801926	[illegible]

การศึกษาผลกระทบสิ่งแวดล้อมเบื้องต้น ในการศึกษาความเป็นไปได้

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ลำดับ	ชื่อ-สกุล	ตำแหน่ง	ที่อยู่	เบอร์โทรศัพท์	ลายเซ็นต์
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3.	อังคณา ศรีวันทนียกุล	เจ้าหน้าที่งานชุมชนสัมพันธ์	ปตท.สผ.	081-7519342	อังคณา
4.	[illegible] เรืองสุวรรณ	— " —	— " —	081-7519335	[illegible]
5	[illegible] [illegible]	[illegible]	[illegible]	02-509-9000	[illegible]

การศึกษาผลกระทบสิ่งแวดล้อมเบื้องต้น ในการศึกษาความเป็นไปได้

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1	[illegible]	[illegible]	9 ม.10 ต.[illegible]	089-8187459	[illegible]
2	นายสมาน [illegible]	ผู้ใหญ่บ้าน ม.5	ต.[illegible]	089-5210200	[illegible]
3	[illegible]	ผอ.รพ.สต.[illegible]	ม.3 ต.[illegible]	081-8888910	[illegible]
4	นาย สัทธิ ก้อนดง	[illegible] ม.5	85/ ม.5 ต.ท่าโพธิ์	0859221790	[illegible]
5	[illegible] สุรพงศ์ พุกจันทร์	ปลัดอบต.บึงพระ	อบต.บึงพระ	0813792325	[illegible]
6	นาย [illegible]	[illegible] ม.3	124/2 ท่าโพธิ์	0861150631	[illegible]
7	[illegible]	[illegible]	[illegible]	087-9072601	[illegible]
8	[illegible]	[illegible]	[illegible]	082-3992851	[illegible]
9	[illegible]	กำนันตำบลวัดพริก	42/2 ม.6 ต.วัดพริก	0872061646	[illegible]
10	[illegible]	[illegible]	65 ม.3 ต.ท่าโพธิ์	089-6410622	[illegible]

การศึกษาผลกระทบสิ่งแวดล้อมเบื้องต้น ในการศึกษาความเป็นไปได้

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ลำดับ	ชื่อ-สกุล	ตำแหน่ง	ที่อยู่	เบอร์โทรศัพท์	ลายเซ็นต์
1	น.ส.ปราณี คำดา	ผู้ใหญ่บ้านหมู่ 1	402/1 หมู่ 1 ต.บึงพระ	089-9072575	[illegible]
2	นาย[illegible] จิตร	ผู้ใหญ่บ้าน[illegible] 2	8/2 หมู่ 2 ต.[illegible]	0862160486	[illegible]
3	นาย สุนทร [illegible]	ผู้ใหญ่บ้าน 3	301/1 หมู่ 3 ต.บึงพระ	0819534413	[illegible]
4	นาย[illegible] [illegible]	ผู้ช่วยผู้ใหญ่บ้าน	20/1 หมู่ 2 ต.ท่าโพธิ์	081-0361086	[illegible]
5	นาย[illegible] [illegible]	[illegible]	รร.[illegible]	084 4954848	[illegible]
6	[illegible]	ผู้ช่วยผู้ใหญ่บ้าน	62/2 หมู่ 7 ต.[illegible]	0914389043	[illegible]
7	[illegible]	[illegible]	150 ม.3 ต.[illegible]	083 4101581	[illegible]
8	[illegible]	[illegible]	[illegible]	086-4378795	[illegible]
9	[illegible]	[illegible] ม.4	58 ม.4 ต.[illegible]	081-5340999	[illegible]

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1	[illegible]	[illegible]	[illegible]	055268201	[illegible]
2	[illegible]	[illegible]	112/5 [illegible]	089-959348[illegible]	[illegible]
3	[illegible]	[illegible] ม.15	291/1 [illegible] ม.15 [illegible]	0814275909	[illegible]
4	[illegible]	[illegible] ม.13	42/1 ม.13 [illegible]	089-2728096	[illegible]
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10	[illegible]	[illegible]	[illegible]	0850506552	[illegible]

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1	[illegible]	[illegible]	[illegible]	081-7075459	[illegible]
2	[illegible]	[illegible]	198/2 ม.7 [illegible]	0810435240	[illegible]
3	[illegible]	[illegible]	20/1 ม.4 [illegible]	0962186169	[illegible]
4	[illegible]	[illegible]	84/8 ม.14 [illegible]	081 4745617	[illegible]
5	[illegible]	[illegible]	258/1 ม.7 [illegible]	089-2691909	[illegible]
6	[illegible]	[illegible]	45 ม.2 [illegible]	0845919129	[illegible]
7	[illegible]	[illegible]	332/1 ม.4	091-9728003	[illegible]
8	[illegible]	[illegible]	14 ม.14 [illegible]	081-9794779	[illegible]
9	[illegible]	[illegible]	19 ม.1 [illegible]	086-9326687	[illegible]
10	[illegible]	[illegible]	[illegible] ม.6 [illegible]	0847543329	[illegible]

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1	นาย ชมพล ทิมทอง	ผญบ.ม.7 ต.บางระกำ	327/3 ม.7	087-2333396	[illegible]
2	นาย วิรัตน์ จันทร์ฉิม	สมาชิกสภาเทศบาล	ต.บางระกำ	0869352226	[illegible]
3	ม.ล.อรุณี ชาตวรรณวงศ์	ประธานชุมชนวัดสุนทรประดิษฐ์		081-886951	[illegible]
4	[illegible]	[illegible]	ต. [illegible]	[illegible]	[illegible]

การศึกษาผลกระทบสิ่งแวดล้อมเบื้องต้น ในการศึกษาความเป็นไปได้

โครงการวางท่อขนส่งน้ำมันดิบจากสถานีผลิตลานกระบือ อำเภอลานกระบือ จังหวัดกำแพงเพชร ถึง คลังน้ำมันบึงพระ อำเภอเมือง จังหวัดพิษณุโลก

ลำดับ	ชื่อ-สกุล	ตำแหน่ง	ที่อยู่	เบอร์โทรศัพท์	ลายเซ็นต์
1	[illegible] ล้วนบ้านยาง	[illegible]	~~47 ม.7 ต. บางระกำ~~ [illegible]	0881629991	[illegible]
2	[illegible]	ผ.ล	121/1	—	[illegible]
3	นาย มนัส กุลธรรม	ผ.ญ.บ.ม.14	ต.บางระกำ	081-6051946	[illegible]
4	[illegible]	[illegible]	6/10 ต.บางระกำ อ.[illegible]	089-8564193	[illegible]
5	นางจิราภรณ์ เลิศศรีมงคล	สท.	อ.บางระกำ จ.พิษณุโลก		[illegible]
6	นางเกศมณี [illegible]	ส.ท	อ.บางระกำ จ.พิษณุโลก	[illegible]	
7	[illegible]	ส.ท	อ.บางระกำ จ.พิษณุโลก		[illegible]

การศึกษาผลกระทบสิ่งแวดล้อมเบื้องต้น ในการศึกษาความเป็นไปได้

โครงการวางท่อขนส่งน้ำมันดิบจากสถานีผลิตลานกระบือ อำเภอลานกระบือ จังหวัดกำแพงเพชร ถึง คลังน้ำมันบึงพระ อำเภอเมือง จังหวัดพิษณุโลก

ลำดับ	ชื่อ-สกุล	ตำแหน่ง	ที่อยู่	เบอร์โทรศัพท์	ลายเซ็นต์
1	นาง ชะลอ คำงาม	ผู้ช่วย ม.10	146 ม.10 ต.ลานกระบือ	083 6289084	ชะลอ
2	นาย[illegible] สายบุญ	ผู้ใหญ่บ้าน	2/3 ต. ลานกระบือ	086-9396302	[illegible]
3	นาย[illegible] ประเสริฐกุล	[illegible]	111/6 ม.6 ต.ลานกระบือ	081-8670373	[illegible]
4	นาย[illegible] [illegible]	ปลัดอำเภอ	155/5 ม.6 ต.ลานกระบือ	0822288499	[illegible]
5	นาย [illegible] ชัยประชา	วิศวกรปิโตรเลียมปฏิบัติการ	กรมเชื้อเพลิงธรรมชาติ	02-7943375	[illegible]
6.	นายประสิทธิ์ [illegible]	เลขานุการตัวแทนอธิบดีกรมเชื้อเพลิงธรรมชาติ / วิศวกรปิโตรเลียม		081-8252767	[illegible]
7	[illegible]	[illegible] อ.ลานกระบือ	[illegible] ม.6 ต.ลานกระบือ	0810398931	[illegible]

การศึกษาผลกระทบสิ่งแวดล้อมเบื้องต้น ในการศึกษาความเป็นไปได้

โครงการวางท่อขนส่งน้ำมันดิบจากสถานีผลิตลานกระบือ อำเภอลานกระบือ จังหวัดกำแพงเพชร ถึง คลังน้ำมันบึงพระ อำเภอเมือง จังหวัดพิษณุโลก

ลำดับ	ชื่อ-สกุล	ตำแหน่ง	ที่อยู่	เบอร์โทรศัพท์	ลายเซ็นต์
1	ว่าที่ร.ต.ธารินี อยู่ครอง	รองนายกเทศลานกระบือ		0816809666	[signature]
2	ละเอียด เกษแก้ว	เลขานุการ	กองการเกษตรมงคลศรี	081-5779143	[signature]

การศึกษาผลกระทบสิ่งแวดล้อมเบื้องต้น ในการศึกษาความเป็นไปได้

โครงการวางท่อขนส่งน้ำมันดิบจากสถานีผลิตลานกระบือ อำเภอลานกระบือ จังหวัดกำแพงเพชร ถึง คลังน้ำมันบึงพระ อำเภอเมือง จังหวัดพิษณุโลก

ลำดับ	ชื่อ-สกุล	ตำแหน่ง	ที่อยู่	เบอร์โทรศัพท์	ลายเซ็นต์
1	นาง เมธ[illegible] สมมา	ผ.6 ม.5	25 ม.5 ต.ลานกระบือ	0849228864	[signature]
2	นาย สมร สุริยวงศ์	ศิริอุตสาหกรรม	42. ม.4. ต.ลานกระบือ	0896489406	[signature]
3	นาง ลำดวน พลศรี	รองนายก อบต	18 ม.9 ต.ลานกระบือ	08963236[illegible]	[signature]

Photos Taken during Community Survey

VITA

Miss Natawan Sittipolkul was born on 10th January, 1988 in Bangkok, Thailand. She went to Chulalongkorn University Demonstration School for her elementary and secondary school before she moved to Traim Udom Suksa for high school. She received her Bachelor of Science degree in Chemical Engineering at University of Illinois at Urbana Champaign (UIUC) in the states. After graduation in 2011, she started working for PTT Exploration and Production Public Company Limited (PTTEP) as an asset planning engineer supporting Sirikit Oil Field asset. In 2013, she continued her studying at a dual degree program to pursue for Master of Engineering degree at Chula Systems Engineering Program (CUSE), Chulalongkorn University and Engineering Business Management by Warwick Manufacturing Group (WMG), University of Warwick, United Kingdom.