Risk Quantification in Coal Procurement for Power Generation: The Development of Supply Shortage Impact Matrix

Jafni A. Ibrahim
College of Graduate Studies
Universiti Tenaga Nasional
Selangor, Malaysia
e-mail: jafni@uum.edu.my

Mokhtar Majid
College of Engineering
Universiti Tenaga Nasional
Selangor, Malaysia
e-mail: mmokhtar@uniten.edu.my

Amir H. Hashim
Institute of Energy Policy and Research
Universiti Tenaga Nasional
Selangor, Malaysia
Email: amir@uniten.edu.my

Razman M. Tahar
Faculty of Technology Management
Universiti Malaysia Pahang
Kuantan, Malaysia
e-mail: razman779@ump.edu.my

Abstract— **Systems are secure if its have lower risks of system interruption. However, to determine the optimum level of security is an area where requires more research. In principle, the optimum level of security that a system provides is determined by the interaction between the cost of providing extra security and the value to consumers. The risks in energy system have to be quantified in order to identify the level of security. To make comparison between the cost of providing energy security and level of security, the quantified risks have to be in the same common variable as the costs. Then, an optimum level of security and cost can be estimated using appropriate methods. As no such attempts have been tried to compare the risks and the cost in the same platform, it is difficult to determine the optimum security point between the risks and cost of providing that security. The objective of this paper is to present the development of Supply Shortage Impact for risk quantification in coal procurements for power generation. This method in combination with Non-delivery Probability Table will provide risk in common variable as the cost for presenting valuable information on security and cost of providing it.**

Keywords- Non-delivery Probability Table (NdPT), Supply Shortage Impact (SSI), Energy Security, Risk Quantification

I. INTRODUCTION

Systems are secure if they have lower risk of system interruption. However, in practice, 100 percent level of security is never intended for any systems for the reason that costs would be excessive [1]. It can be concluded that there is a rule of trade-off between level of system security and cost of providing it.

All energy systems provide some level of security to their consumers. However, determining the optimum level of security is an area where more research is required. In principle, the optimum level of security that a system provides is determined by the interaction between cost of providing extra security and value to consumers.

A good starting point in analyzing the level of energy security is by using risk. Many studies have been conducted in order to find a common ground between risk and energy security ([2] – [7]). It can be concluded that from these works, the degree of risk reduction provided to consumers depends on the cost of providing the extra security. Thus, risks in energy systems have to be quantified in order to identify the level of security. To make comparison between cost of providing energy security and level of security, the quantified risks have to be in similar common variable as the costs. Consequently, an optimum level of security and cost can be estimated using appropriate methods. As no such attempts have been tried to compare risks and cost in the same platform, i.e. monetary unit, it is difficult to determine the optimum security point between risks and cost of providing that security.

The objective of this paper is to present the development of Supply Shortage Impact (SSI) for risk quantification in coal procurements for power generation. This method in combination with Non-delivery Probability Table (NdPT) will provide risk in common variable as the cost for presenting valuable information on security and cost of providing it. This information then can be used for searching the optimum level between the cost and the level of security. The rest of this paper is organized as follows: Section II introduces coal markets and issues. Section III states the Overview and Development of Proposed Method, Section IV describes the Application of the Proposed Method, Section V states the Results and Discussions and Section VI is allocated for Conclusion.

II. COAL MARKETS AND ISSUES

Coal-fired power generation accounted for 39% of the world electricity generation [8]. Even though the use of coal in some European countries have shown static or some reduction, significant increase in coal-fired electricity generation in developing countries such as China and India made coal still an important fuel in power generation. It is

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believed that coal will continue to have important effect on energy diversity and security for many countries as coal market development has demonstrated the value of coal as flexible and secure energy source [9].

Internationally, the coal market is divided into two regional markets due to seaborne transportation costs: the Atlantic Market covers most of Europe, and the Pacific Market which covers Japan, north and south of Asia. There are three types of vessel that are usually used in transporting the coal: Capesize vessel. (100,000 to 200,000 dwt), Panamax size vessel (60,000 to 75,000 dwt) and Handy size vessel (20,000 to 35,000 dwt).

There are different types of transactions that are usually used in world coal market. According to [10], Australia's coal exports sold their coal via three terms of transaction which are:

- Long term contracts – which cover sales for a period greater than one year,
- Term contract – which cover sales for a period of up to one year)
- Spot sales – which cover a particular sale.

Meanwhile, coal prices are related to metric tons or an equivalent fuel to make them easier to compare with other energy carriers [11].Two kinds of prices in coal market [12] are:

- Contract price – referring to specific long-term transactions between designed buyers and sellers under specific contract terms, including tonnage, quality, exchange rate etc.
- Spot price – pertaining specific cargoes and reflecting shorter-term market conditions.

There are several issues related to security in coal supply in Pacific Market such as weather inclement, volatility in coal and freight market, and logistics infrastructure in key coal producing countries [13]. Heavy rains and storms can cause coal mines and railroads to be flooded and delay vessels berthing and loading. For example, in February 2010 the Central Queensland, Australia, two coal terminals – Hay Point and Dairymple Bay –experienced coal shipment issues due to inclement weather [14].

Meanwhile, rapid increase of coal demand especially from China and India has created bullish markets for suppliers which can lead to unexpected impacts on coal security. For example, in January 2010 strong domestic demand has push China's coal imports to 16.07 million mt and demand for foreign coal has remained strong for China throughout first quarter of 2010 [14]. As the demand largely exceeds the supply, there are possibilities that some suppliers will take advantage of high cost of coal by dishonorably defaulting term contracts in order to bid for higher offers.

Another issue is that, the logistic infrastructures in key producing countries could also provide some impacts on the security of coal supply. For example, lack of infrastructure in coal chain and supporting infrastructure particularly rail, as in the NSW Hunter Valley, Australia, could stop the coal chain from meeting demand [14]. This lack of infrastructure can compel coal producers to declare a '*force majeure*' – a common clause in contract which essentially frees both parties for liability due to extraordinary events beyond control of both parties – to its customers.

There are many factors that can affect coal supply security to customers. These security issues can have impact in term of delaying and failing coal delivery. The possibility for these issues to happen is high since there are many factors contributing to it. An accurate and efficient tool for accessing probability of potential delayed and failed delivery should be employed in procuring foreign coal in order to ensure the security of coal supply.

III. Overview and Developments of Proposed Method

The proposed method in this paper is designed to quantify risk by predicting likelihood of supply shortage in long-term coal contracts from several suppliers. It focuses on interruptions of coal shipments due to suppliers' liability based on historical data of shipments. Such outside forces (i.e.: mine disasters, transportation congestions, environmental regulations, labor disruptions, political climates, etc.) can affect the ability of suppliers to supply contracted coal and consequently affected the operation of power utility companies. The quantified risk method proposed in this paper will then help power utility company in selecting coal supply portfolio in procurement by providing optimal options of the best cost with least risk.

In order to quantify the risk of system interruption, with regard to supply interruption, this paper has formulated Supply Shortage Impact (SSI) values for the use with Non-delivery Probability Table (NdPT) which will be discussed in the later part of this paper. The NdPT of coal supply will be multiplied with financial cost of supply shortage to represent a risk factor. By comparing risk value to the cost of providing coal supply, a decision can be made if the risk factor is excessive, the number of suppliers and shipments can be increased and vice versa.

The NdPT is depended on inability of coal suppliers to supply contracted coal [15]. It will take into account shipments that do not arrive at promised time as an interruption in coal supply. There are two types of shipments that will be considered to have interruption to coal supply – shipments that fail in delivery and shipments that are delayed in delivery. For shipments that fail in delivery, a power utility company has to procure coal supply from other resources (i.e.: spot market) in which the price is usually more expensive. Meanwhile in delayed delivery, as long as the power utility company has extra shipments from other suppliers which can be rescheduled to accommodate the delayed shipments, no new procurement is needed. However, if there is not enough or no other shipments are available, that particular utility company has to procure extra coal from spot market. Consequently, these situations will incur extra cost to utility.

Meanwhile, SSI values will be calculated for these two conditions – impacts for delayed delivery and impacts for failed delivery. These conditions are separated because they would have different impacts in term of procurement cost of coal and operation of power generation. In the condition of delayed delivery, impacts would be assessed according to

cost of extra coal procured. In other words, the power utility company has to procure coal more than its needs to accommodate delayed shipments. However, there is no cost in term of power generation if load from delayed delivery can be covered by rescheduled shipments from other suppliers or reserved supply that utility has. Otherwise, the power utility company has to incur cost for not able to generate electricity. For delivery that fails to arrive, the impact is valued from cost to procure the unsupplied coal from spot market and disruption in utility generation's operation.

Lastly, these SSI values are multiplied with probability values in NdPT mentioned above to determine risk at every possible shortage level. Then, summation of these risks at shortage levels will give total risk of procurement for that particular option.

A. The Non-delivery Probability Table (NdPT)

The development of Non-delivery Probability Table (NdPT) is a modification of Capability Outage Probability Table (COPT) from [8]. NdPT determines probability values for all levels of shortage possible for supply shortage combinations and Supply Interruption Rate (SIR) of each supplier. SIR is the probability of incapability for every supplier involved in procurement portfolio toward supplying the contracted coal. It calculates the probability of incapability toward supplied contracted coal based on historical data with the power utility company. Regardless of the factors that affect the incapability of suppliers (i.e.: mine disasters, transportation congestion, environmental regulation, labor disruptions, political climate, etc.), SIR will only consider weight of shipments' load that are failed or delayed to be delivered in its calculations. SIR is based on two types of shipments – SIR for delayed delivery and SIR for failed delivery. The probability values calculated in NdPT are used to multiply with SSI which gives values of risk in term of losses. Below are the summarized steps in developing NdPT (refer to [15] for detail).

- Find the possible combination of supply interruption quantity, shortage of load, and unaffected load due to delayed delivery
- Calculate the individual probability for delayed delivery in each possible interruption level
- Find the possible combination of supply shortage due to Failed Delivery and probability of failure in each combination.

B. The Development of Supply Shortage Impact (SSI)

Supply Shortage Impact (SSI) is an impact on the utility company due to shortage of coal supply. It calculates extra cost incurred on the utility company due to the shortage in term of cost of procuring coal for new sources and interruption of power generation operation. In general, SSI is made up of two components – cost of generation loss and cost of new procurement.

Cost of generation loss is a cost that power the utility company has to bare due to the shortage in coal supply. Considering the situation where coal supplied for power generation in normal condition, the supply of coal, $C_{S,}$ is equal to demand, C_D, for power generation with some levels of supply reserve, C_R (Figure 1.a). For second situation where there is an interruption in coal supply, C_{out}. However, the interruption level is less than the coal supply reserve (Figure 1.b). This situation will have no effect on power generation since the coal available is still greater than the demand. In third situation, the interrupted quantity of coal supply is more than the available supply reserve. This situation will result in the shortage in supply for not able to cope with the demand of coal in generating the electricity (Figure 1.c). The utility company will face the opportunity losses for not being able to generate electricity and this is called the generation loss. Meanwhile, the cost of new procurement is the cost incurred by the utility company to procure new/extra coal for the shortage (insufficient) amount of supply.

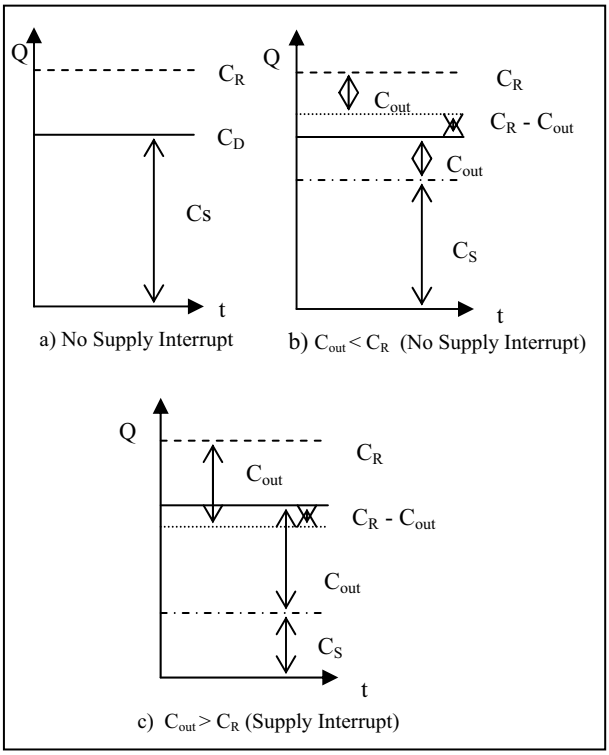

Figure 1. Visualization of the level of Supply Interruption

1) SSI for Delayed Delivery

SSI for delayed delivery consists of two components – the impacts of cost of procuring an extra supply of coal and the impacts on cost of generation loss. The impacts on cost of procuring an extra supply of coal come into perspective when there are not enough loads of shipments or unavailable loads of shipments from other suppliers to accommodate the load of delayed delivery. Consider the equations below:

$$KP_{delay} = (L_{short} - L_{reserve}) \times P_{spot} \quad (1)$$

Where

KP_{delay} *: Extra procurement cost for delayed delivery*
L_{short} *: Load of shortage due to delayed delivery*
$L_{reserve}$ *: Utility's reserve coal supply*

P_{spot} : *Spot price of coal*

Delayed delivery will only have an impact on cost of extra procurement only if there are positive values on the shortage (insufficient) load which is the different between quantity of interruption (interruption level) and quantity of unaffected supply.

Meanwhile, impacts on generation loss are the impacts that utility company has to incur if there is not enough supply of coal to generate electricity due to delayed delivery. This cost is described in (2) below:

$$KG_{delay} = (L_{short} - L_{reserve}) \times FED \times TE \times K_{levelized} \quad (2)$$

Where:
KG_{delay} : *Cost of generation losses due to delay delivery*
L_{short} : *Load of shortage due to delay delivery*
$L_{reserve}$: *Load of coal reserve quantity*
FED : *Fuel energy density for coal*
TE : *Thermodynamic efficiency of coal power plant*
$K_{levelized}$: *Levelized cost for coal power plant*

The summation of these costs (Equation (2) and Equation (3)) makes up SSI for delayed delivery (Equation (3)).

$$SSI_{delay} = KP_{delay} + KG_{delay} \quad (3)$$

2) SSI for Failed Delivery

In the case of failed delivery situation, utility has no other options but to purchase coal in order to compensate the shortage amount of coal. The only option that utility has is to buy coal from spot market. However, the price in spot market is usually more expensive compared to contract price. So, the cost to procure the (insufficient) shortage amount of coal can be calculated by using (4) which is the quantity of shortage multiplied by the differences between spot and contract price for coal from suppliers that fail to deliver.

$$KP_{fail} = L_{short} \times (P_{spot} - P_{contract}) \quad (4)$$

Where:
KP_{fail} : *Cost of procuring the interrupted amount of coal*
L_{short} : *Shortage of load due to failed delivery*
P_{spot} : *Price of coal at spot price*
$P_{contract}$: *Price of coal at contract price*

Meanwhile, the generation loss for failed shipment is calculated using (5).

$$KG_{fail} = (L_{short} - L_{reserve}) \times FED \times TE \times K_{levelized} \quad (5)$$

Where:
KG_{fail} : *Cost of generation loss due to failed delivery*
L_{short} : *Load of shortage due to failed delivery*
$L_{reserve}$: *Load of coal reserve quantity*
FED : *Fuel energy density for coal*
TE : *Thermodynamic efficiency of coal power plant*
$K_{levelized}$: *Levelized cost for coal power plant*

The summation of cost of procuring the shortage (insufficient) amount of coal (Equation (4)) and cost of generation loss (Equation (5)) will give the Supply Shortage Impact (SII) value which is an extraneous cost when interruptions occurs in coal procurement (Equation (6)):

$$SSI_{fail} = KP_{fail} + KG_{fail} \quad (6)$$

IV. The Application of the Proposed Method

Consider a power utility company that needs 750,000 ton of coal yearly. The utility company has options to procure them from five different suppliers at three different major ports. Different suppliers located in different locations are considered in supplying the coal to the utility company as it is practically applied in procurement strategy in many utility companies [16]. Summary of suppliers, locations of ports, and prices is shown in Table 1 below. It is assumed that for different ports, the insurance and freight cost is different (i.e.: distance of suppliers to the buyers is a significant element affecting the delivered price of coal) [17]. For simplicity, it was assumed in this paper that all suppliers have similar SIR for delayed shipments of 0.10 and SIR for failed shipments of 0.02. Also several parameter assumptions are made and summarized in Table 2.

Three options (5, 10 and 11 shipments) are randomly made with the intention of increasing the number of shipments. Loads of each type of shipment are assumed in this analysis to be as followed: Capesize - 200,000 mt, Panamax – 75,000 mt, Handy – 35,000 mt.

For each option, the NdPT and SSI are developed. In order to calculate risk of each option, (7) is used.

$$Risk = Probability \times Impact \quad (7)$$

The probability value at each level of possible shortage is calculated by probability of delayed delivery multiplied by probability of failed delivery for the particular shortage level. Equation 8 shows the general equation for the probability value at each level of possible shortage.

$$Pr_{mn} = Pr(m\ delay) \times Pr(n\ fail) \quad (8)$$

Where:
Pr_{mn} : *Probability of m level delayed delivery and n level failed delivery*
$Pr(m\ delay)$: *Probability of m level delayed delivery*
$Pr(n\ fail)$: *Probability of n level failed delivery*

Then, the SSI delayed delivery at each level of possible delayed shortage is added up to every SSI failed delivery at possible failed shortage. Equation 9 explains this calculation.

$$SSI_{mn} = SSI\ (m\ delay) + SSI\ (n\ fail) \quad (9)$$

Where:
SSI_{mn} : *SSI at m level delayed delivery and n level failed delivery*
$SSI(m\ delay)$: *SSI at m level delayed delivery*

SSI(n fail) : *SSI at n level failed delivery*

The risk at m level delayed shortage and n level failed shortage is calculated by multiplying value from (8) and value from (9). Lastly, the summation of all risk values at every possible level is calculated to form Risk of Procurement (RoP) of that particular option

TABLE I. FOB, INSURANCE AND FREIGHT, AND CIF FOR DIFFERENT SUPPLIERS

Supplier	Port	FOB price (USD/ton)	Insurance and Freight cost (%)	CIF price ($/ton)
A	Kalimantan	130.00	10%	143.00
B	Kalimantan	132.00	10%	145.20
C	Newcastle	121.30	20%	145.56
D	Newcastle	122.70	20%	147.24
E	Richards Bay	119.10	30%	154.83

TABLE II. PARAMETERS ASSUMPTIONS

Parameters	Value
Average Spot Price [18]	$210/ton
Fuel Energy Density for Coal	6.67 kWhr/kg
Thermodynamic Efficiency of Power Plant	35%
Power Plant Fuel Reserve	10% of total demand
Levelized Cost for Power Plant	$190 MWhr

TABLE III. PROCUREMENT OPTION

Option	Supplier	Shipments		
		Capesize	Panamax	Handy
5 Shipments	A	1	0	0
	B	1	0	0
	C	1	0	0
	D	0	1	0
	E	0	1	0
10 Shipments	A	0	2	0
	B	0	2	0
	C	0	2	0
	D	0	2	0
	E	0	2	0
11 Shipments	A	1	1	1
	B	0	1	1
	C	0	1	1
	D	0	1	1
	E	0	1	1

V. RESULTS AND DISCUSSIONS

The above calculations were carried out in Matlab environment and the results for cost of procurement and risk of procurement were then gathered. For the cost of procurement (CoP) in Figure 2, an option with 10 shipments had the highest value of $110.37 million and an option with 5 shipments had the lowest value of $109.41 million. The result shows that increasing loads supplied with higher price will lead to a higher final cost of procurement.

In term of risk of procurement (RoP) also in Figure 2, an option with 5 shipments had the highest risk valued at $4.6119 million and an option with 10 shipments had the lowest risk value of $1.9232 million. The option with 5 shipments had the highest risk value because it depended on the largest load the three suppliers – Supplier A, B and C. This dependency had led to a higher risk value when the shipment was delayed or failed. The shipments from these suppliers affected a large number of loads which then translated into higher cost of SSI. In contrast to the option with 10 shipments, each supplier only had two shipments with smaller load. This had led this option to have the lowest risk value.

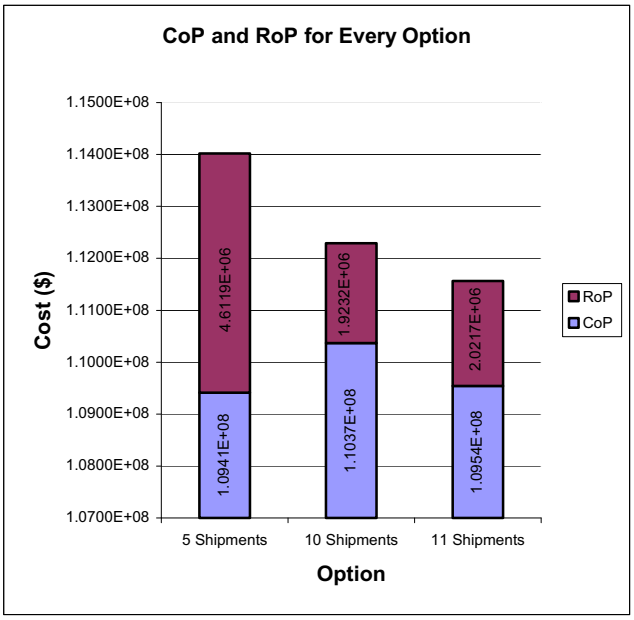

Figure 2. Graph of CoP and RoP for Every Option

From this figure, it can be seen that the risk of procurement is decreased as the cost of procurement is increased and vice versa. Thus in terms of cost of procurement increased from $109.41 million (Option 5 shipments) to $110.37 million (Option with 10 shipments), the risk of procurement had decreased from $4.6119 million (Option with 5 shipments) to $1.9232 million (Option with 10 shipments). Meanwhile, as the cost of procurement decreased from $110.37 million (Option with 10 shipments) to $109.54 million (Option with 11 shipments), the risk of procurement had increased from $1.9232 million (Option with 10 shipments) to $2.0217 million (Option with 11 shipments). So, this example has shown that there is an inversely proportional relationship between the cost of procurement and the risk of procurement. This is an ability which is novel and has not been covered in any other known works.

Finally, to choose the best option to be selected for supplying coal to utility companies, total exposure can be calculated. Total exposure is the summation of the cost of procurement and the risk of procurement for every option. Equation 10 gives this equation of total exposure.

$$Total\ Exposure = CoP + RoP \quad (10)$$

Where:
CoP : Cost of Procurement
RoP : Risk of Procurement

In this case, the option with 5 shipments had risk of procurement of $4.6119 million and the cost of procurement of $109.41 million. So, total exposure for the option with 5 shipments was $114.02 million. It can be seen from the graph that the option with 11 shipments was the best option since it offered the lowest total exposure which was $111.56 million. This result would be different if procurement option decisions are solely based on the cost of procurement or the risk of procurement which were the option with 5 shipments and the option with 10 shipments respectively.

VI. CONCLUSION

This paper has illustrated the development of Supply Shortage Impact (SSI) that can be used in combination with Non-delivery Probability Table for risk quantification in coal procurement for electricity generation system. The application of this method is very essential in the first step of risk assessment in which it can identify the probability of event to happen. By multiplying the probability values identified in NdPT with impact values in SSI, the risk can be quantified in term of monetary value that gives a useful indicator to decision makers. For example, decision makers have a choice to choose between options of lower cost of procuring the fuel with a higher risk to another option of slightly higher cost of procuring the fuel with a slightly lower risk. In addition to that, with further research on the area, the development of the proposed method can be a starting point in setting strategies in other factors in fuel procurement. For example, SSI can provide information for setting up the fuel reserve quantity as shown in Section III on how this reserve can affect the final value of risk in fuel procurement. Besides, the proposed method can also be used as a tool in the negotiation process of coal price contract as it provides information regarding the significant impact of coal price to power utility company's risk. Manipulating fuel price into the above equations will provide valuable information on the best price for fuel contracting which would benefit both parties. The application of the proposed method is not limited to energy system only. With modification, this concept can be applied to any other systems involving supply security.

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