Operation Risk Management of Planning and Piping Design in a Large Petrochemical Plant Project

Kamolwan Deeswasmongkol
International Graduate Program in Industrial Engineering, Faculty of Engineering, Kasetsart University, 50 Pahonyothin Rd, Jatujak, Bangkok 10900, Thailand
townintownmsn@hotmail.com

Punnamee Sachakamol
International Graduate Program in Industrial Engineering, Faculty of Engineering, Kasetsart University, 50 Pahonyothin Rd, Jatujak, Bangkok 10900, Thailand
fengpmsa@ku.ac.th

Abstract

Purpose – The purpose of this paper is to present practical and research lessons learned from analysis and the identification of failures which can occur. Failure mode and effects piping analysis (FMEPA) has been shown to be an effective way of improving piping design reliability. FMEPA is also employed for making sample control plans.

Design/methodology/approach – To reduce project losses by using failure mode and effects piping analysis as a tool for analysis of the piping design department. The samples were selected from five projects. It was found that nine major points yielded a risk priority number (RPN) higher than 125.

Findings – Results of RPN calculation concerning four topics revealed that the RPN value was reduced from 211 to 75, demonstrating a 64.4 percent improvement.

Research limitations/implications – The study is limited to a planning and piping case study which considers RPN. Testing of the performance network regression model can be employed in companies, in which quality control has been implemented of solutions for failure prevention of piping design.

Practical implications – This paper serves practitioners as a guideline and tool to understand and implement the FMEPA methodology. At this level, management sets the limits for determining measures. Management also decides whether a risk is acceptable or not. Management needs to clarify which risk priority number (RPN) represents the critical level above which requires risk reduction.

Social implications – Conflicts and social unrest can cause costly delays to new projects and operations. Conflicts can also result in damage to a company's reputation. This depends on the company's responses to the conflict and the consequences or perceived consequences of its behavior and actions.

Originality/value – This paper furnishes lessons learned for practitioners in various industrial sectors in preference to other methods of risk assessment and control activities.

Keywords: failure mode and effects analysis, piping design and drawing process, control plan

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1. Introduction

The "Operation Risk Management of Planning and Piping Design in a Large Petrochemical Plant Project" is in a state of uncertainty. Some possible event could have either a desirable or undesirable effect on maintainability and operability. This project concerns large chemical production at a petroleum plant project. It is based on a 3D piping design model that revolves around the following four steps: 1: Identifying key project risks in a timely manner. 2: Assessing and analyzing the likelihood of risks crystallizing and the consequent cost/schedule impacts on the project. 3. Developing appropriate strategies and actions to respond to risks. 4. Monitoring and controlling risks and implementing action.

The piping problems were identified during fiscal years 2012 to 2014 during which time numerous projects were unable to be completed according to the requirements of the customers. The problems were mainly caused by internal processes. The problems focused sharply on piping design which was not directly related to actual site work. Many faults in piping design forced the company to reorder and rework. From the track record of problems during the period of this study, the project cost for reordered materials increased dramatically compared to original offer costs. Internal processes such as waiting for piping design between internal departments also delayed the overall process. Under current organization, each department is independently managed, leading to poor cooperation between departments. These issues led to poor quality of work and project delays caused overall lack of efficiency. Customer satisfaction and trust were damaged, threatening the company's chances of winning further projects. At the end of fiscal year 2014, on-going projects were valued at 32,200 million Thai baht. Meanwhile, backlogged projects were valued at 6,740 million Thai baht.

Loss of investment capital is the main factor that threatens any company. In most settings, 7 QC tools (Varsha *et al.*, 2014) are applied and analyzed under statistical methods. For solving quality problems, the seven QC tools used are Pareto diagrams, cause and effect diagrams, histograms, control charts, scatter diagrams, graphs and check sheets. All of these are important tools that are widely used in the manufacturing field to monitor overall operations and to assure continuous process improvement. These tools are used to determine root causes and eliminate them in order to improve the manufacturing process. The modes of defects on a production line are investigated through direct observation and statistical tools.

The collected data is then used to make decisions on current problems with appropriate direction. Statistical tools are then employed for data collection using checklists. Data is then input into a Pareto diagram. From there, a team selects and arranges the problems according to their severity. They are all put into a cause and effect diagram, which shows the systematic relationship between a result, a symptom or an effect and its possible causes. It is an effective tool to systematically generate ideas about causes for problems and to present these in a structured form. This tool was devised by Dr Kaoru Ishikawa and is also known as an Ishikawa diagram.

On the other hand, several local industries have applied failure mode and effects analysis: FMEA is a systematic process intended for reliability analysis. It improves the operational performance of production cycles and reduces their risk level (Scipioni *et al.*, 2002). FMEA was initially used in the industrial production of machinery, motor cars, mechanical and electronic components and electric motor control systems for vehicle heating, ventilation and air conditioning (Cassanelli *et al.*, 2011). It has also been used in the pastry industry (Antikalamos and Kalamata, 2011) and food companies (Antonio *et al.*, 2001). From failure analysis, the effects are classified in 3 groups. The first group of FMEA is used for analysis by the design team to evaluate potential failure trends, including mechanisms that can lead to failure. The second group of FMEA is needed to establish understanding of each activity in processes that poses risks. The third group of FMEA links these activities together to determine failure trends and employs analysis to control and reduce risks during the processes. Similar research having equivalent procedures started with rearranging the level of severe problems, then doing analysis with a fish-bone diagram, followed by analysis of failures and effects with FMEA. Finally, all analysis data was input to the control plan. Pasuk *et al.*, (2009) studied waste reduction in the chromium plating process using FMEA and developing the quality of plating surface using six sigma. Their research reduced waste from the process by up to 70 percent. Jiwawongsawas *et al.*, (2007) applied FMEA and AHP for process improvement in the ceramic coating industry as a major product faced serious quality problems. Prada and Kuptadsathien, (2007) performed analysis using FMEA for the fire protection coat production for all processes and calculated risk priority numbers (RPN) with a Pareto diagram. Next, they conducted a control plan showing that productivity increased up to 15.32 percent and waste in the process decreased by 11.15 percent.

Rittipakdee, (2011) studied ways to improve the painting process in the automobile industry. He used cause and effect diagrams to determine production problems and developed a relationship diagram together with a tree diagram, employing new 7 QC Tools to determine the problems. Thongpraiwa and Kuptadsathien, (2010) applied FMEA to improve the efficiency of the glass molding design and development processes. They found process RPN of 100 points or more. The major failures of mold design that needed immediate correction included 33 out of 65 topics. As a result of RPN correction, failure of mold testing was reduced from 2.7 times to 1 time for each molded product. Furthermore, production lead time was reduced on average from 75 days to 45 days, representing a 40 percent improvement.

A review of related literature reveals numerous ways to apply FMEA theory to real jobs of planning and piping design. It can be used to analyze and identify potential failures. FMEA has also been used to create a control plan for a sample company.

2. Literature review

Similar research concerning equivalent procedures began with analyzing the severity of problems, then conducting analysis using a fish-bone diagram, followed by analysis of failures and effects with FMEA. Finally, all of the analysis data was input to a control plan. Jiwawongsawas *et al.*, (2007) applied FMEA and an analytic hierarchy process (AHP) for process improvement at a ceramic coating industry facing major quality problems with some of its products. Prada and Kuptadsathien, (2007) analyzed FMEA for the production of fire protection coats for all processes and calculated the risk priority number (RPN) using a Pareto diagram. The control plan in that study revealed that productivity increased up to 15.32 percent and waste in process decreased by 11.15 percent. Rittipakdee, (2011) studied methods to improve the painting process for the automobile industry. He used cause and effect diagrams to determine production problems plus he created a relationship diagram and tree diagram to determine the major problems. Scipioni *et al.*, (2002) applied FMEA to categorize risk evaluation as follows: slight risk (RPN<60), moderate risk (RPN<80), high risk (RPN<100) and crisis risk (RPN>100).

Review of related literature has enabled the researchers to apply FMEA theory in genuine planning and piping design. Scipioni *et al.*, (2002) studied the ways in which FMEA can control and reduce waste from design processes which affect quality in the petrochemical industry. Klomjit and Kaewsaithom, (2010) studied ways to reduce downtime caused by machine breakdown during operation and to select preventative maintenance task categories based on reliability-centered maintenance (RCM) for machine components. The study began by identifying the critical machine or equipment that impacted paper production and then analyzing the root causes and failures analysis using FMEA. The next step was to simulate the failure patterns of component parts using statistical data to forecast reliability parameters. The final phase was selecting preventive maintenance tasks which met the reliability parameters of each failure mode. This study has shown that downtime decreased. Meanwhile, machine availability increased.

Jang-Shyong *et al.*, (2006) studied a probable failure analysis to determine the failure probabilities of piping segments, and a probable risk assessment model was employed to identify risks at a nuclear power plant. The multiplication of the piping failure probability and the consequences of that particular failure results in the risk contribution of the pipe. The degrees of risk for different piping segments can then be ranked and the results can be used as the basis for planning a risk-informed inspection program.

Tavner *et al.*, (2010) researched FMEA techniques to compare the prospective reliability of three versions of the geared R80 turbine with different drive train solutions. These solutions have been proposed to reduce the overall wind turbine failure rate and raise its reliability. The first solution incorporated a conventional LV doubly fed induction generator (DFIG) with partially-rated electrical converter and transformer. The second solution incorporated an innovative hydraulic converter coupled to an MV synchronous generator (SG) without a transformer. The third solution incorporated an innovative LV brushless doubly fed induction generator (GDFIG) with a partially-rated electrical converter and transformer. Their research proposed modifications to the FMEA method to analyze and compare reliability. They applied that approach to three alternative designs in order to identify optimum solutions.

3. Methodology

FMEA, which originated in 1950, is a form of reliability analysis technology used for the prevention of accidents. It was first used in the primary operation system in the Grumman Aircraft Corporation to analyze relevant processes, detect potential failure modes and effects, take corrective action to eliminate potential failures and bring about continuous improvement. Included is the important concept and skill of the risk classification/assessment method.

FMEA is a reliable technology for preventing defects and improving product safety and quality. The main function of FMEA is to point out a design or system failure mode, explore the impact of the failure on the system, give qualitative or quantitative assessments, take necessary corrective measures and then implement preventive policies.

This method is often used in the product design stage or applied to the improvement of manufacturing engineering and safety analysis. Although FMEA has been widely used in the definition and elimination of known or latent failures in order to improve reliability and security, it was not until recent years that hospitals began to use FMEA for improvement. The main operating procedures of FMEA include: establishment of the team, analysis of the current situation work process, latent failure and impact analysis, risk assessment, failure cause identification, implementation of countermeasures, countermeasure tracking and outcome measurement (Ching and Chao, 2014).

A research method consisting of eight processes is shown in Figure 1. It begins with a study of design and collection of data of the piping design and drawing process, followed by analysis of the data to determine failures. Using a cause and effect diagram, analysis is performed using FMEPA. The findings are then arranged according to RPN using a Pareto chart. Processes with high RPNs are then selected for rework. Finally, the data is applied with a control plan and the results are summarized.

3.1 Studying design and drawing process

The process of design and drawing comprises a variety of steps. It begins with project data as shown in Figure 2. The FMEPA technique does not account for technical specifications, design and drawing. After the design and drawing are complete, the isometric process, plus the piping and instrument diagram (P&ID) are matched with the vendor's drawings together with information from other departments. Then, the data is rechecked and calculated. If the data is not correct, the process goes into a loop until it passes the qualifications before it is handed over to the construction department.

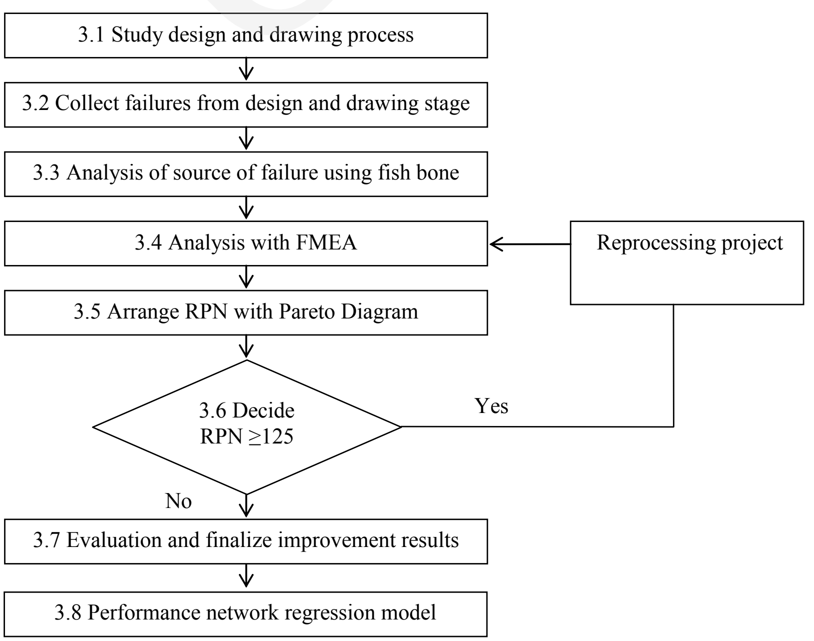


Figure 1:
Research Methodology

3.2 Fault data from design and drawing

3.2.1 Design and drawing before improvement

This research collected data between the years 2012 and 2014. It was found that the percentage of losses over the project value tended to increase continuously as demonstrated in Table 1 and Figure 3. Faults were classified into four types of problems. Each group includes internal details with a description of the type of loss as shown in Table 1.

Table 1: Unplanned costs due to design and drawing faults from 2012 to 2014

Year	Project Value (P) (in Millions USD)	Re-Order Cost (A) in Millions USD	Cost of project correction (B) in Millions USD	Total Cost (A+B) in Millions USD	Percentage of Loss (A+B) /P, %)
2012	455	0.19	0.24	0.42	=(0.42*100)/461 =0.09
2013	500	0.44	0.52	0.95	=(0.95*100)/507=0.19
2014	976	0.93	1.24	2.17	=(2.17*100)/990=0.22
		Average			0.17

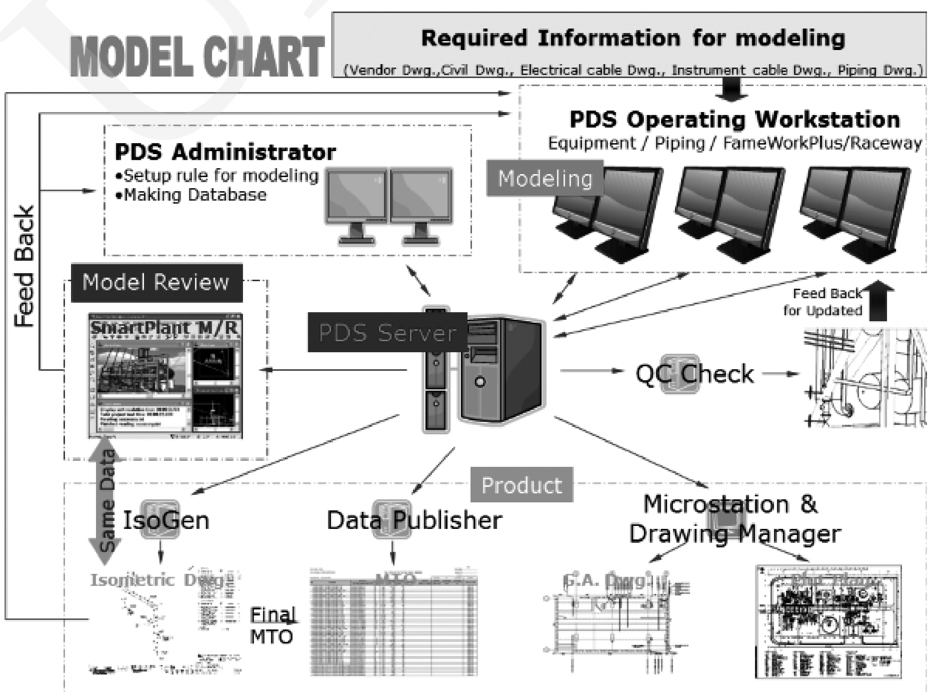


Figure 2: Design and drawing process

3.3 Cause and effect of faults and waste analysis using fish-bone diagram

From the design and drawing process through the project handover to the end customer comprises 8 internal processes. Group brainstorming among several departments was conducted to analyze the effects of faults. The quality tool used for this analysis was a cause and effect diagram as shown in Figure 3.

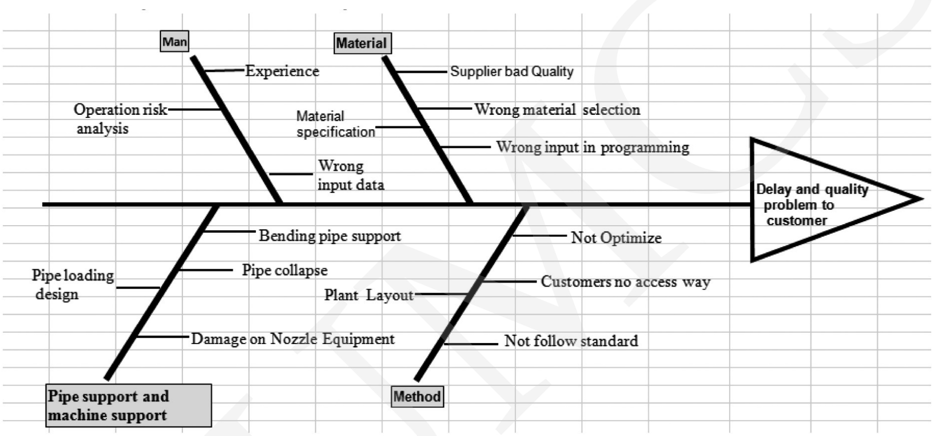


Figure 3: Cause and effect diagram

3.4 Failure analysis using FMEA technique

Failure analysis is very important to determine cause and effects in the manufacturing process. It is used to solve problems systematically. It helps prevent losses before they occur. FMEA technique also enhances systematic problem solving skills. It is used by a project team to rearrange processes and prevent the high probability of loss on projects. FMEA consists of the methods explained below.

3.4.1 Pipe layout, material selection, pipe loading design and risk analysis are considered for selection and design. Brainstorming raises issues for design properties. Requirements for internal work and design must consider maximum usage; design must meet customer requirements and must aim for maximum safety. From brainstorming to analyzing the trends of failures due to piping design, nine types of failures were categorized. Failures were mainly caused by poor design which did not comply with the customer's specifications. Some designs contributed to poor efficiency. Some designs failed due to material selection. Moreover, some design work caused parts damage during actual use. Table 5 summarizes the processes that led to failures.

3.4.2. Potential failure mode is a normal specification in the sub-processes. If a sub-process does not comply with original specifications, it raises the question, "what will each department do to resolve the failure?" Potential failure mode is shown in Table 5.

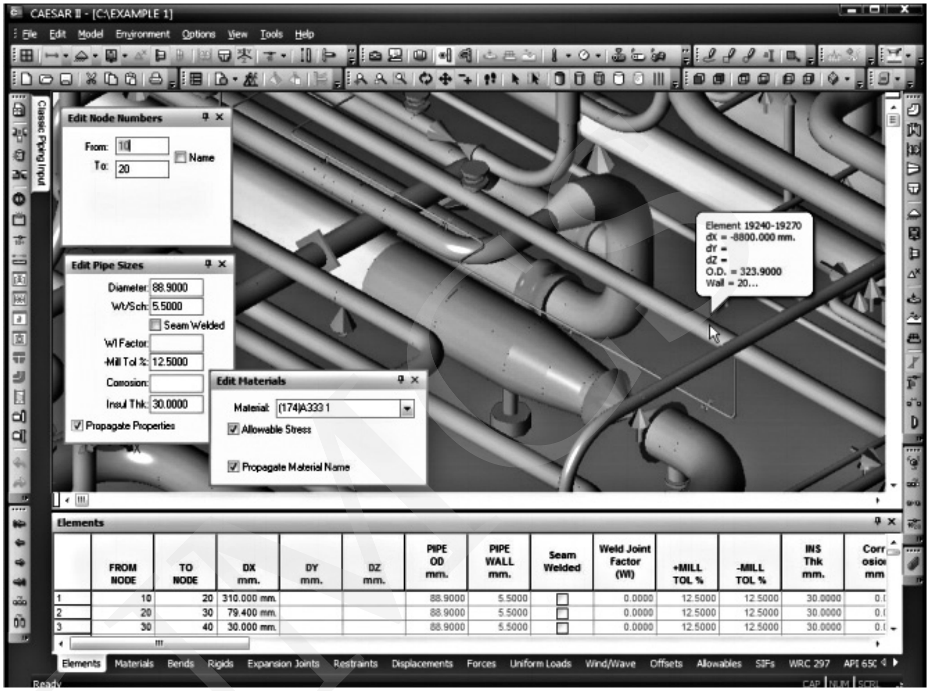


Figure 4:
Cutting-edge, annotated graphics make it easy to access or review analysis input data.

3.4.3 Failure detection methods in the current situation employ 3D simulation. These methods are used to determine failures and test the most suitable design. The design is then transferred to CAESAR II program (Pipe stress analysis) for design and calculation of mechanical support as shown in Figure 4.

3.4.4 Process control during the current situation is employed to control possible failures. Table 3 shows guidelines for fault control. This data is used for calculations in FMEA by arranging the risk priority number (RPN). RPN refers to results that will cause harm to the project. A higher RPN relates to a higher degree of risk. The calculation of RPN is shown in equation 1 (American Society for Quality (ASQ), 2005) as follows:

$$RPN = S \times O \times D \quad (1)$$

Where S is Severity, O is Occurrence, D is Detection constraints: S, O and D, are integers ranging from 1–10

Evaluation	Classification	Explanation
1	Very low	No adverse effects on product/process quality can be derived. The failure consequences are wholly insignificant.
2	Low	No adverse effects on product/process quality are likely to be derived. The failure consequences are insignificant.
3	Low	An applicable product can be expected. The master batch record is fulfilled, although some deviations in the process exist.
4	Low	An applicable product can be expected. The master batch record is fulfilled, although considerable deviations in the process exist.
5	Medium	The use of the product is limited; process is stable.
6	Medium	The use of the product is limited; slight deviations in the process exist.
7	Medium	The use of the product is limited; process is unstable.
8	High	The product has to be rejected;
9	High	The product has to be rejected; Process change has to be considered.
10	High	The product has to be rejected; Process must be changed.

Table 2: Severity (S) of a Failure

Evaluation	Classification	Explanation
1	Very low	Failure frequency <0.01% or failure is not expected
2	Low	Expected failure frequency ≥0.01% and <0.05%
3	Low	Expected failure frequency ≥0.05% and <0.1%
4	Low	Expected failure frequency ≥0.1% and <0.2%
5	Medium	Expected failure frequency ≥0.2% and <0.5%
6	Medium	Expected failure frequency ≥0.5% and <1%
7	Medium	Expected failure frequency ≥1% and <2%
8	High	Expected failure frequency ≥2% and <5%
9	High	Expected failure frequency ≥5% and <10%
10	High	Expected failure frequency ≥10%

Table 3: Probability of Occurrence (O)

Table 4: Probability of Detection (D)

Evaluation	Classification	Explanation
1	Very low	The failure is detected in 100% of cases; automatic measuring/test system, 100% control, and process is halted immediately when failure is detected.
2	Low	The failure is detected in 100% of cases; automatic measuring/test system, 100% control.
3	Low	The failure will probably be detected; automatic measuring/test system, random sample control, process is automatically halted, if failure is detected.
4	Low	The failure will probably be detected; automatic measuring/test system, random sample control (>20%).
5	Medium	The failure will probably be detected; manual 100% control (e.g. test system, test tools are in place).
6	Medium	The failure will probably be detected; visual 100% control.
7	Medium	The failure can be detected; manual control (>20%) test system, test tools, etc. are in place).
8	High	Failure can be detected; visual control (> 20%).
9	High	The failure can be spotted visually at random; sporadic visual test or monitoring.
10	High	The failure is not detected (no control).

3.4.5 Risk Priority Number Calculation (RPN)
Results from RPN calculation reveal that the highest RPN value was 280 points and the lowest value was 32 points as shown in Table 5. This table shows the RPNs for the piping layout process.

3.5 Process selection for analyzing control plan with Pareto diagram

When RPN numbers are rearranged using a Pareto diagram, the data is distributed and grouped to reveal the stability of data by frequency distribution count. Important data will have a low number or a few vital points. In contrast, less important data will yield a high number or many trivial points. Data analysis revealed that the major processes can be classified into nine crucial processes as demonstrated in Table 5.

Table 5: Summary of failure analysis trends and cause of failure due to piping design

Item	Requirement	Potential Effect Mode	Potential Effect of Failure	SEV	CLASS	Potential Cause Of Failure	OCCUR	Current Design Control: Prevention	Current Design Control: Detection	DETECT	RPN	Recommended Action (s)	Responsibility & Target Date	Action Results: Action Taken	Action Results: SEv	Action Results: OCC	Action Results: DET	Action Results: RPN
1. Pipe Layout	1) 1A. Piping layout is fit on specified area	1A-S1 Tight pipe layout does not conform to drawing	1A-S1-E1 Pipe crushed, causing damage.	7		1A-S1-C1 No standard of pipe layout	6	Review drawing before handing to customers	Simulation using 3D Program	4	168	Preparation for Standard of Pipe Installation	Piping Dept. Month/YY	Preparation for standard of pipe alignment	5	3	4	60
	2) 1B. Installation of pipe to machine of equipment	1B-S1 Wrong connection of pipe to nozzle, does not conform to drawing	1B-S1-E1 Damage on Equipment	8		1B-S1-C1 Fault from designer	2	Review drawing before construction	Simulation using 3D Program	4	64							
	3) 1C. Pipe layout based on ease of access	1C-S1 Customers have suitable access to equipment	1C-S1-E1 Inconvenient work space	7		1C-S1-C1 Design and installation for valve at high position	7	Review drawing before handing to customers	Simulation using 3D Program	4	196	Preparation for standard of valve installation	Piping Dept. Month/YY	Preparation for standard of valve installation	5	4	4	80
	4) 1D. Need flow efficiency	1D-S1 Liquid moves with high friction	1D-S1-E1Reduction in machine efficiency	8		1D-S1-C1 Design by avoid pocket is made by drip leg.	3	Review drawing before handing to customers	-	2	48							
2. Material Selection	1) 2A. Material specification must conform to design specification	2A-S1 Wrong material selection	2A-S1-E1 Corrosion during operation	8		2A-S1-C1 Incorrect input to design program	7	Review before handing to customers	-	5	280	Prepare standard check list	Piping Dept. Month/YY	Preparation of check sheet	5	5	4	100

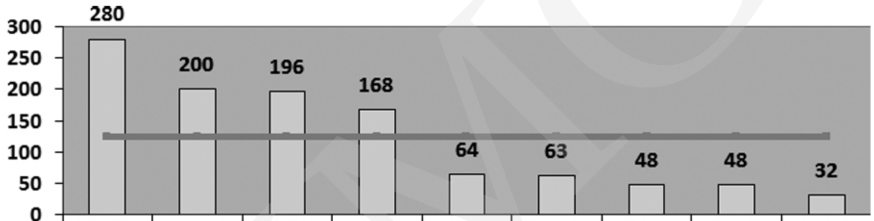
Table 5: Summary of failure analysis trends and cause of failure due to piping design (continued)

Item	Requirement	Potential Effect Mode	Potential Effect of Failure	SEV	CLASS	Potential Cause Of Failure	OCCUR	Current Design Control		DETECT	RPN	Recommended Action (s)	Responsibility & Target Date	Action Results				
								Prevention	Detection					Action Taken	SEv	OCC	DET	RPN
4. Operation risk analysis	3) 4A. Proper sizing for pipe support	4A-S1 Under-sized pipe support	4A-S1-E1 Bending support, collapsed pipe Pipe support deflection	8		4A-S1-C1 Wrong input for pipe support	5	Review drawing before handing to customers	Use CEASAR II program for load simulation	5	200	Prepare standard check list	Piping Dept. Month/YY	Preparation of check sheet	5	3	4	60
	4) 4B. Pipe appearance must not crack or bend during operation	4B-S1 Defect and cracks of pipe	Plant/Factory down	8		4B-S1-C1 Wrong material	2	Review before handing to customers	Use CEASAR II program for load simulation	3	48							
	5) 4C. Nozzle joint must not be damaged	4C-S1 Nozzle damage	Chemical leakage	7		4C-S1-C1 Inappropriate support for pipe	3	Review before handing to customers	Use CEASAR II program for load simulation	3	63							

3.6 Results from RPN arrangement

RPNs were arranged from low to high as shown in Figure 5. In this study, RPNs higher than 125 points were selected for improvement. This included four out of nine problems. The important issues comprised pipe layout in two problems, material selection in one problem and risk of use in one problem. Based on Table 5, the action team discussed the problems and solved them by referencing other project databases. The problems were solved as demonstrated in Table 6.

Results were discussed to resolve failures. Topics with RPNs higher than 125 points are summarized in Table 6. From RPN point re-calculation of four major types of failure, it was found that RPN points were reduced from 211 to 75 after improvement, representing a 64.4 percent reduction in RPN.



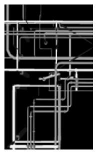
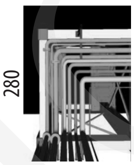
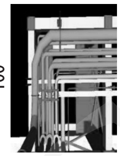
	2A-S1-C1	4A-S1-C1	1C-S1-C1	1A-S1-C1	1B-S1-C1	4C-S1-C1	1D-S1-C1	4B-S1-C1	3A-S1-C1
RPN	280	200	196	168	64	63	48	48	32
Target	125	125	125	125	125	125	125	125	125

Figure 5: Risk priority number for each issue

3.6.1 Rearrangement and Evaluation of revised RPN

After reviewing the processes with RPNs, the piping designers revised the standard of design. The quality control team then recalculated the RPNs. New RPNs were less than 125 points for each of the four failures evaluated in this study, representing an improvement of 64.4 percent. Therefore, new piping design methods will be applied to confirm the results. Table 6 shows the RPNs before and after improvement.

Table 6: RPNs before and after improvement and summary of problem solving for piping design causes and effects to resolve topics with RPNs higher than 125 points.

Piping design properties	Trend of Failure	Cause (Trend of problem)	Solution	Before solving RPN	After solving RPN	Percentage Improvement RPN
1. Pipe layout	1A-S1 Pipe laying too close together	1A-S1-C1 No standard of alignment	Prepare standard of alignment	168 	60 	64.3%
	1C-S1 Customer must reach very high to operate the valve	1C-S1-C1 Improper valve location	Prepare standard installation	196 	80 	59.1%
2. Material selection	2A-S1 Material selection is not correct according to customer specifications	2A-S1-C1 Wrong input for material specification	Prepare material check list	280 	100 	64.3%
4. Operate risk analysis	4A-S1 Improper pipe support size	4A-S1-C1 Wrong input for pipe application	Prepare standard check list	200 	60 	70.0%
Average				211	75	64.4%

3.7 Evaluation and final improvement results

A summary of the problems causing rework due to design errors are summarized in Table 7. Conclusion costs from design errors in Table 12 are based on the project valued at 17.8 million USD for the study.

Properties	Potential Cause	Trend of Failure or Mechanism	Solution
1. Pipe layout	1) 1A. Piping layout is fit in specified area	Not found	
	2) 1B. Tie in pipe with designed equipment	Not found	
	3) 1C. Pipe alignment for ease of use	Not found	
	4) 1D. Need flow efficiency	The noise impact of fluid inside the pipe.	New pipeline planned in accordance with the type of liquid.
2. Material selection	1) 2A. Material must conform to design specification	Not found	
3. Pipe loading design	2) 3A. Support must be able to take load from pipe	Not found	
4. Operate	3) 4A. Proper sizing for pipe support	Not found	
risk analysis	4) 4B. Pipe appearance must not crack or bend during operation	Found cracked pipes due to poor quality of raw materials	Change to other source supplier for quality. And reinstallation.
	5) 4C. Nozzle joint must not be damaged	Not found	

Table 7: Summary of problems causing rework due to design error

The results reveal that the average percentage of the cost due to design error decreased from 0.31 to 0.08 percent, achieving the goals that were set. Using a reduced percentage of losses, costs were reduced to 74.2 percent (percentages comes from 100-(0.08/.31)*100).

Trend of Failure or Mechanism	Solution	The cost of reorder materials (in millions USD)	The cost of Rework (in millions USD)
The noise impact of fluid inside the pipe.	New pipeline planned in accordance with the type of liquid.	0.17	0.08
Found cracked pipes due to bad quality of raw materials.	Change to other source supplier for quality plus reinstallation	0.14	0.07
Total cost of each topic.		0.31	0.15
Total cost		0.46	
Percent of the cost compared to the value of the project. (overall 17.6 million US dollar)		**0.08**	

Table 8: Conclusion of costs due to design errors

3.8 Test of the performance network regression model in the piping department

The most commonly used measure for profitability is the ratio of revenue and cost. Productivity represents the ability of the organization to utilize its resources for generating outputs. Then, performance measures (in terms of a ratio) that relate to the two performance criteria are developed. The following Table 10 demonstrates some of the performance measures and their respective results from the data that has been collected.

The next step involves the use of the performance network concept. This concept represents an attempt to cluster different performance measures into one group. This cluster is based on the cause-and-effect relationships among the performance measures. Given the establishment of the PNs on profitability and productivity, the next step is to test the significance (in terms of the reliability and the goodness of the equations) of the interrelationships among different measures (which have been clustered). Usually, the Significance-F Value is less than 0.05. Figure 6 demonstrates this step in details for the PNs on both profitability and productivity respectively.

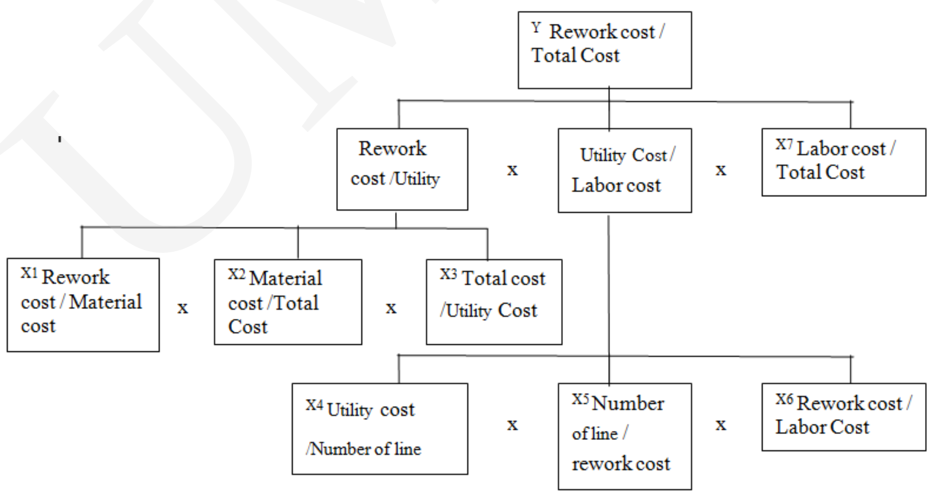


Figure 6: Piping Detail Design Network Performance Measurements for 21 weeks

Table 9: Performance Measures (Ratios) and Results

Measure / Period	DATA							RATIO								Remark
	Rework cost (Baht)	No. of Line	Total Man-Hr.	Total Labor Cost	Utility	Material	Total Cost	Y	X_1	X_2	X_3	X_4	X_5	X_6	X_7	
1	170.000	7	97	135.125	430	809	136.364	1.24666	210.13597	0.00593	317.12558	61.42857	0.000041	1.258094	0.990914	
2	195.000	20	300	166.005	1.680	2.510	170.195	1.14574	77.68924	0.01475	101.30655	84.00000	0.000103	1.174663	0.975381	
3	340.000	20	297	293.232	1.666	2.489	297.387	1.14329	136.60104	0.00837	178.50360	83.30000	0.000059	1.159491	0.986028	
4	340.000	38	558	291.360	2.952	4.677	298.989	1.13717	72.69617	0.01564	101.28354	77.68421	0.000112	1.166941	0.974484	
5	370.000	44	649	313.613	3.431	5.435	322.479	1.14736	68.07728	0.01685	93.98980	77.97727	0.000119	1.179798	0.972507	
6	65.000	23	339	55.916	3.726	2.901	62.543	1.03928	22.40607	0.04638	16.78556	162.00000	0.000354	1.162458	0.894041	
7	64.000	21	314	55.916	3.456	2.691	62.063	1.03121	23.78298	0.04336	17.95804	164.57143	0.000328	1.144574	0.900955	
8	54.000	26	377	45.100	2.570	3.231	50.901	1.06088	16.71309	0.06348	19.80584	98.84615	0.000481	1.197339	0.886034	
9	160.000	35	515	142.552	3.511	4.413	150.476	1.06329	36.25651	0.02933	42.85844	100.31429	0.000219	1.122397	0.947340	
10	185.000	30	446	158.421	2.433	3.822	164.676	1.12342	48.40398	0.02321	67.68434	81.10000	0.000162	1.167774	0.962016	
11	64.000	30	440	53.580	2.400	3.771	59.751	1.07111	16.97163	0.06311	24.89625	80.00000	0.000469	1.194476	0.896721	
12	54.000	32	468	45.496	3.281	4.097	52.874	1.02130	13.18038	0.07749	16.11521	102.53125	0.000593	1.186918	0.860461	
13	57.000	36	531	47.260	3.281	4.650	55.191	1.03278	12.25806	0.08425	16.82140	91.13889	0.000632	1.206094	0.856299	
14	49.000	16	235	41.007	1.640	2.060	44.707	1.09603	23.78641	0.04608	27.26037	102.50000	0.000327	1.194918	0.917239	
15	20.000	8	114	16.757	796	999	18.552	1.07805	20.02002	0.05385	23.30653	99.50000	0.000400	1.193531	0.903245	
16	140.000	6	82	117.782	523	719	119.024	1.17623	194.71488	0.00604	227.57935	87.16667	0.000043	1.188637	0.989565	
17	150.000	17	255	131.007	1.624	2.231	134.862	1.11225	67.23442	0.01654	83.04310	95.52941	0.000113	1.144977	0.971415	
18	175.000	23	343	153.739	2.510	3.005	159.254	1.09887	58.23627	0.01887	63.44781	109.13043	0.000131	1.138293	0.965370	
19	32.000	19	275	27.230	2.012	2.408	31.650	1.01106	13.28904	0.07608	15.73062	105.89474	0.000594	1.175174	0.860348	
20	32.000	16	237	25.241	1.580	2.075	28.896	1.10742	15.42169	0.07181	18.28861	98.75000	0.000500	1.267779	0.873512	
21	34.000	18	263	27.005	1.757	2.308	31.070	1.09430	14.73137	0.07428	17.68355	97.61111	0.000529	1.259026	0.869166	
Sum	2.750.000	485	7.130	2.343.344	47.259	61.301	2.451.904									

Figure 6 shows that a cluster at the lowest level represents the set of performance measures for determination of the profitability level is shown as follows:

Target Y: Rework Cost-to-Total Cost ratio Measures
X_1: Rework Cost-to-Material Cost ratio
X_2: Material Cost-to-Total Cost ratio
X_3: Total Cost-to-Utility Cost ratio
X_4: Utility Cost-to-Number of Pipe Line ratio
X_5: Number of Pipe Line-to-Rework cost ratio
X_6: Rework Cost-to-Labor Cost ratio
X_7: Labor Cost-to-Total Cost ratio

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.999916162
R Square	0.999832331
Adjusted R Square	0.999742047
Standard Error	0.000927976
Observations	21

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	7	0.066755906	0.009537	11074.36	1.67821E-23
Residual	13	1.11948E-05	8.61E-07		
Total	20	0.0667671			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-1.508929753	0.241076081	-6.25914	2.93E-05	-2.029742962	-0.98812	-2.029742962	-0.9881165
X Variable 1	-9.77782E-05	3.47142E-05	-2.81666	0.014558	-0.000172774	-2.3E-05	-0.000172774	-2.278E-05
X Variable 2	-0.933734552	0.27902436	-3.34643	0.005257	-1.536530032	-0.33094	-1.536530032	-0.3309391
X Variable 3	6.54675E-05	2.79977E-05	2.338317	0.036001	4.98214E-06	0.000126	4.98214E-06	0.00012595
X Variable 4	0.00014472	7.52301E-05	1.923699	0.076567	-1.78047E-05	0.000307	-1.78047E-05	0.00030724
X Variable 5	188.9813215	54.2607207	3.482838	0.004045	71.7581615	306.2045	71.7581615	306.204482
X Variable 6	0.984201458	0.02627805	37.45337	1.25E-14	0.927431183	1.040972	0.927431183	1.04097173
X Variable 7	1.519541961	0.212170698	7.161884	7.35E-06	1.061175035	1.977909	1.061175035	1.97790889

Figure 6:
Summary of the regression analysis

Analysis of the multiple regression for statistical testing was performed on the set of the measures with time order (T) by using the target as variable Y and the measures as variable X. The multiple regression equation for profitability is:

$$Y = -1.55 - 0.000100\,X_1 - 0.945\,X_2 + 0.000066\,X_3 + 0.000156\,X_4 + 197\,X_5 + 0.988\,X_6 + 1.55\,X_7 \quad (2)$$

The profitability PNs regression equation has R-square equal to 0.999 or 99.9%, meaning the set of 7 measures and time order with their coefficients can estimate about 99.99% of the variation of Y (a profitability measure). Standard error of regression analysis is 0.000927976. It is close to zero (meaning this regression analysis is accurate with a margin of error of about 0.000927976). For the F-test, Significance-F of this regression analysis is 1.67821×10^{-23}, meaning the probability of F (7,13,0.99) > F-statistic = 11074.36 is about 1.67821×10^{-23} %. When the F-statistic value = 11074.36, > F (7,13,0.99) = 4.441, it implies that this regression is significant and could be applied for the estimation of Y.

A plot scatter diagram of each pair of variables shows two perspectives. The X-axis represents independent variables. The Y-axis represents response variables. The scatter plots show the distribution of the individual variables. The shape or curve of the plot can help to indicate the possible behavior of an interrelationship as shown in Figure 7.

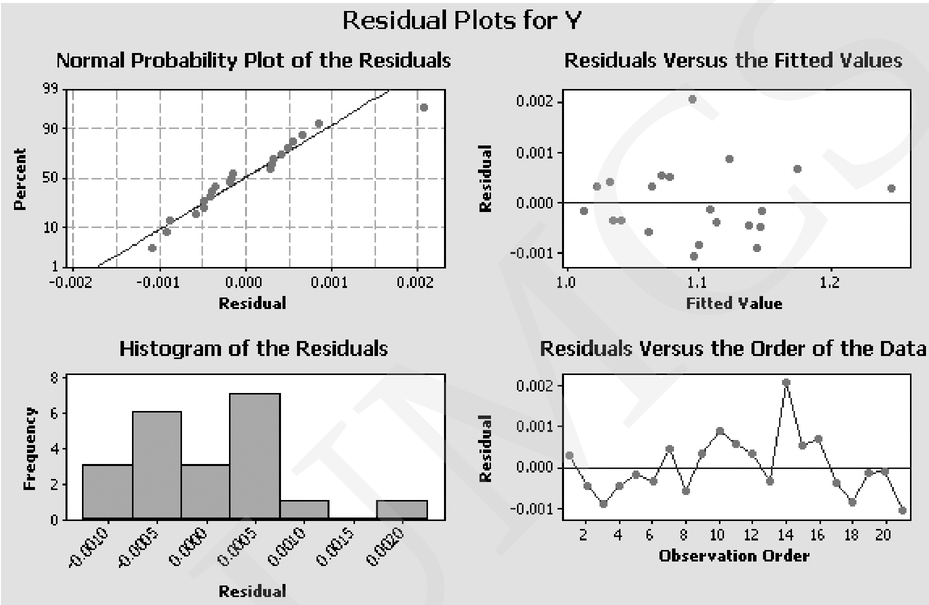


Figure 7: Residual Plots for Y

4. Results

4.1 This research has established the necessary steps for risk assessment for the piping design process from a sample company. The company is mature in the petrochemical and chemical plant building business. Design failure mode and effects piping analysis have been applied to evaluate and determine the risks involved in process failures. Solutions were designed to protect piping systems before failures could occur. Nine crucial topics of failure were evaluated in this research. Each topic yielded a risk priority number (RPN) higher than 125 points. A summary of how to prevent failures or problems is shown in Table 9.

Table 9: Summary of solutions for failure prevention of piping design

Trend of Failure or Mechanism	Solution
1A-S1-C1 No standard of alignment	Prepare a standard of installation based on customer specifications.
1C-S1-C1 Improper valve location	Prepare a standard of piping design and installation at proper position for ease of access.
2A-S1-C1 Wrong input for material specification	Prepare standard checklist of material before actual construction.
4A-S1-C1 Wrong input for pipe application	Prepare standard checklist for support to match actual site work and construction.

Failure mode and effects piping analysis (FMEPA) of late project transfer to customers significantly reduced problems. During the study of FMEPA on five ongoing projects, nine crucial failure topics were identified. Four topics had RPNs higher than 125. A committee then researched ways to determine solutions to the problems. The RPNs were reduced from an average score of 211 points to 75 points, representing a 64.4 percent reduction of problems.

4.2 The equations model was obtained from the multiple regression equation of the Rework cost / Total cost (Y) ratio.

The research revealed that coefficient X_5 yielded the highest value. This indicates that the Number of Pipe Lines-to-Rework cost ratio (X_5) affects the Rework cost / Total cost (Y). Therefore, managers should consider the weight value for optimization.

From equation Y, the value of the high secondary coefficient was 1.55. This indicates the Labor Cost-to-Total Cost ratio (X_7). Therefore, the piping design should improve the Number of Pipe Lines-to-Rework cost ratio.

5. Conclusion

This research shows the importance of applying operation risk management analysis and identifying potential failures by improving piping design reliability. Due to the difficulty of each piping design pattern, managers should increase the knowledge of technical staff and improve procedures before starting work. Therefore, employees can increase the number of pipes to make more quality in the model. Overall, working hours can be reduced.

6. Recommendations

The RPN cannot be used to measure the effectiveness of corrective actions. Further, the three risk factors (S, O and D) are difficult to precisely evaluate. There is a need to split risk factors to reduce their vagueness and add other risk factors in the determination of risk priority of failure modes. FMEA innovation can become a more powerful tool for safety and reliable analysis of systems, processes, designs and services in an organization when risk factors and risk priority methods are appropriate for the specific risk evaluation problems.

7. Contribution

Financial benefits are also derived from the design improvements that FMEA is expected to facilitate, including reduced warranty costs and increased sales through enhanced customer satisfaction. Conflicts and social unrest can cause costly delays to new projects and operations. Conflicts can also result in damage to a company's reputation. This depends on the company's responses to conflicts and the consequences or perceived consequences of its behavior and actions.

8. Future research

Using FMEA to identify the risk factors related to those sustainability metrics and integrating them into QFD to formulate the best sustainability strategy of service operation is still relatively scarce in the literature.

9. Management Implications

Management determines measures and then decides whether a risk is acceptable or not. Management needs to clarify which RPNs represent a critical level above which risk reducing measures need to be implemented as shown in Figure 8.

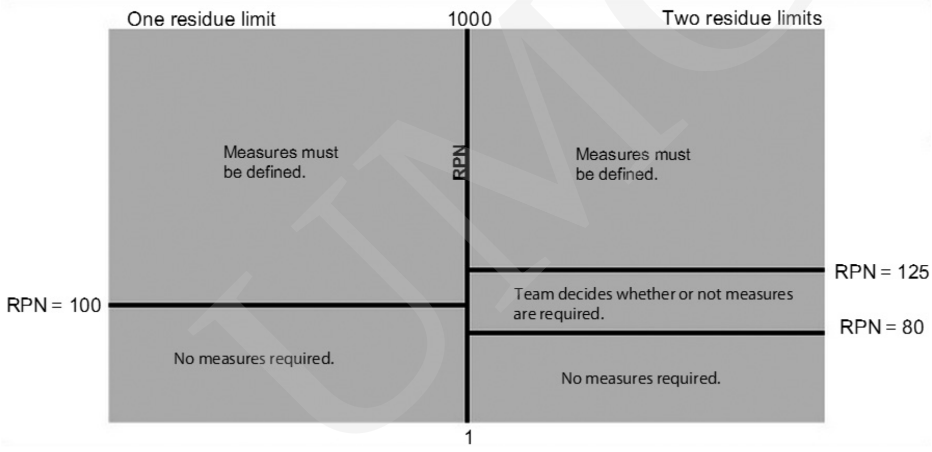


Figure 8: Management Implications for determining RPN limits

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Biographical Notes

Kamolwan Deeswasmongkol currently works as section chief of the piping and planning division at Toyo-Thai Corporation Public Company Limited (TTCL). She is a part time Ph.D. student in Industrial Engineering at the Faculty of Engineering at Kasetsart University in Thailand. She holds a Bachelor's degree in mechanical engineering and a Master's degree in engineering management. Her research interests include how to use game theory for strategic decisions.

Punnamee Sachakamol is a lecturer in the department of Industrial Engineering in the Faculty of Engineering at Kasetsart University. He received his B.A.Sc., M.A.Sc. and Ph.D. in Industrial System Engineering from the University of Regina in Canada. His research interests are optimization of production processes, ecological footprints, supply chain/value chain management, cool chain management, and pharmaceutical operation management. He has experience with numerous large-scale projects with private firms.