

Research on Risk-Based Piping Inspection Guideline System in the Petrochemical Industry

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Abstract

The purpose of this research is to create an expert risk-based piping system inspection model. The proposed system includes a risk-based piping inspection system and a piping inspection guideline system. The research procedure consists of three parts: the risk-based inspection model, the risk-based piping inspection model, and the piping inspection guideline system model. In this research procedure, a field plant visit is conducted to collect the related domestic information (Taiwan) and foreign standards and regulations for creating a strategic risk-based piping inspection and analysis system in accordance with the piping damage characteristics in the petrochemical industry. In accordance with various piping damage models and damage positions, petrochemical plants provide the optimal piping inspection planning tool for efficient piping risk prediction for enhancing plant operation safety.

Key Words: Risk-Based Inspection (RBI), Reliability-Centered Maintenance (RCM), Risk-Based Maintenance (RBM), Rational Unified Process (RUP)

1. Introduction

Piping damage accounts for the greatest statistical proportion of equipment damage in the petrochemical plant [18]. Piping is more complex than other equipment in the work field. The amount of piping is huge and only inspection specialists that are familiar with piping design are efficient at piping inspection planning efficiency. This has long been a blind spot in inspection planning. In Taiwan, because the piping inspection standard is not regulated, greater risk is incurred from piping damage [3]. Piping inspection strategies may reduce pip-

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ing risks, safety, and production efficiency. Efficient strategy application, well-developed planning, highly reliable implementation, professional analysis, and substantial improvement are all indispensable to piping inspection theory. This also includes safety management efficiency, quality, and cost control. Currently, in Taiwan, no standards or efficient inspection methods are regulated for piping safety operation and inspection periodicity. In foreign countries, planning for piping inspection in petrochemical plants is classified into three piping groups (American Petroleum Institute (API) 570) [4]. In recent years, internationally, a new trend involves determining the best inspection periodicity for related equipment based on the equipment risks. This might prevent accidents caused by insufficient equipment inspection and reduces the cost and resources in making too many inspections on too much equipment. A systematic planning strategy that takes the cost benefit into account is needed to enhance the safety of piping operations and optimize the reliability and productivity from the invested resources. In this study, a piping inspection plan for a petrochemical plant is proposed. This plan is based on the risk-based inspection concept (RBI). With the piping inspection database configured in accordance with different piping configurations and corrosion types, this software could allow petrochemical plant inspection specialists to make professional judgments and evaluations of the piping system status.

The final aim of this study is to classify the piping risks and provide a quantitative analysis method for the petrochemical industry for making improvements and reducing the risk caused by piping. In the research procedure, a plant field visit was conducted. The related information on domestic and foreign standards and regulations were utilized, including "Safety Codes for High Pressure Gases Labors", "Related Criterions of the Safety Codes for High Pressure Gases Labors", "Organization Management and Auto-Inspection Regulations for Labor Safety and Health", and "American Petroleum Institute, API 570." Risk-based inspection analysis is used to create a strategic analysis system for risk based piping inspection. In accordance with several piping damage models and damage positions, the related petrochemical plant personnel are given the optimal piping inspection planning tool.

2. Literature Review

2.1 Risk-Based Inspection (RBI)

In 1996, entrusted by APT, the DNV Corporation completed "API 581, Base Resource Document on Risk-Based Inspection, 1996 (Preliminary Draft)". The formal edition API 581 was released in 2000 [5]. The DNV decided to develop a quantitative risk based inspection software tool and new package software, "Orbit Onshore," was designed. This software can shape the information on any fluid with the characteristics of heat objects and access information on more than 1,500 materials from the DIPPR database. Institutions with the re-

lated technology include S-RBI, Dutch Shell Groups of Companies; AEA, UK; TWI, UK; ABS, USA; and API [12]. Risk-based inspection technology prioritizes inspection planning by computing the risk value and fully implementing the inspection plan. For a factory at work, a great proportion of the risk results from a small part of the equipment. RBI transfers the inspection and maintenance resources to the risky equipment items, giving appropriate attention to the low-risk equipment. RBI is quite beneficial at increasing the plant operating time, improving or at least maintaining the risk at the existing class [8, 9, 13, 17]. The RBI takes account of the conditions without risk restraining matters, and computes the failure probability and result for every event and condition. Risks are the result of failure probability and consequences that could be used to confirm which equipment items need inspection service the most. Full notice is taken of every corroded or failing machinery component. A proper and specific inspection plan is developed, including the suggested inspection method, category, and frequency. A fully integrated RBI system includes the inspection activity, inspection information collection, update, and continuous quality improvement. Risk analysis is the investigation of certain equipment in certain time periods. Because the procedure and system change with time, any risk investigation could only reflect the conditions at information collection time.

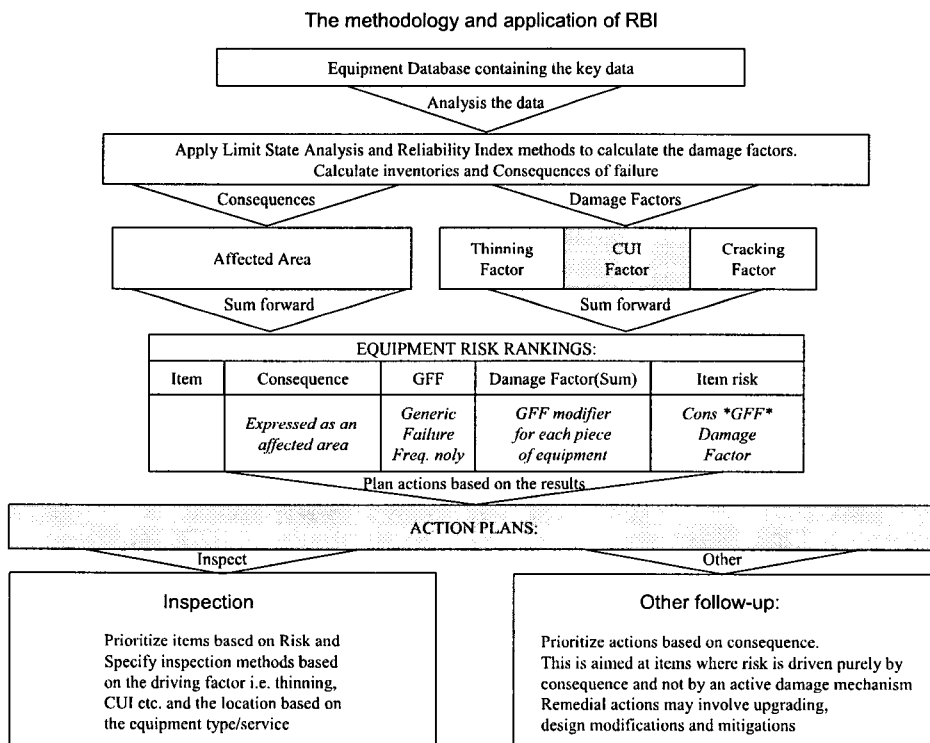


Figure 1. RBI Methodology and Application

Initially, although there might be a lack of necessary information in creating any system, risk-based inspection planning could be developed using currently accessible information (conservative presumptions could be used for the unknowns). As knowledge is acquired from the inspection improvements, the inspection plan, database, analysis uncertainty and risk computed result could be reduced. Figure 1 is the essential element input in conducting the quantitative RBI analysis [7]. Similar to any risk-based research, the two main quantitative RBI analysis elements are estimated according to the risk probability and consequence.

2.2 Risk-Based Maintenance (RBM)

In labor-intensive production, the equipment structure and components were quite simple. The problems such as equipment failure could be judged by sight. With the development of technology, equipment functions have become more complex. Maintenance specialists face complex work and logistic support uncertainty, with the risks for making mistakes increasing. Thus, timely reaction is demanded in maintenance and repair. As improper equipment parameters might cause defective product, it is very important to timely monitor the production parameters. As equipment failure might cause production loss, it is necessary to reduce the failure probability, enhance equipment reliability, increase equipment maintainability and shorten the maintenance time.

In an attempt to enhance the product competitiveness and achieve the business target of high quality and profit, evaluating the performance index has become more important. In confronting the impact of petrochemical industry and products competitiveness, decision makers must analyze the link between production equipment and maintenance management with information technology and key performance index. In strategic planning for reliability-centered maintenance (RCM), the equipment maintenance information is the most important aspect in the overall reliability, maintainability, and usability of the equipment [14]. The RCM procedure is centered on the failure model and consequence analysis. First, it is analyzed from the risk perspective of various equipment categories to determine the most important equipment (Equipment Class A) for creating the risk matrix diagram. The failure model is built according to the malfunctioning condition [10]. To effectively compute the system performance index and extend the RCM, a risk matrix analysis function is used with the quantitative analysis to compute the equipment reliability, maintainability, and usability as a reference for the maintenance specialists in making further decisions.

The low-risk systems are separated from the middle/high risk systems. After defining the scope of the system and equipment, FMEA (Failure Model Effect Analysis) [6] and risk analysis are conducted to identify the influence of failure on safety, environment, operation, and other aspects, and, then, the consequences are quantified for risk classification. For the middle/high risk equipment, maintenance strategy and relevant maintenance supporting meth-

ods shall be made for reducing the cause of failure. These maintenance methods are also optimized in accordance with the economic risk optimization [22, 23].

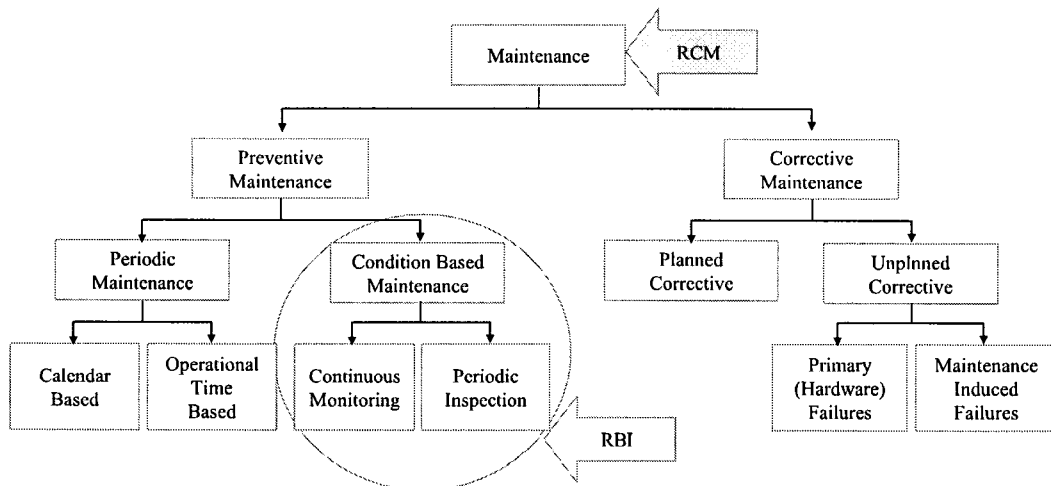


Figure 2. Strategies Planning of RBM

2.3 Rational Unified Process (RUP)

RUP is a software engineering process that provides a R&D unit, a precise method for assigning software development work and responsibility. The purpose is to ensure the creation of high quality software that meets the needs of the customers within the expected time under the allocated budget. Thus, RUP is also a process framework that could be adjusted or expanded according to the needs of the users. Project managers might resist this iterative method, as it seems to be an endless and uncontrollable action. In the rational unified process this iterative method is controllable. Every iteration is well arranged by its code, periodicity, and target [15]. The work and responsibility of the participants are clearly defined, and the scheduled progress is measured objectively. Hence, initially, it's already been decided to process the current project by this method. Although some amendment might appear iteratively, it's still controllable. In a project, there may be all sorts of demands in no matter hardware, software, or human resources. The RUP adopted in this project includes demand management. The RUP demand management is a systematic method for guiding, organizing, communicating, and managing the demands of a changeable software system and application program. RUP demand management is applied in this project to better control the complicated project efficiently; improve the software quality and customer satisfaction; reduce project cost and delay; and improve team communications. It can also allow the participants to participate in the initial stage of the processes, and ensure that their demands are fulfilled. Such a demand management builds up the common consensus between the agree-

ment and the demands of the stakeholders towards this project. These stakeholders include the users, customers, managers, designers, and testers.

3. Research Structure and System Design

The development of this research is divided into three parts. First, information collection and analysis is performed. Then, the system models are constructed. After the system models are installed, a system output evaluation report is presented. The description is as follows:

1. Risk-based inspection model

- (1) Information collection and analysis
- (2) Risk category framing
- (3) Failure consequences/failure probability model
- (4) Risk classification model
- (5) Risk priority model

2. The piping risk-based inspection model

- (1) Piping inspection database
- (2) Qualitative analysis model
- (3) Inspection method/technology planning project

3. The piping inspection guideline system model

- (1) The collection and sorting of basic piping information
- (2) Detailed specification of the piping inspection guideline system
- (3) Optimal piping inspection guideline system design analysis report

3.1 The Configuration of Risk-Based Inspection Model

The objective of this phase is to build a piping risk-based inspection guideline model for the petrochemical industry. The content includes collecting and analyzing the related domestic and international information as well as confirming the standard for verification [2, 20] (see Figure 3).

3.1.1 Information Collection Structure

From Figure 3, this phase stresses the collection and sifting of information. In this phase, the information collection structure for qualitative RBI analysis is clarified and the following information is collected and defined (see Figure 4):

1. Equipment Factor (EF): EF evaluates the quantity and type of the equipment, and esti-
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mates the possible risk range. This research involves the collection of various information, including the basic field information of piping and the related equipment components.

2. Damage Factor (DF): DF evaluates the risk of the existing or potential damage mechanism of the equipment that is to occur. The collection of the information includes piping related damages and corrosion types.
3. Process Factor (PF): PF evaluates the potential or abnormal operation condition that might cause uncontrollable events. The collection of information includes piping related processes such as fluid and control valve as well as the qualitative information of operation safety.
4. Inspection Factor (IF): IF evaluates the validity of the inspection planning for equipment damage. The collection of information includes the inspection methods such as visual or magnetic particle inspection.
5. Condition Factor (CF): CF evaluates the validity of plant maintenance and cleanliness. The collection of information includes the operation related information such as operation temperature and pressure.

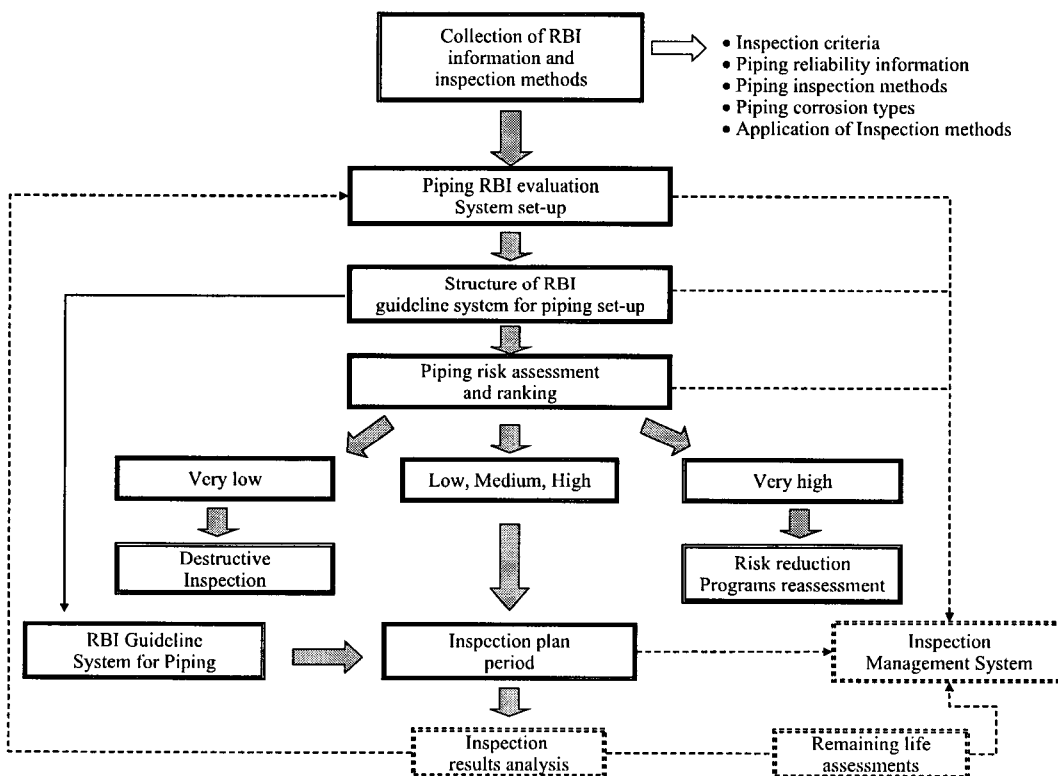


Figure 3. Structure of the piping guideline system

6. Mechanical Design Factor (MDF): MDF evaluates certain design problems of the equipment. The collection of information includes all sorts of equipment design information such as designed temperature and pressure.

The foregoing information is for constructing a qualitative risk-based inspection system that meets international standards and the needs of the Taiwan petrochemical industry. This research takes many foreign standards as references; the statutory Taiwan industrial safety standards as secondary information; and the field information collected from visiting Taiwan petrochemical plants as primarily information. The representative factor selected and the results of the information collected could meet the domestic needs and international standards. Information concerning safety personnel and management is also collected from local plant interview for follow-up research and development.

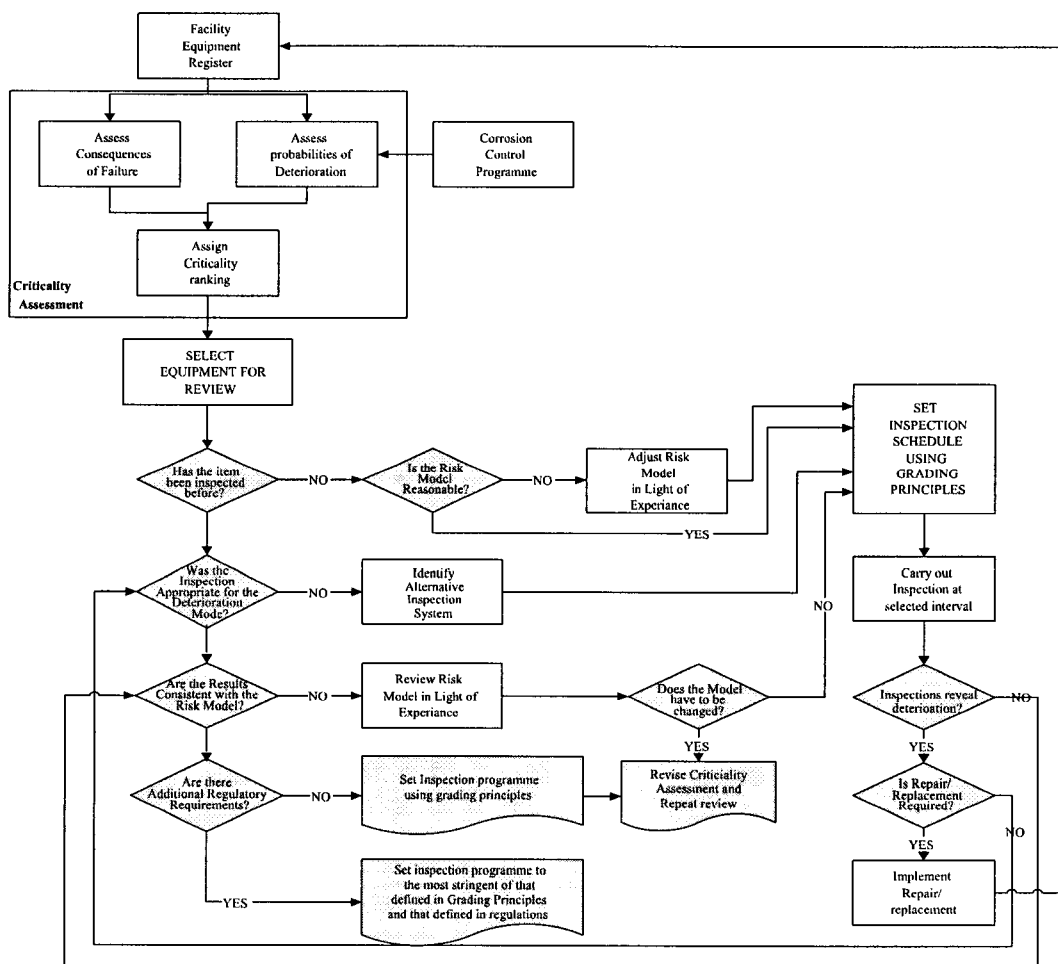


Figure 4. Qualitative RBI Model System

3.1.2 Risk Computing Database

In the typical risk-based inspection research, the configuration and collection of information is grounded on equipment. The risk types and probability are categorized and ranked for selecting assessment equipment and deleting non-risk and micro-risk items. The actions taken on the targeted equipment are explored for determining the necessity in adjusting the standard model, and the adjustment direction. In the API 581 report, 2000 Edition, the assessment model of the accident probability and failure consequences of the select unit based on the chemical matters' nature is clearly defined. According to the previous analytic reports, failure consequences could be divided into explosion and poison gas risk. API 581 categorized explosion risk to the category of damage consequences as the consequence of explosion incident often damages the equipment itself. The poison gas risk is categorized by the health consequence. Accordingly, the entire qualitative analysis model could be divided into three parts for classifying piping risks: Part A, Likelihood Factor and Damage Consequences Factor; Part B, Damage Consequence Category; Part C, Health Consequence Category and Piping Inspection Consequences [5] (see Figure 5).

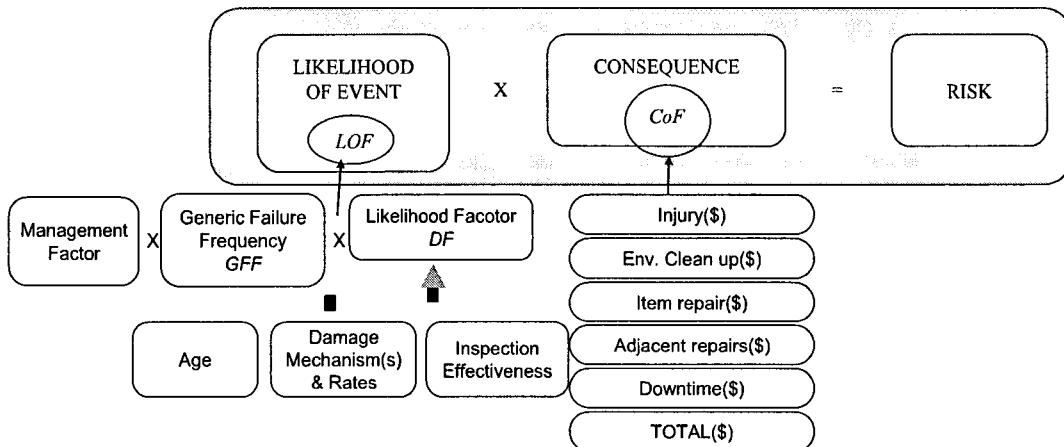


Figure 5. Risk Analysis Model

The risk analysis model is based on confirming the corrosion type and differentiating the risk consequences to understand all of the equipment in the process. This includes selecting the inspection range and inspection methods. This information is forwarded to the control center for inspection planning. These information resources are also used for inspection prioritization and corrosion management. The risk management information is saved and maintained with the equipment. The applied information is regularly reviewed and verified against the target equipment [11]. The system analysis content in this research is constructed in accordance with the international standards of API 581 and local factors as well as the needs

of the domestic industries by taking qualitative method as the research subject [1, 2, 5]. In the qualitative method, it's mainly focused on the inspection of failure probability and failure consequences [5] (see Figure 6). Failure probability includes the quantity of the equipment affected, the possible damage mechanism such as general corrosion, weary cracks, and high-temperature deterioration, the inappropriateness of the inspection methods, and process/design factors. The failure consequence focuses mainly on two categories; fire/explosion risk and gas poison risk. The former takes account of the chemical substances physical nature, leakage and release, release types, protection, etc. The latter takes into account the amount of toxic matter, spreading range, population density, isolation, etc. The database is defined and categorized accordingly.

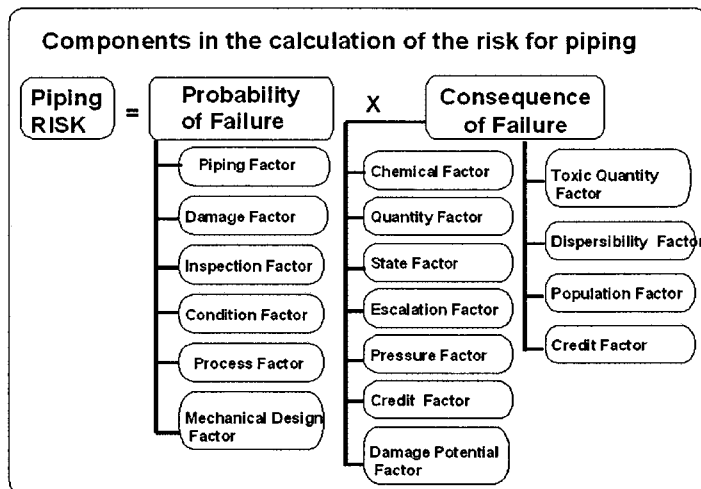


Figure 6. Qualitative RBI for Piping

Risks are classified by the damage probability distribution and consequences (See Figure 7, Distribution of RBI Classification for Piping). Among which, damage probability 1, 2, 3, 4, and 5 represents the damage probability from 1 to 5 in an increasing order, respectively. The damage consequence A, B, C, D, and D represents the consequence of damage consequence from A to E in an increasing order for clearly taking hold of the distribution of the piping risks [7, 10].

3.2 The Risk-based Piping Inspection Model

The failure category of piping affects the judging logic of piping inspection method. The main judging and consequence factors are corrosion category, inspection method, and inspection position in order [1, 20]. The sorting of these information resources helps to configure the database of Root of Cause Factor Analysis (RCFA) for piping risk inspection.

After appropriate sifting, suggestions for the optimal non-destructive inspection method are proposed as Figure 8 [5].

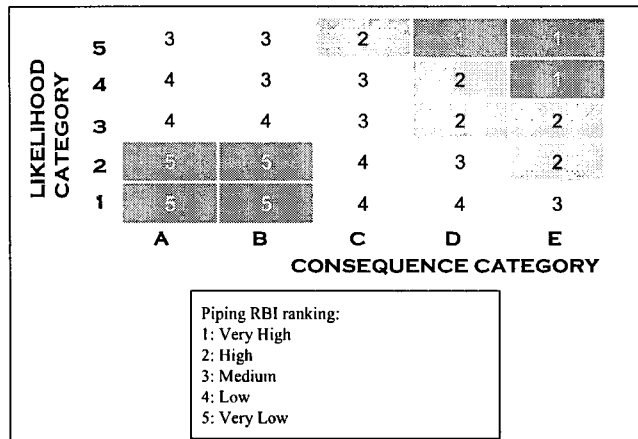


Figure 7. Distribution of RBI Classification for Piping

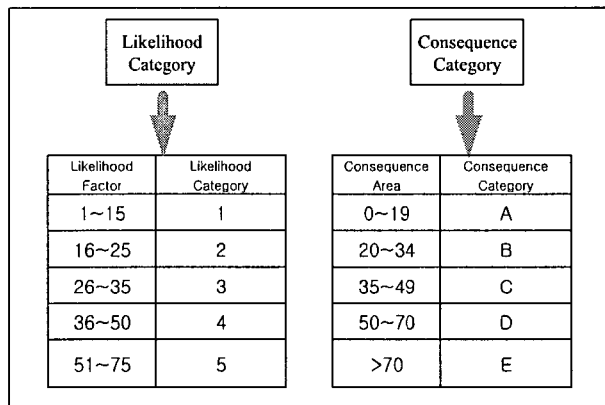


Figure 8. The Root of Cause Factor Analysis

3.2.1 Piping Inspection Database

Different corrosion types and various piping positions and operating conditions shall be inspected using different methods for detecting flaws. These inspection methods shall also be implemented by qualified non-destructive inspector under precise inspection procedure. Different inspection method has its applicable scope, limitation, advantages, and disadvantages. Ultrasonic thickness gauge is applicable to general corrosion environment, and compensation is needed in high temperature environment. Liquid penetration inspection is applicable to surface flaw detection but unsuitable for porous material, and better surface cleanliness is required. The inspection method of the on-stream inspection which is frequently applied re-

cently also has its limitations. For instance, although Pulsed Eddy Current (PEC) can measure the thickness of the object through the thermal insulation material, it is only applicable to carbon steel or low-alloy steel material. There is also a limitation in the thermal insulation thickness as the metal loss of the inspected carbon head is taken as the general corrosion proportion. Therefore, the measurement error in partial corrosion and pitting is larger. Besides partial corrosion and pitting, PEC is also inapplicable to crack inspection. In the on-stream inspection, the inspection method for the pipe corroded at support also differs based on the needs of size, fluid, and cost.

Currently, more than 20 non-destructive inspection methods are used in the industrial field. Every method has its applicable scope and limitation. Thus, it is essential for a successful inspection-planning specialist to consider the inspection methods, efficiency, probability of detection (POD), personnel, and cost. In the judging logic of piping inspection, the selection and definition of the inspection position plays a very important role in piping risk inspection. In the past, as "possible" inspection data is often acquired from the expert or experienced specialist in the plant field by "guessing" the inspection position and "testing" with different inspection methods for making maintenance, replacement, or tracing, it required more cost for down time and assessment error (Type I and Type II). Traditionally, in general, ultrasonic thickness measurement or visual inspections are taken as inspection strategies and then planned and implemented with "experience." However, piping errors might differ because of damage type, operation condition, environment, and the material used. Although part of the problems could be found by the selective inspection strategy derived from experience and the traditional inspection technique, most of the potential risks could not be detected. Only by understanding the possible problems in advance for determining the appropriate inspection technique could the problems be solved.

In positioning the piping inspection, the piping and instrumentation diagram (P&ID) of the inspection plants must be prioritized from the top down for defining different inspection areas. Generally, the interval between two control values which could be disconnected independently is taken as an inspection interval. Then, different inspection positions are positioned as inspection points based on the piping engineering standard and API 581, and also coded for collecting physical and chemical information for further management and tracing. Concerning the current personnel training and deployment, it's rather difficult and inefficient to request the working staff to be equipped with both maintenance operation capability and overall expert judgment knowledge at the same time. At this time, a well-designed guideline system can undertake the task of recording the knowledge and proposing professional suggestions for providing the management the best inspection method and timing that meets the plant benefit and work efficiency. The system design in work guidance shall start from equipment classification and positioning. The most direct method is to refer to the corrosion loop information for selecting inspection methods according to different piping types, possible

corrosion category, and inspection technique so as to acquire the best and steadiest probability of detection. With guideline system, the users do not have to hastily search for the applicability and efficiency of the inspection methods for making occasional decision, so that the probability of successful inspections could be maintained in certain standard. However, the system itself must be equipped with extension and amendment mechanism to meet the needs of different time and space to ensure the growth of the expert system.

3.2.2 Qualitative Analysis Model/Inspection Method/Technical Planning

The purpose of defining the failure probability model lies in providing different process units an amendment mechanism for coping with the consequences caused by different operating and management conditions. This model is divided into failure frequency and specific field adjustment factors, and further divided into equipment and management system factors:

1. Failure frequency: Generally, the content of the failure frequency database is a record about the history of equipment failure. These records could be produced from different sources, including computer application software or management lists. Mostly, failure frequency records are made according to different equipment types and piping diameters. Suggested analysis categorization is provided in API 581 as Figure 9 [5].

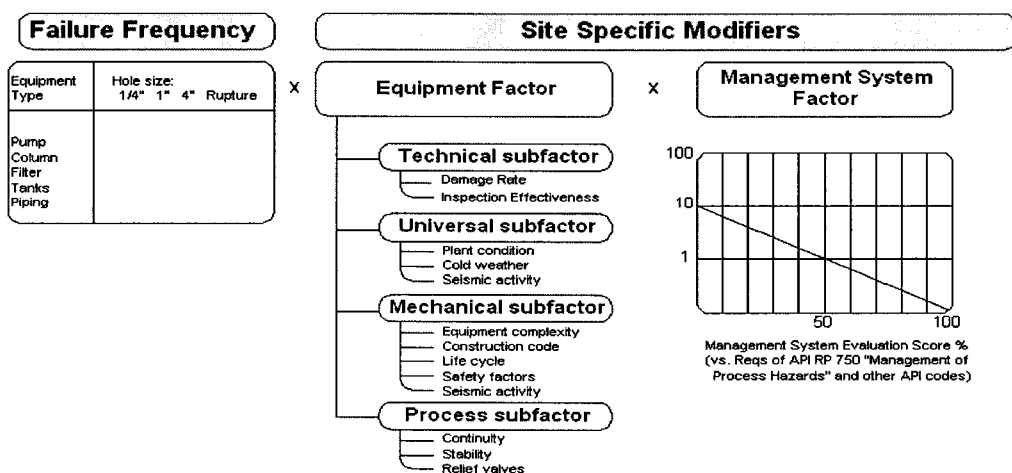


Figure 9. RBI Quantified Risk Analysis

2. Specific field adjustment factor: Different work fields may have different consequences on risk failure probability. In API 581, such adjustment factor is divided into two parts, equipment factor and management system factor.
3. Equipment factor: The equipment adjustment factors define the specific conditions that cause main consequences on equipment failure frequency. These conditions are divided

into four sub-factors:

- (1) Technical sub-factor: It checks the construction material, environment, and inspection planning, and focus on damage rate and benefits.
 - (2) Overall sub-factor: It indicates all the elements that affect the entire equipment, and the focus is on observing the plant condition, weather, and the geographical activity such as earthquake.
 - (3) Mechanical sub-factor: It indicates the differences among the equipment items, and focuses on observing the consequences of the complexity, coding, life cycle, safety, and vibration of the equipment.
 - (4) Procedure sub-factor: It is the procedure that affects the integrity of the equipment, and it's focused on observing the continuity and stability.
4. Management system factor: The implementation of work safety management in a corporation may affect the equipment unity to a certain extent. The process of RBI includes the tool for evaluating the facilities management system to further understand the management system that has direct influence on the failure frequency of the equipment. The entire evaluation process includes a series of interviews related to inspection, maintenance, production process, and work safety staff.

3.2.3 Risk Analysis and Model Technical Planning

For business management, risk could hardly be absolutely eliminated. However, most of the risks can be avoided by the implementation of effective norm. The top priority of an enterprise is to survive. In considering about how to profit from the business operation, an enterprise must also take account of preventing loss and confronting unexpected risk. According to the experiences of experts, in typical petrochemical industry, 80% of the loss caused by operation equipment could be reduced by inspection. The purpose of inspection, just as the health examination of human body, is to identify and treat or monitor the problems. As for the timing of inspection, generally, it depends on the current usage as well as the frequency and seriousness of the problems that might occur in the future. Basically, a large inspection quantity does not guarantee high safety. The key to figure out problems lies in understanding the types of the possible problems and take effective inspection method to work out appropriate inspection strategies. The risk-based inspection guideline system for piping in this study is a system that can analyze and display the effectiveness of risk-based inspection. By means of this, the plant does not have to stop production for making inspection as the traditional way, but to operate properly with efficient way in the proper time. With the increase of the accumulated usage time year by year, the frequency of equipment maintenance also becomes higher. A systematic method which is cost-effectiveness with the inspection resources invested where necessary is needed for enhancing the operation safety and achieving the best reliability and productivity to gain the greatest benefit from the re-

source invested. In making the strategy for proper inspection or related activities/effectiveness, it's a prerequisite to accumulate the necessary information for the manager. As information accumulated with time, an efficient and well-designed management tool is highly desired. Especially, in the e-century, most of the information is accessible from the Internet. However, does this huge mass of information represent knowledge? Similarly, could huge mass of data really represent the actual conditions? If there is a lack of a professional knowledge database behind information management to analyze and integrate the information into useful suggestion while managing it, after all, data would be nothing but numbers.

With the analysis of this research, it's found that the systematization and automation of the risk evaluation for equipment could be extended. For instance, the inspection software, ULTRAPIPE, which is currently quite popular domestically and internationally could only be used for RBI analysis and report output, not for the systematic information recording of the selected equipment or the work assignment and recording of the inspection work. Thus, it's considered that the functions of an effective inspection management software must include the followings:

1. The function of managing static piping information: For searching the latest basic information of piping, design information, material information, inspection history, inspection basis, procedure planning, related apparatus, plant material, unit of the person in charge, or cost; for further linking efficiently to the inspection procedure, document related to the piping, graphic file, and defection pictures; or for monitoring the information, etc.
2. The function of managing inspection operation: For making and managing the inspection work lists, including work application, work evaluation and planning, the delegation of inspector or contractor for undertaking the inspection work, the recording of inspection data, auto-tracing of inspection work, etc.
3. Analysis function of piping inspection: Effective standard database shall be equipped with, e.g., the computing equation and material list of ASME, API, and BS, for computing the minimum design and operation thickness of the equipment so as to assess the corrosion rate, remaining life, and best inspection timing.
4. Reports management function: Reports could at least be divided into standard report, calculation report and statutory reports. Among which, the standard reports mainly include inspection list, fixed equipment list, inspection scheduling list, major repairs plan, inspection requirement list, etc. The calculation reports are for providing corrosion analysis report, corrosion tendency chart, remaining life calculation, suggested inspection timing, etc. As for the statutory report, it's mainly for providing the inspection report required by the local statute and for on-line searching.

The key points of general piping inspection strategies lie in piping risk control, safety en-

hancement, and production efficiency. From efficient strategic application, well-designed planning, reliable execution method, professional analysis to substantial improvement, all of these elements are indispensable to the piping inspection philosophy. The main purposes of piping inspection are to take hold of the timing, the position, and the methods for making inspections. This involves not only safety, management, efficiency, and quality, but also the control of cost. In this research, the best piping inspection strategies in petrochemical plants involve the collection of basic piping information, the application of risk-based inspection strategies, the theory and application of piping life assessment, the selection of proper inspection method to the description of effective piping inspection management system. With the development and use of integrated piping inspection guideline system, it can provide the related business operators or inspectors with a valuable asset of effective piping inspection strategies and work safety practices to allow our petrochemical industry to extend and enhance the capability with sufficient work safety preparation.

3.3 Model of Piping Inspection Guideline System

In this research, a regular, systematic method provided by the rational unified process (RUP) is adopted for designing, developing and testing the system. The RUP template is also adopted for describing the structure from various perspectives. At the same time, the specific activities involved in the RUP design process components are taken as the reference to find out the limitation and important elements of the structure of this project, and several main technical risks are also taken into consideration in the project planning. These reusable components serve as the solutions to the similar problems for enhancing the overall productivity and quality of this project [16]. The presentation of model can help most project participants understand this project. The visual modeling better impels the project participants to become devoted to this project from various dimensions. Rational unified process is related to the development and maintenance of the developed system models in a great part. Using these models helps us to understand and clarify the problems and also provides the related solutions for the actual conditions to help us effectively control this complicated system. The Unified Modeling Language (UML) graphics can visualize, specify, structure, and document the work results of software-intensive system. UML allows us to create the system blueprint in a standard way [15, 21].

In the development of this expert system, no participants are assigned to be responsible for quality control because quality shall not be the duty of just a few participants. Quality is the responsibility of all project members. In developing the software, we especially stress the quality of two parts, products and process. In the development process, iterative amendment of product content occurs quite often. This is for flexibly planning and implementing the development work and also for allowing the change of requirements. The iterative development is focused on the important issues of tracing change and synchronizing artifacts. In

an attempt to meet the need of project development, change management must administer request changes, design and practice systematically. Change management also includes tracing defects, misunderstanding, and project agreement as well as the specific artifact and version related to these important activities. The development of this software system is based on engineering theory and users' needs. The first half this report is stressed on the engineering theory. In converting from theoretical foundation to practical system, we must add the practical experience of related users to better meet the actual needs. Viewing from engineering theory and users' needs, the purposes of this software system are as follows:

1. Provide a convenient piping login tool for saving the factors related to piping and inspection.
2. Provide a risk evaluation method that satisfies API 581 for classifying the piping risk with this software.
3. Allow the users to automatically record various inspection dates and the maximum thickness and corrosion rate, and calculate the remaining life.
4. Provide the expert inspection system for the users to select the proper inspection methods according to the suggestions.
5. Provide piping reports, and the information for surveying the basic information, risk classification and risk distribution of piping.
6. Provide an easy-to-use Chinese user interface.
7. Provide a software tool with extensible and open structure which is easy to install.

In considering the foregoing requirements, JAVA language could be taken as the best development tool with off-the-shelf, stable, and portable platform [19]. In terms of function, as this system takes easy-to-use as the top priority, it's designed into a single machine which could be used by many people in turns. By linking to the same database, it could also be used by several machines. The features of the system are as the followings:

1. Easy programming without long-term training required to meet the needs of system maintenance.
 2. Object-oriented programming that stresses information and interface techniques.
 3. Well-designed and distributive libraries for extending the functions with ready-made components.
 4. Highly stabile developed system.
 5. Safety methods for protecting against virus invasion and destruction.
 6. The objects created by the compiler must be in object file format so the codes could be processed in many processors with portability.
 7. Fast program loading and linking to save the loading time.
 8. The conversion of original objects or meta objects to machine codes must be effective.
 9. Quick response capability and real-time execution.
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3.3.1 System Model Analysis

Object-oriented is adopted in this software system for system analysis, design, and development. From users' requirements interviews to system designing, prototyping, and testing, after different phases of objects extraction and characterization, the objects that meet the needs of users are designed and sufficient detailed design information are provided for the program developers as reference. The development of this software refers to Rational Unified Process (RUP), and this preliminary research is defined as the first iteration of software development. Although there is only one iteration, based on the RUP development, the analysis, design, development, testing, and feedback of every iteration are quite complete. Thus, in addition to converting the files from the requirement dimension to design dimension, the completion of preliminary development project can also create a prototype system for verifying the design requirement direction and provide a start condition for the coming iteration. The main users of this system are divided into general users, piping types experts, piping risk evaluation experts, inspection experts, and system managers. The related information and functions of these roles are shown in the Table 1. The main purpose of the software system is to provide the general users with a users' interface which is readily understandable, and have the functions enabled quickly in the integrated screen structure. The exemplification of the operations centered on general users is designed to be the function or screen relation of this system.

Table 1. Categories and Functions for System Users

Users Categories	Related Information and Functions
General users	<ol style="list-style-type: none"> 1. Main users of the software 2. Input the basic piping information 3. Input the thickness inspection data of piping position
Piping types experts	Assist in dividing the piping into different positions and provide the technical specification information of piping
Piping risk evaluation experts	Proceed the Q&A for the risk evaluation of piping
Inspection experts	Select the appropriate piping inspection method
System managers	Manage the system parameters, installation, and maintenance

The main purpose of this software system is to provide the general users with a users' interface which is readily understandable, and have the functions enabled quickly in the integrated screen structure. The exemplification of the operations centered on general users is designed to be the function or screen relation of this system. In general, users have four options after entering the system: Piping Browsing, Piping Selection, Piping Amendment, and Quit, as shown in Figure 10.

1. Piping Browsing

- (1) In using the function of “Piping Browsing”, the user can select one or more than one piping items as needed for viewing the related information including the piping and piping position.
- (2) The users can see the piping information including contents, maximum design pressure, maximum design temperature, failure probability class, failure consequences class, risk class, risk factor, remaining life, and next inspection date. As for the piping position information, the users can see the information of least permitted thickness, measured thickness, measured date, corrosion percentage, remaining life, etc.
- (3) Aside from browsing the piping, if there is any change in the field value of the input piping information, it can be changed under this screen, and the changed piping information can be saved, as shown in Figure 10.

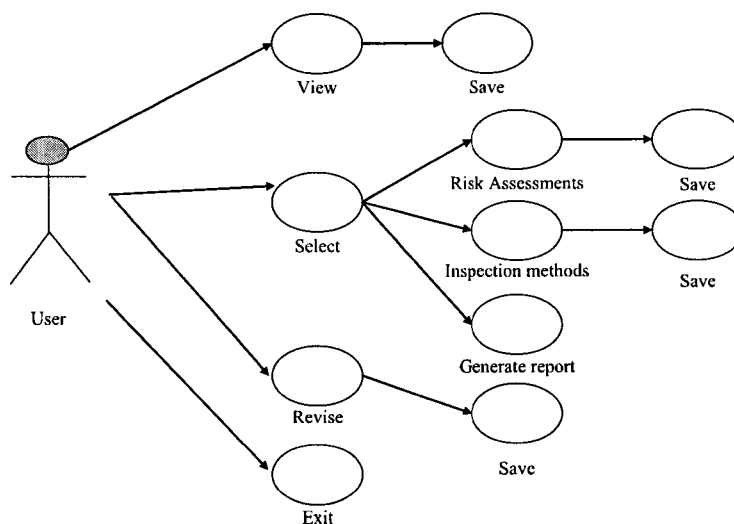


Figure 10. Four Actions of the User after Entering this

2. Piping Selection

For making detailed inspection, risk evaluation, inspection method setting, or checklist report for certain or several piping, the user can use the “Piping Selection” function. The method for selecting piping is quite simple. Check the selection box in the left side of the opened piping, and the buttons of “Risk Evaluation”, “Inspection Method”, and “Checklist Report” will appear on the left side of the screen. For making risk evaluation, setting inspection method, or producing checklist reports for certain or several piping, just press these buttons, then, the functions could be executed.

- (1) Risk Evaluation: Click “Risk Evaluation” to enter the operation screen of risk evalua-

tion. In using the function of risk evaluation, the user can make piping evaluation or quit evaluation to return to the former main page, as shown in Figure 11. In making evaluation, the user can move up and down to different piping or move right and left on a certain piping to make different piping evaluations. At the top of the screen are the evaluation conditions of different piping; the lower left, the options of the said evaluation item; and the lower right, the evaluation description. Click the mouse for evaluation, and the related corresponding relationship of scores and the summing of evaluation factors will be calculated by the system automatically. After the evaluation of an item is completed, the user can choose to continue the evaluation of the next item or move to another pipe for other evaluation. In addition, if the “Auto Forward” option at the bottom of the screen is clicked, after an evaluation item of a certain piping is completed, it will move to the next evaluation item automatically to make it more convenient for the user.

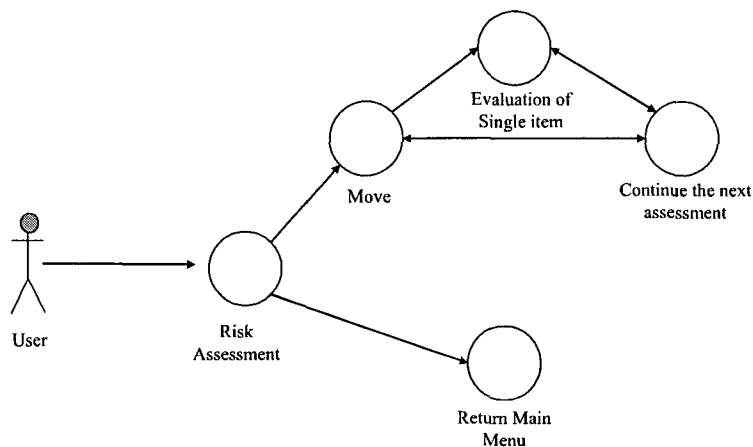


Figure 11. Functional Design of Piping Selection for Risk Evaluation

- (2) **Inspection Method:** The user can click “Auto Add Method” to add new inspection method to a certain piping, or press “Expert System Suggestions” to choose the built-in inspection methods in the system for the pre-set methods provided for different piping positions and problem types. Just check the box of “Choose” on the left side of the inspection method and click “Add”, then the said inspection method will be added to the piping. Click “Close”, and it will go back to the screen of inspection method setting, as shown in Figure 12. In the screen of “Inspection Method Setting”, the user can move to different piping for browsing the related inspection method check-lists of the piping, including data source, inspection part, problem type, and suitable inspection method.

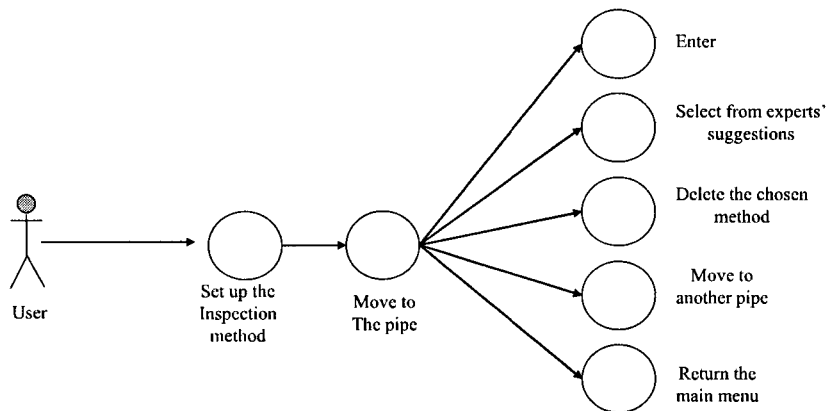


Figure 12. Functional Design of Piping Selection for Inspection Methods

- (3) Checklist Reports: The options of “Checklist Report” provide three different reports for the user to evaluate certain or several piping. These three reports are “Piping Checklist Report”, “Risk Checklist Report”, and “Risk Matrix Report.”

3. Piping Amendment

After browsing the piping, in addition to changing the related information of the piping and piping position, the user can add additional piping or piping positions. To add other piping, click “Add Piping” at the top of the screen. For adding piping positions, please choose the piping for adding piping positions, and click “Add Positions” at the right side of the screen, as shown in Figure 13.

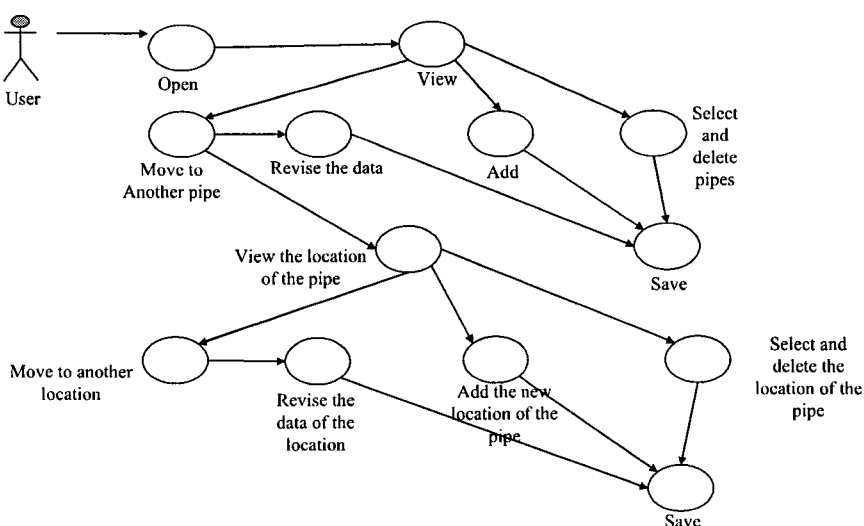


Figure 13. Functional Design of Piping Selection for Information Amendment

4. "Quit"

When all the jobs scheduled to be done on this system are completed, click "Quit" to quit this software system.

3.3.2 Object Model Analysis

This software system supports the structure and modeling requirements for analyzing all sorts of information. With the functional analysis the model and category design requirements are met in the design phase. According to vocabulary analysis, the information of this system are divided into piping information, inspection data and time, risk evaluation standards, risk evaluation information of piping, inspection method standards, information of piping inspection method, and information of system management. In system design, the following requirements must be met:

1. Basic Piping Information (see Figure 14)

- (1) The piping must be clearly identifiable by piping codes.
- (2) Be able to input the basic information such as piping content, temperature, pressure, etc.
- (3) Manage the piping as a file, and manage several piping at the same time.

The screenshot displays a software interface with the following components:

- Top Menu Bar:** Includes options like '数据', '帮助', '退出', '打印', '清除', '删除', '新增', '修改', '删除', '打印', '清除', '删除'.
- Table 1 (Left):** A table with columns: '管段号', '管段名称', '内容物', '危险等级', '最大设计压力', '下次检查日期'. It lists items like AG-1001, AG-1002, AG-1003, F-101, F-103, F-122.
- Table 2 (Right):** A table with columns: '管段号', '管段名称', '直径', '壁厚', '最大设计压力', '下次检查日期'. It lists items like AG-1001-2, AG-1001-3.
- Form Fields (Bottom):**
 - 管段信息:** Fields for '内容物' (二氯化碳), '危险等级' (低), '最大设计压力' (20.2), '最大设计温度' (20.5), '失效概率等级' (B), '失效概率等级' (B), '腐蚀等级' (Low), '腐蚀等级' (B), '制造年份' (2002/04/02), '下次检查日期' (2002/12/31).
 - 管段位置信息:** Fields for '最低允许厚度 (mm)' (12.0), '最大厚度 (mm)' (12.8), '量测日 (yyyy/mm/dd)' (2002/1/1), '腐蚀率 (mm/年)' (0.5), '制造年份' (2003/06/08).

Figure 14. Design of Main Page Checklist Information and Control

2. Inspection data and time for the piping

- (1) The specifications and limits of the piping may differ by the diameter. Therefore, it is necessary to segment the piping and input different inspection data of different

segments, including diameter, inspection time, piping wall thickness, tolerable thickness, etc.

- (2) Be able to calculate the estimate life of different piping segments automatically.
- (3) Be able to set the shortest estimate life of a piping segment as the estimate life of the entire length of piping.

3. Risk evaluation standards for piping

- (1) Evaluation shall be conducted in accordance with the standards of API 581 risk evaluation standards.
- (2) The risk evaluation results shall be able to be converted to risk factor for calculating the next piping inspection date.

4. Information of piping risk evaluation (see Figure 15)

- (1) Risk evaluation shall be able to be conducted on several piping at the same time.
- (2) Risk evaluation results and inspection data determine the next inspection date at the same time. However, in general, either the inspection data might be obtained first, or the risk evaluation conducted first. Therefore, the system shall be able to deal with these two conditions.
- (3) In risk evaluation Q&A, the answer to the question and the points earned shall be shown at the same time.

管線編號	EF	DF1	DF2	DF3	DF4	DF5	DF6	DF7	DF8	DF
AG-1001	5	0	0	4	3	3	3	2	1	
AG-1002	0	0	0	0	0	0	0	0	0	
AG-1003	0	0	0	0	0	0	0	0	0	

評估項目說明

詳情

由此項評估開始是根據標準評估。

DF1:

是否存在已知的損壞機制，會造成破損或低合金鋼的腐蝕？

自動重溫

回主畫面

Figure 15. Piping Risk Evaluation Design

5. Inspection method standards

- (1) The standards of inspection methods shall differ by the piping positions and problem types.
- (2) The inspection method standards shall be able to display the advantages and disadvantages for reminding the user in making selection.
- (3) The inspection method standards shall be able to be added or adjusted by experts.
- (4) The inspection method standards might have fixed coding regulations.

6. Piping inspection method information (see Figure 16)

- (1) Be able to inspect the proper inspection method for different piping.
- (2) Be able to choose from the inspection methods suggested by experts for different piping.
- (3) Be able to allow the user to add proper self-designed inspection method.
- (4) Be able to add the similar inspection methods continuously or imitate the same inspection part or problem type.

檢查方法專家系統

檢測方法加入管線編號: A-C-1001

管線部位	問題型態	選取	代號	檢查方法	備註
伸縮管	腐蝕	<input checked="" type="checkbox"/>	DM	尺寸檢測	優點：簡單、便宜、人員要求較低缺點：1. 只能...
彎焊層	保溫下腐蝕	<input checked="" type="checkbox"/>	MT	磁粉探傷	優點：簡單、便宜、人員要求較低缺點：1. 需要...
法蘭	氣蝕裂縫	<input type="checkbox"/>	PT	液滲檢查	優點：簡單、便宜、人員要求較低缺點：1. 表面...
小插管	內部腐蝕	<input type="checkbox"/>	R	金相檢測	優點：可了解材料劣化情況缺點：1. 費時...
管塞	洩漏	<input type="checkbox"/>	UT	超音波檢測	優點：較便宜缺點：1. 校正要求嚴格 2. 定...
管壁	材料確認				
焊接	機械損壞				
	外部管線腐蝕				
	表面裂縫				

加入 重選 關閉

Figure 16. Selection and Control of Piping Inspection Methods

7. System management information (see Figure 17)

- (1) Be able to classify the functions for the users with different access levels.
- (2) Be able to change the system parameter such as defining the title of the report.
- (3) The system can be installed and operated easily.
- (4) The system interface shall be consistent to make it easy for learning.
- (5) The system must be able to define different user accounts and passwords.

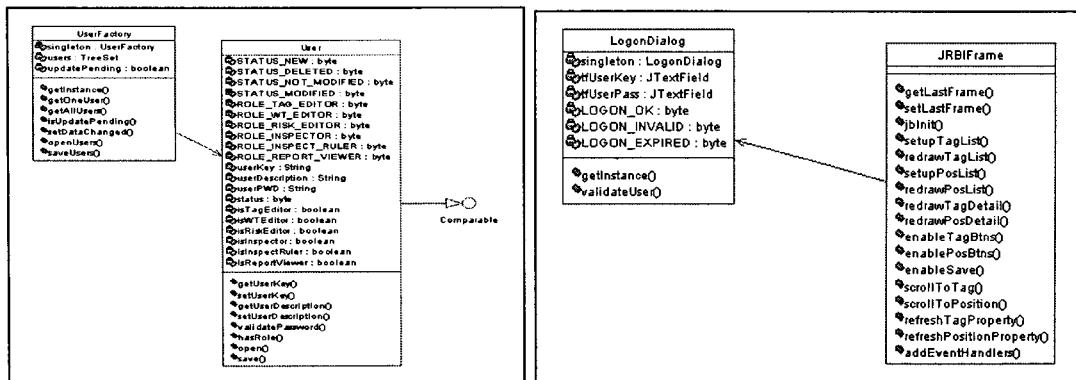


Figure 17. User's Access Role/Account Management Category Design

8. Report management information (see Figure 18)

- (1) At a minimum, the checklist of basic piping information checklist and report of risk evaluation result shall be provided.
- (2) The report form must be able to be changed by the user for presenting the same information in different forms.
- (3) The report produced by the system shall be able to be kept in file.

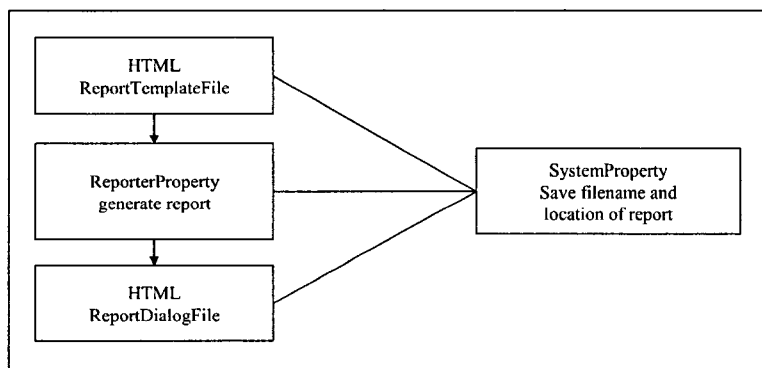


Figure 18. Mechanism for Report

4. Conclusions

The objectives of RBI research analysis are managing, predicting, and inspecting damage risk. The RBI analysis is a powerful tool for checking risk and judging risk management. The analysis result can be taken as a crucial element of overall inspection/maintenance planning. In an attempt to make the research on RBI effectiveness, it's essential to better

understand the difference between this method (RBI) and the traditional method. In the traditional method, inner inspection of equipment is performed once every few years. Such a method requires less management control as it's but execution. However, every interruption for inspection costs a great deal. The RBI activities are more centralized, and the production operation does not necessarily have to be halted for inner inspection. However, more efforts are definitely needed for doing the right thing at the right time. At times, the procedure and work practices must be changed to develop an auditable management system. Thus, as this method is basically an information analysis, the entire database must be complete and reliable. From the static information change in the operation stage in designing to the information collected in the inspection stage, all the information is very important. Although extra efforts must be extended to manage this system, in comparing with the traditional analysis, it's obviously much more effective.

Domestically, although the RBI application was promoted in several corporations for years, for instance, Shell Co., and Chinese Petroleum Corp., and risks were actually reduced. This project is still in the initial stage. In complying with the regulations, domestically, pressure vessels must be halted for inspection every year. According to the statistic, the expense on this exceeds 50 billion NT dollars. However, it could hardly really take control of the risky equipment. In "Guide to the Alternatives for Prolonging Risky Equipment Inspection" [1], concerning the criteria of the alternatives for prolonging the open inspection of pressure vessels in domestic petrochemical plants. This is stipulated by the Research Institute of Labor Safety & Health, Council of Labor Affairs, Executive Yuan, Taiwan. The RBI analysis result and inspection planning can be taken as the main reference for the application of prolonging open inspection. The need for RBI and inspection planning in Taiwan will be in high demand in the future. However, the piping information is not as complete as that of the equipment. Provided quantitative RBI analysis is conducted, it might be less accurate because of having too many presumptions. Moreover, as many experts must participate in the analyzing process, it's too complicated and costly to be promoted domestically. As for semi-quantitative RBI, as it's based on qualitative evaluation, and the actual corrosion percentage of the inspection result is taken for amending the subjective judgment of quantitative analysis. This has long been adopted by the petrochemical plants. Owing to the complexity of piping and the difficulty in acquiring information, the use of semi-qualitative RBI will be more appropriate than qualitative RBI.

This development project is a software system structure. However, as this software involves the information about the requirements and standards of RBI risk evaluation, as well as the position, types, and inspection methods of the piping damage in the petrochemical plant, the industrial knowledge about petrochemical industry is needed for providing correct information and defining the needs. Based on the piping in petrochemical plants, the objectives of the RBI guideline model is to enhance the operation safety and attain the best

reliability and productivity of the equipment. As the investment of the inspection resources on the equipment that really demands inspection, and the use of the effective inspection method are for detecting the potential piping risk and benefiting from the invested resources to the utmost, it's applicable to all the petrochemical plants that stress the importance of reducing risk and enhancing equipment productivity and competitiveness. This analysis method, process and software are sure to be effective to the petrochemical industry in controlling the potential piping risks and meet the safety requirements.

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