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Lift Cycle-Based Decision Support Solution Plan for Pipeline Integrity Management

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Abstract

With the development of industrial big data, the Internet of things, cloud computing, and artificial intelligence, the pipeline operation management mode has changed and thus shows a gradual development from the digital pipeline toward the intelligent pipeline. The construction of a decision support technology platform can effectively solve the issue of data accumulation, the problems of various currently used systems, and the separation between data acquisition and application. This is necessary to achieve safe, efficient, and sustainable development of oil and gas pipelines. This paper comprehensively analyzes the construction of digital pipeline in both domestic and foreign pipeline businesses as well as the situation of data acquisition and utilization. Furthermore, the characteristics and difficulties in the development of decision support technology and establishment of data standards and databases of the life cycle data of pipelines are discussed. The integrity management decision support architecture infrastructure for the life cycle of pipelines was proposed, including construction period control, operation period control, and decision support. The paper introduces an integrity decision support platform for pipelines on the basis of Geographic Information System (GIS), and constructs an integrity management decision support platform combining pipeline construction, operation, and maintenance. This platform can be applied to 1) data acquisition during the construction period, the visual management of the construction quality, and the handover of the digital database; 2) online data acquisition in the operation period of the pipeline, high consequence area, management and risk assessment, integrity assessment, corrosion protection potential control, risk control in regional upgrading areas, and Unmanned Aerial Vehicle (UAV) inspection; 3) decision support for the integrity management of the pipeline, such as big data modeling, emergency decision support, risk identification for big data of welding seams, disaster monitoring, early-warning on the basis of Internet of Things (IOT), real-time monitoring of pipeline leakage, training for maintaining remote equipment, visual inspection for remote faults and hidden problems, and mobile applications.

Keywords: Database; Decision Support; GIS Platform; Life Cycle; Pipeline Integrity Management

Introduction

Focusing on the development of pipeline management both at home and aboard and with the development of information technology and integrity management technology, the construction of digital pipelines has become the main goal of domestic and foreign pipeline operators. Most pipeline enterprises established geographic information system (GIS) and integrity management systems, leading to important results. However, during recent years and especially with the development of big data, the Internet of things, cloud computing, and artificial intelligence, the operation and management modes of such pipelines have changed. They exhibit a gradual development from digital pipelines to intelligent pipelines, introducing big data analysis, data mining, decision support, mobile application, and other ways into pipeline management to supplement the shortage of traditional management methods [1-2].

The integrity management decision support system is the means and carrier to achieve the management of intelligent pipeline networks. It can integrate all information from both pipeline and station, adopt the analysis concept of big data modeling, and consequently provide a mature and reliable intelligent integrated solution for the pipe network. The solution includes: 1) through the IOT platform, the comprehensive monitoring of the risk points of production safety and the full sharing of all required information for all management stages is achieved; 2) through big data modeling, real-time analysis and processing of equipment and facilities data to ensure safe and orderly production activities is achieved. The intelligent pipe network can further highlight the low-cost and high-efficient goals, automatically acquire comprehensive data, and link upper and lower management stages. Finally, it can achieve closed-loop management, consisting of pre-optimized prediction for pipe network operation, real-time monitoring, and a comprehensive analysis after incidents, thus reducing operational costs of oil and gas pipeline networks.

The General Development Situation of Decision Support Systems for the Integrity Management of Pipelines

Domestic Study Development

The China National Petroleum Corporation (CNPC) first proposed China's digital pipeline, and then the digital technology was gradually applied to the survey, design, and construction periods of the oil and gas pipeline industry. In 2004, during the West-to-East natural gas transmission project, the contact line of the Ji-Ning pipeline applied this digital technology. In 2008, during the second line construction of the West-to-East natural gas transmission project and the oil and gas pipeline between China and Burma, satellite remote sensing technology, global positioning technology, and GIS mapping technology were employed for the survey, design, and construction periods to help optimizing the route; the real-time data acquisition technology and monitoring technology of pipeline network operations was used to achieve a centralized monitoring and operational scheduling, which narrowed the gap between the domestic digital pipeline and that of the developed countries in Europe and America [3-7].

The China National Petroleum Corporation has identified digital pipeline construction as the focus of technological development and thus implemented the unified planning and deployment for established or proposed projects of the Internet technology, GIS, and GPS applications. Furthermore, it can be combined with automation management technology such as Supervisory Control and Data Acquisition (SCADA) and then develop the pipeline integrity management (PIS) and the GIS geographic information system to provide a data platform for online leakage detection, operation optimization, and integrity management of the administered oil and gas fields. Currently, an overall information system has been established, with the support of SCADA, the Early-Warning Platform (ERP) for meteorological and geological disasters, the natural gas and pipeline ERP, pipeline production management, Pipeline Engineering Construction Management (PCM), PIS, natural gas sales, and other information systems, which can fully support the two main lines of business: assets and logistics.

In 2001, pipeline enterprises under the administration of the China National Petroleum Corporation began to introduce the concept of integrity management and thus, gradually established an integrity management system. The corporation started to promote the application of the integrity management system in 2001, constructed a PIS integrity management system in 2009 (with an integrity management coverage of 48%) and achieved coverage of all long-distance pipelines in 2012. The pipeline accident rate declined from 1.67 times/thousand kilometers in 2006 to 0.48 times/thousand kilometers in 2009, while the pipeline integrity management level increased from the 4^{th} grade in 2007 to the 6^{th}-7^{th} grade in 2009; the drilling incidence rate decreased by 35%. The CNPC Beijing Natural Gas Pipeline Co., Ltd. introduced an integrated platform for data in construction and operation periods, established a life cycle database, built the first GIS emergency decision support system based on life cycle, achieved safety assessment, risk assessment, and integrity assessment, and realized the digitalized and visualized dynamic safety monitoring and management of both production operation process and equipment status. Its GIS emergency decision support platform closely combines the production practice, including through loading of pipeline-based geographic data, one-button output of automatic maintenance platform, the GIS platform, and the emergency decision support, and thus achieves the pile-loading data extraction of all pipelines [8-12].

The China National Offshore Oil & Gas Corporation Co., Ltd. Completed the construction and deeper application of the production and emergency command center, trade platform, LNG vehicle filling operation and management platform, fund platform, tanker remote monitoring system, and emergency command system. These systems constitute the main frame of informatization form the group-class holographic "base platform" of production operation systems. Furthermore, production data acquisition and display platforms were established to integrate GIS data, digital pipeline data, DCS/SCADA, and other production and management data of every project company, ultimately forming a unified "data warehouse". Further built systems and projects include a comprehensive office information system, expansion and internet application of video conferencing systems, the expansion project of mobile phone platform, the internet and internal portal websites, dual-line integration of Sap financial system and UF financial system, and a comprehensive information platform of equipment management. Currently, the advanced information network with merits of intelligent gas power, full coverage, and high integration is being constructed with the goal of acquiring, understanding, and judging the operation status of the whole industrial chain of the group in a quick, comprehensive, and accurate manner, finally enabling intelligent decisions.

During the construction period of the Yuji pipeline engineering project, the China Petrochemical Co., Ltd. simultaneously implemented the data acquisition. On the basis of a two-dimensional GIS-based platform, including the graphs of pipeline direction and burial depth, the construction of the digital pipeline was implemented between 2007 and 2008, acquiring more construction data and a superimposed photo map. The system construction during the operation period dealt with basic data in accordance with the intelligent pipeline system standard of the headquarters. The digital construction of the Sichuan-to-East gas pipeline project has also been progressively put into operation. After commencing operation, the 3-D pipeline GIS system has been built and the construction data has been supplemented, which achieves professional GIS of the large-diameter, high-pressure, and long-distance natural gas pipeline. The achieved professional GIS possesses numerous characteristics such as being a whole-distance and whole view real 3-D system, integration of underground, surface, and over ground, the integration of station and line, and the integration of 2-D and 3-D information. The data can cover more than 2200 km of pipeline body and ancillary facilities along the whole pipeline [13-15]. In 2014, SINOPEC launched the "SINOPEC Intelligent Pipeline Management System" project and completed top-level design of the project, and R&D of five principal functions, including pipeline digital management, pipeline integrity management, pipeline operation, emergency response management, and integrated management. Additionally, SINOPEC applied the system to 39 pipeline systems of seven enterprises, with a total length of 1939 km, and achieved digital and visual management of 27 stations. At the same time, the corporation concentrated on data standardization and on building templates of operational flow, thus forming standard specification with five categories and a total of 21 items. The objectives of intelligent pipeline construction for the China Petrochemical Co., Ltd. where: constructing an integrate data center and share service platform, building six major application modules that can link up and down: pipeline digital management, pipeline integrity management, pipeline operation and management, emergency assistant management, management of handling hidden problems, and comprehensive management. Eventually, the formation of a safe and reliable work platform can meet the requirements of the safety operation management of the pipeline.

Foreign Study Development

Pipeline construction and operation abroad gradually develops into intelligent pipeline networks and has obtained several important results. The intelligent pipeline network follows a coincident development with the information technology. Mobile storage based on cloud computing, IOT-based precise data acquisition and decision analysis for big data have been applied during the construction and operation periods of pipelines [16-22].

In the United States, a Control Center at Houston controls the natural gas business all over the country, while the oil pipeline business is monitored and managed by the Control Center at Tulsa to achieve Real-Time Modeling (RTM), Predictive Modeling (PM), compressor station optimization (CSO), compressor performance automatic optimization (RTCT), Gas Load Forecasting (LF), and historical data storage. A national unified GIS that has the ability to integrate physical and geographical data of the pipeline has been constructed. The system can cover 4 x 104 miles (1 mile = 1.609 km) of natural gas pipelines, connect to other information systems (such as risk management systems, equipment management systems, and pipe network model system) and achieve the national unified management for dynamic and static pipeline data.

The Norwegian Statoil ASA has developed a pipeline integrity management system that can integrate data of SAP, Maximo, STAR, Intergraph, Inspection, and other systems. The administrator can access the complete information of the entire pipeline from the same interface. The displayed information includes pipeline design, operation condition and maintenance history, which greatly reduces the difficulty in management, while improving management efficiency. The American Chevron corporation has developed a volumetric management and customer service (VMACS) system to acquire, analyze, and share relevant pipeline data, and finally achieve the purpose of reducing costs, optimizing resources, and maximizing the productivity of a pipeline.

British BP companies use the Internet of Things technology to improve the safety of pipeline assets as well as personnel. Via advanced wireless intelligent terminal applications, location marking and identification of equipment as well as instruments can be achieved. Additionally, inquires for asset cycles, historical data, and correlation were realized, which include the operating procedure introduction for on-site personnel, the on-site work-list reminding and task allocation, and the tracking of working status, development, procedure, and position. The BP Company also used UAV technology with a high-resolution camera and thermal sensors to inspect leakages and monitor safety for the pipelines in complex natural environments.

The Cherry Point oil refinery of the BP Company developed a corrosion management system on the basis of big data analysis and IOT technology. The refinery installed wireless corrosion sensors on key locations of the pipeline, which can form an IOT monitoring network, acquire a large amount of data and upload the acquired data into the system. Severe environments will affect data loading of corrosion sensor data of the electrical system and generate wrong data, while the number of data generated can offset the fluctuation effect. Therefore, the oil refinery can always monitor the subjected pressure on key locations of the pipeline, and then the administrators can understand in real-time, whether a certain type of crude oil is more corrosive than other types of crude oil.

Enbridge, a Canadian corporation, used the IOT technology to acquire, summarize, and transmit data of instrument and asset in real-time through an intelligent mobile terminal. Additionally, the established system can process on-site repair and maintenance data, work order, and the inspection data of pipeline, implement the HSE examination for environmental, health, fire and safety, and process other information such as compliance checks.

The American CDP pipeline company introduced a comprehensively applicable plan for the IOT technology in the field of intelligent pipelines. The company established an intelligent personnel life safety equipment system (ALSS), which can continuously monitor harmful gases and track personnel position under a WIFI environment. Through geological disaster monitoring systems, the company can monitor the deformation, leakage, and other anomalies of the pipeline, process on-site maintenance data and work order through the mobile terminal, carry out video calls, and eventually achieve the route monitoring as well as early-warning via unmanned aerial vehicles.

Characteristics and Construction Difficulties of Decision Support Systems for Integrity Management

The integrity Decision Support System (DSS) is a significant applicable engineering system that can digitalize, integrates, and productize several relatively independent pipelines, integrate the systems on the basis of massive databases, and then achieve data sharing. The system possesses the characteristics of intelligence, digitization, visualization, standardization, automation, and integration. Furthermore, it features professionalism, compatibility, sharing, openness, and security. All these characteristics and features of the system lead to the elimination of information islands as much as possible. The main features were introduced as following: 1) intelligent means of achieving an interactive response between operation optimization, predication, and early-warning of risk, and emergency treatment for disaster; 2) digitalization means, via structuration and indexation of document and picture data, strengthening knowledge sharing to provide applicability for the renewal of equipment; 3) visualization focused on achieving multidimensional inquiry and visual display of graph, image, video, and graph analysis information of pipeline-related data; 4) standardization including the business, technical, and data standards during the life cycle and the digitized handover standard of results during design and construction periods; 5) automation means improving automatically-controlled equipment and devices, detection facilities, and monitoring systems, eventually achieving automatic monitoring of the operational status of the pipeline; integrity refers as fully integrating the real-time data during production and operation, and the business data during management and application, achieving decision support via big data modeling analysis.

The main difficulties and constraints in constructing a decision support system include the following aspects:

(1) Difficulty in data accuracy: intelligent pipe network platforms are platforms that ensure integrity of data in both construction period and operation period. Since the platform covers all stages of pipeline life cycle, its accuracy can directly affect the intelligence level of the pipeline.

(2) Difficulty in data unification: under the premise of applying identical data frame and dictionary to the construction and operation periods, the construction of the system can have a solid foundation and the data can be called freely.

(3) The difficulty in intelligent application is reflected to establish a model that can match the real operation condition of the pipeline. The key issue is decision support analysis; i.e., how to provide supporting services for the decision-making procedure of the pipeline enterprise.

(4) Difficulty in system operation speed and self-maintenance: system speed directly determines whether the construction of an intelligent pipe network can succeed. Therefore, we need to use novel technology that can call and store data via GIS. Additionally, problems of how to activate data, increase refresh speed, and improve self-maintenance performance are to be solved.

(5) Difficulty in synchronization between constructions in system and platform, the system construction must be synchronized with platform construction, otherwise future application and operation maintenance are difficult to achieve practicability.

The Decision Support Plan for Integrity Management

Establishing Data Standard for The Life Cycle of the Pipeline

To form data assets corresponding to pipeline entities, and to ensure data integrity and repeated application, data standards and specifications need to be established. Consistent data standards need to be implemented throughout the life cycle and all business data need to be integrated with a consistent data model. Through constructing the data standards of intelligent pipeline, everything a business generates, transmits, shares, and applies during its life cycle, forms a complete data information chain.

Establishing the Life Cycle Database of a Pipeline

The definition of Pipeline Life Cycle Management (PLM) is: during the entire life cycle including planning, feasibility study, preliminary design, construction diagram design, construction, beginning operation, completion and acceptance, operation and maintenance, and alteration and discard, business and data information of every stage are integrated to establish a unified pipeline data model, which achieves all-business and all-process information management from planning to discard.

In establishing the data model of the life cycle of a pipeline, planning and operation are important objectives. The APDM data model was created, which can load and align the business and data information during various stages. Via loading all data into the data model of the pipeline, the data of the pipeline entity and surrounding environment, the GIS data of pipeline, the data of business activity, and the real-time production data are centralized, stored, and utilized, thus achieving the integration of physical pipelines and digital pipeline model (Figure 1).

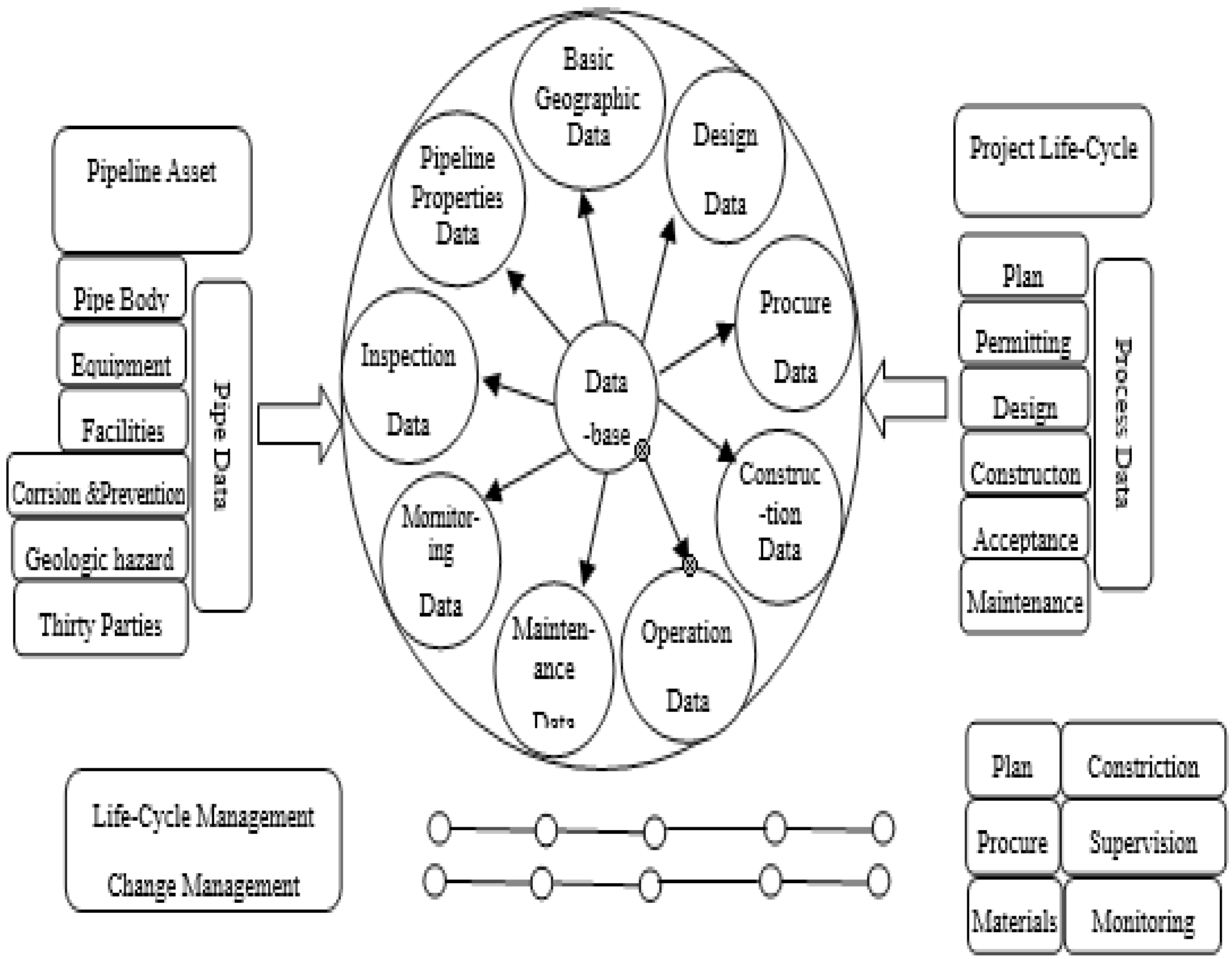

Figure 1: Schematic diagram of constituent parts of the life cycle database of a pipeline.

Designing the Decision Support Plan for the Integrity Management During the Life Cycle

The life cycle includes two stages: pipeline construction and pipeline operation. Furthermore, we considered the decision support as an important constituent part to emphasize the decision support function of intelligent pipelines (Figures 2 and 3).

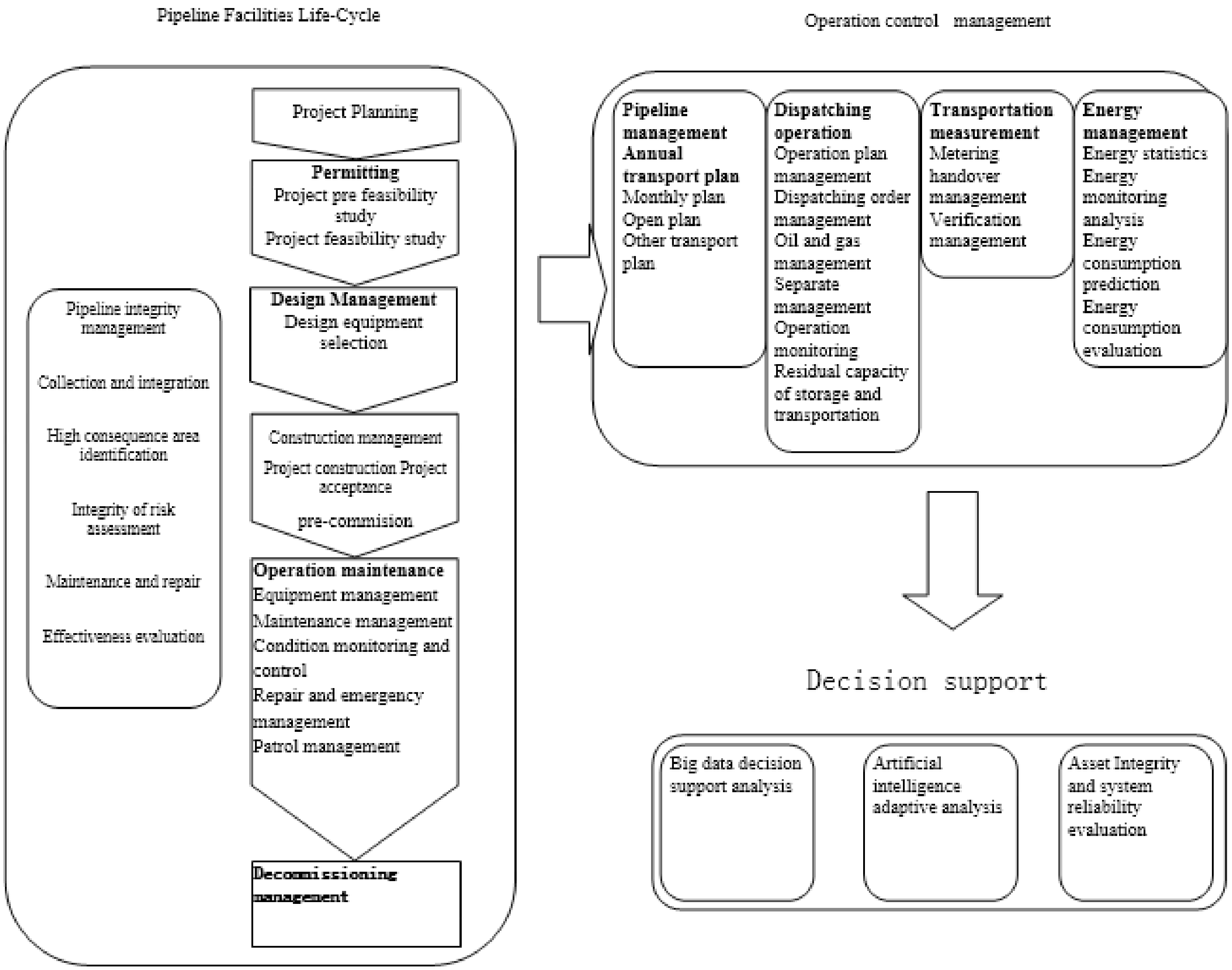

Figure 2: Structural design diagram of life cycle integrity management and decision support.

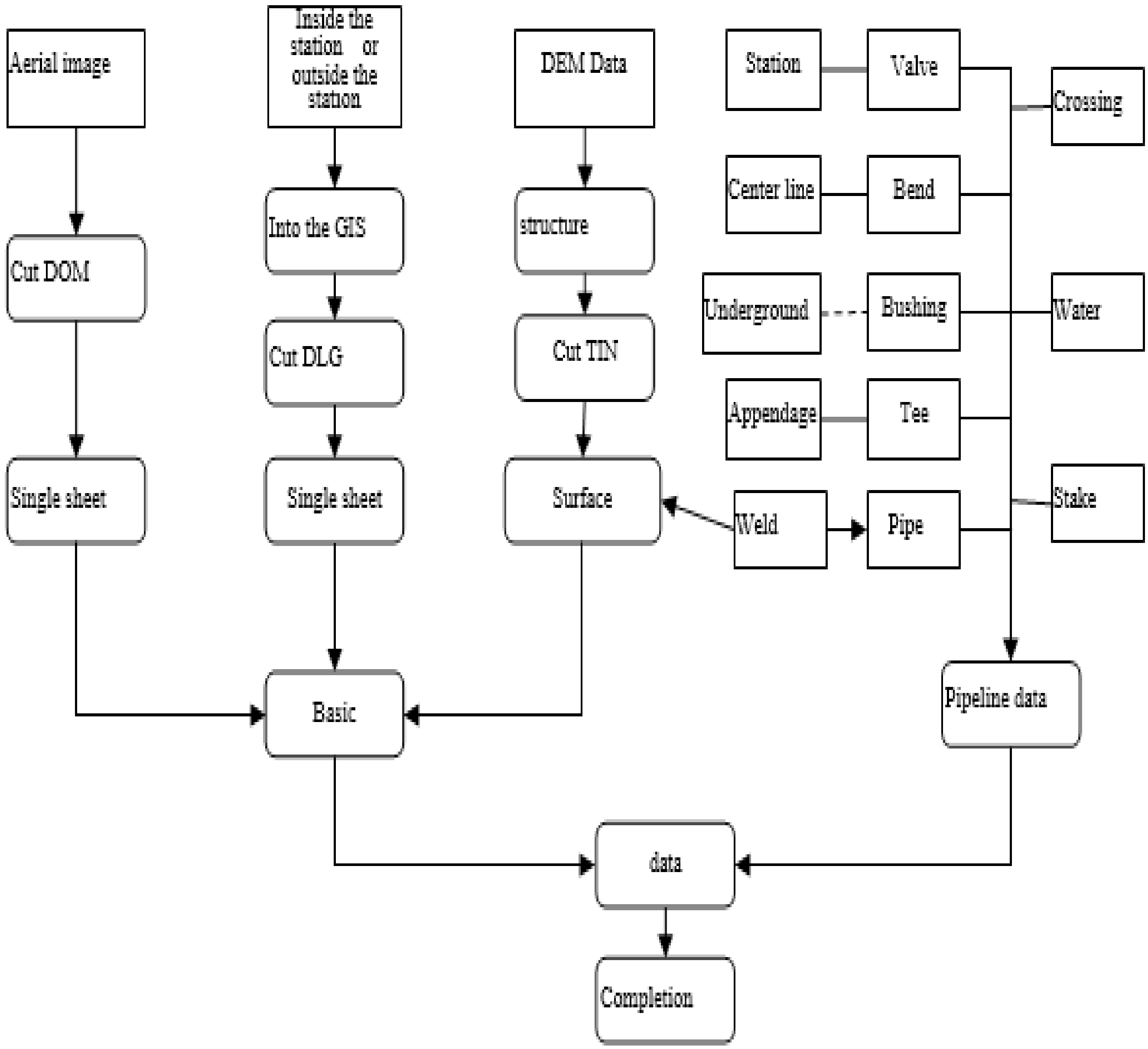

Figure 3: Analytic flow-chart of big data-based decision support and analysis.

Establishing a GIS-based Life Cycle Data Platform of Intelligent Pipeline Network

According to the mentality of the "unified system, unified platform, unified safety, unified operation and maintenance", we constructed a data center, application platform, and sharing service system based on the cloud infrastructure, form unified, and integrated construction-operation platform. We furthermore constructed the pipeline construction and operation application functions to satisfy the business requirements of engineering construction and operation management (Figure 4).

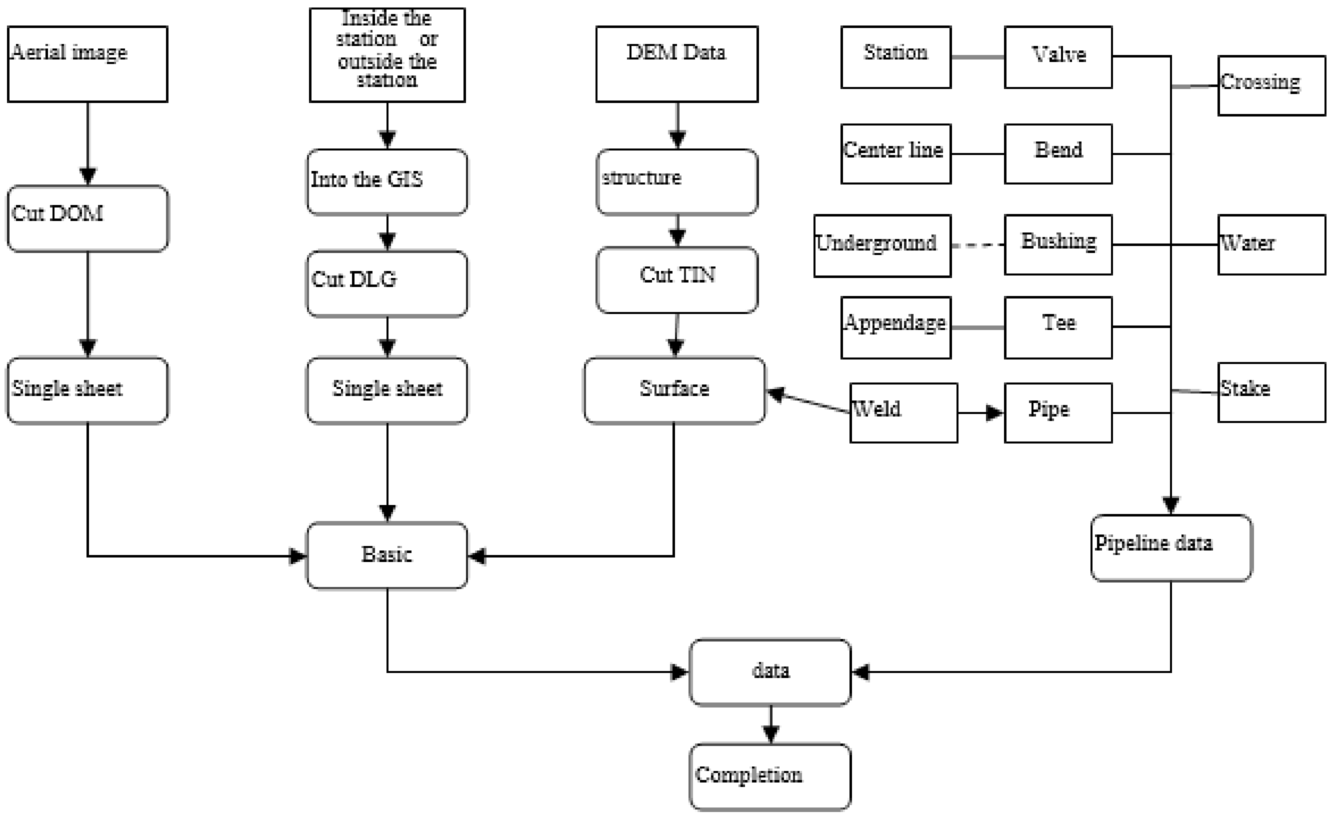

Figure 4: Construction flow chart of GIS-based life cycle data platform and database of pipelines.

Construction Management

Acquisition, Warehousing, and Management of Construction Data

The warehousing process of construction data includes the acquisition, processing, transformation, transmission, and loading of data during the whole construction process. The warehousing process does not only have to meet the requirements of data integrity, compliance, reliability, extension extensibility, and logical consistency, but also needs to satisfy the accurate correlation between spatial data and property data, as well as the compatibility precision requirement with other data sources such as remote sensing data, aerial survey data, design data, terrain data, and engineering data. For the logical structure of the warehoused data, field, data type, field length, and unit must meet the requirements of intelligent pipe standards.

Visual Management of the Construction Process

The visual quality management of the construction process has an object of supervising the standardization of the construction process. Using spatial images and pictures as means can reflect existing issues, consequently generating an effective method to achieve the visual management of the construction process. Via a hand-held intelligent terminal, the system can quickly take photographs, effectively record the construction process, and locate the contractor according to the coordinate information within these photographs.

Digitalized Handover of Engineering Data

The life cycle database of the pipeline can be handed over and this handover result is the construction database of the pipeline, which can help to inquire and call technical parameters and properties of facilities during the future operation and management process of the pipeline. The data have strong usability and can directly provide fundamental information for subsequent application systems.

Pipeline Operation and Maintenance Management

The GIS-based operation and maintenance management module was developed to achieve close-loop management for the life cycle of a pipeline during operation and maintenance periods. The module can meet requirements of six-step cycle of integrity management and achieve total process management of data acquisition, identification of high consequence area, risk assessment, integrity assessment, repairing and slowing down, and performance assessment (Figure 5).

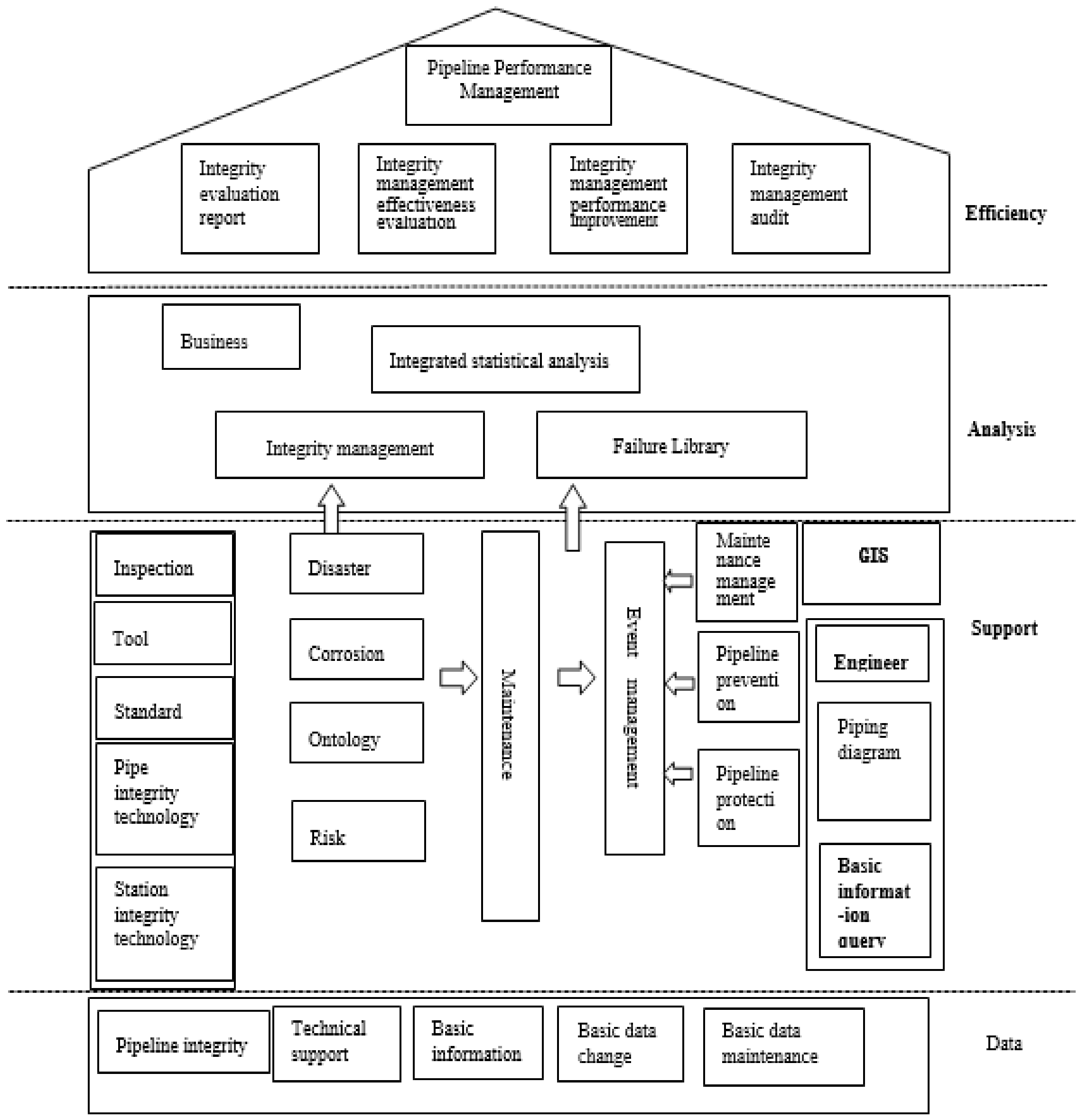

Figure 5: Schematic flow chart for the operation, maintenance, and management of the pipeline.

Off-Potential Management During Corrosion Control

Off-potential management has been implemented in cathodic protection engineering. The management applied the remote potential method to achieve both upload and automatic reporting of daily cathodic protection data such as protection potential, natural potential, potentiostat, and protection current density. Consequently, scientific management of detection and repair situation of anti-corrosive layer was achieved.

Risk Assessment of High Consequence Areas and Level-Upgraded Areas

Due to issues in high consequence and level-upgraded areas, a computational model based on historical failure data and reliability theory was selected, which considers the effect of failure mode of a natural gas pipeline on the consequence and establishes a computation method for the failing probability of a pipeline; the type of pipeline accident and disaster was analyzed and failure consequences such as property loss, casualties, pipeline damage, service interruption, and media loss are considered. Eventually, a quantitative estimation model for failure consequences of natural gas pipeline was established [23] (Figure 6).

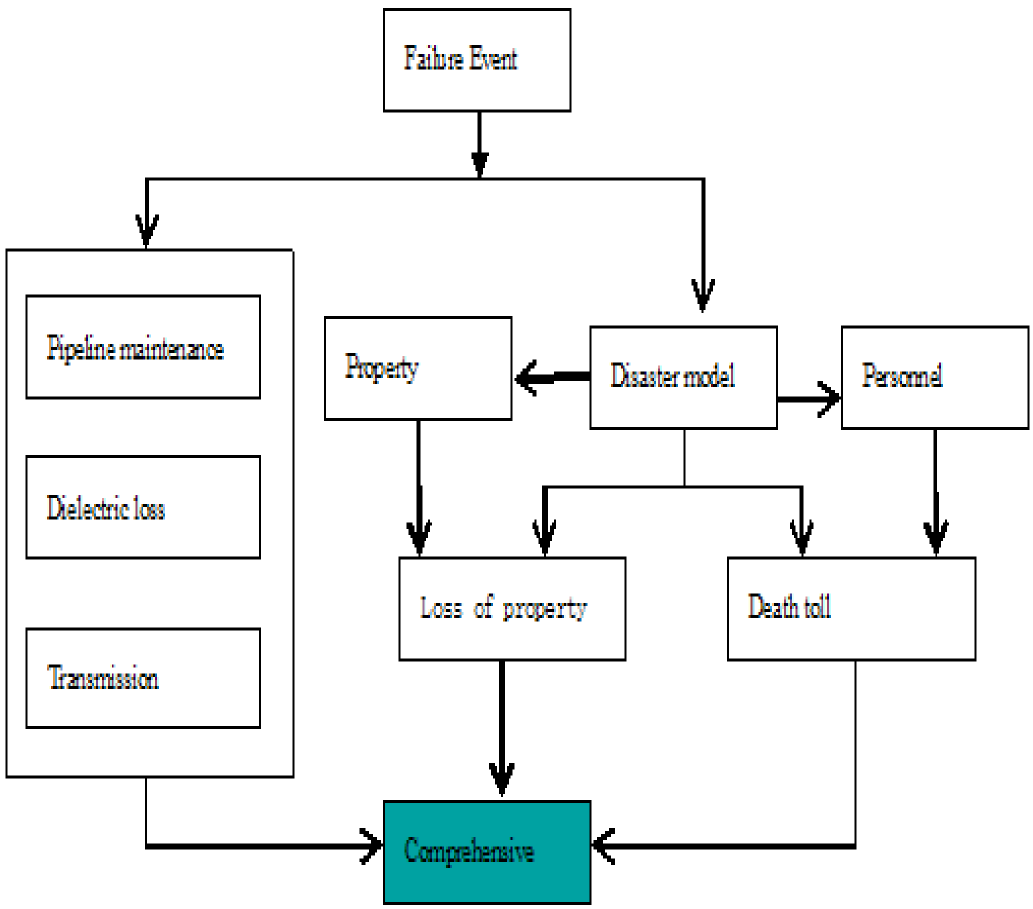

Figure 6: Quantitative estimation flowchart for the failure consequences of a natural gas pipeline.

Intelligent UAV Inspection

The traditional manual inspection method does not only bring heavy workload, but also faces difficult conditions. Especially for mountains, rivers, swamps, and unmanned areas as well as for inspection along pipelines in conditions of ice, floods, earthquakes, landslides, and at night, they require a considerable time, consumes significant labor, and introduces tremendous difficulties. Therefore, implementing UAV digital inspection in dangerous areas of pipeline, as well as implementing third-party and leakage inspection for special and dangerous areas can overcome the shortages of the tradition manual inspection method. Among these, leakage inspection equipped with high-precision infrared camera or infrared spectrometer can identify leakages occurring in dangerous areas and generate timely early-warning and alarm.

Online Integrity Assessment of Pipelines

Finite element evaluation models were established to solve issues within various conditions, such as internal and external detection defects, geometrical deformation, heavy vehicle rolling, flood impact, mine heap, pipeline suspension, valve house settlement, pipeline buckling, mountain landslide, landfill of pipeline drop furrows, parallel pipelines, and blasting. Recently, the study focused on assessing the applicability of steel pipelines with different grades; theoretical evaluation methods were established for hydrogen-induced cracking, welding seams, planar defects, as well as volume and geometric defects; finite element and boundary element mathematical simulation models were established, and a series of assessment software was developed. The criterion of hydrogen-induced cracking fracture was proposed and the effect of the hydrogen concentration on pipeline fracture was studied, which established a new relationship to assess pipeline failure and to provide a failure assessment diagram. Under the condition of certain transportation pressure and H_2S content, we determined the safety degree and safety range of pipelines with cracking defects, and provide the corresponding safety factor. Direct assessment methods such as ICDA, ECDA, and SCCDA were established to achieve real-time online integrity assessment of the pipeline. The developed modules and models [24] include: Pipeline Applicability Assessment Standard API579, Pipeline International Defect Assessment Criteria DNV-RP-F101\ASMEB31.G\Rstreng\ Modified B31.G, Pipeline Weld Seam Assessment System, Pipeline BS7910 Assessment System, and Hydrogen Induced Cracking Integrity Evaluation and Life Prediction System.

Pipeline Data Mining and Decision Support

Emergency Decision Support

We expect to exert emergency command and decision support functions of intelligent pipeline network systems to satisfy the demand of emergency command and decision support. The main objectives include the achievement of the timely call of base data of pipeline and the data of the environment surrounding the pipeline under emergency conditions, automatically calculating the evacuation range and safety radius, and automatically exporting an emergency pre-arranged plan and response plan. Through route optimization of repair materials and repair team, the one-click output of the emergency response document can be achieved and the output data can be included such as: the basic information of the pipeline, impacting range of accident, emergency facilities, population distribution, optimized route, and emergency treatment plan.

Big Data-Based Decision Support

Based on the correlation and non-causal analysis theory of big data, the sources of big data of pipeline system include real-time data, historical data, system data, and network data. The data categories include pipeline corrosion data, pipeline construction data, pipeline geographic data, asset equipment data, detection and monitoring data, operational data, and market data. The big data of future pipeline network systems can be integrated through the Internet, cloud computing and the Internet of Things. The data are unified and integrated, through the establishment of a big data analysis model; therefore, we can solve the current issues in an effective application such as leakage, corrosion, impacts of natural and geological disasters, and damage from third-party. The integrated and global analysis conclusion about corrosion control, energy consumption control, efficiency management, disaster management, market development, and management control can be obtained (Figure 7), which can thus guide the sustainable development of pipeline enterprises [25].

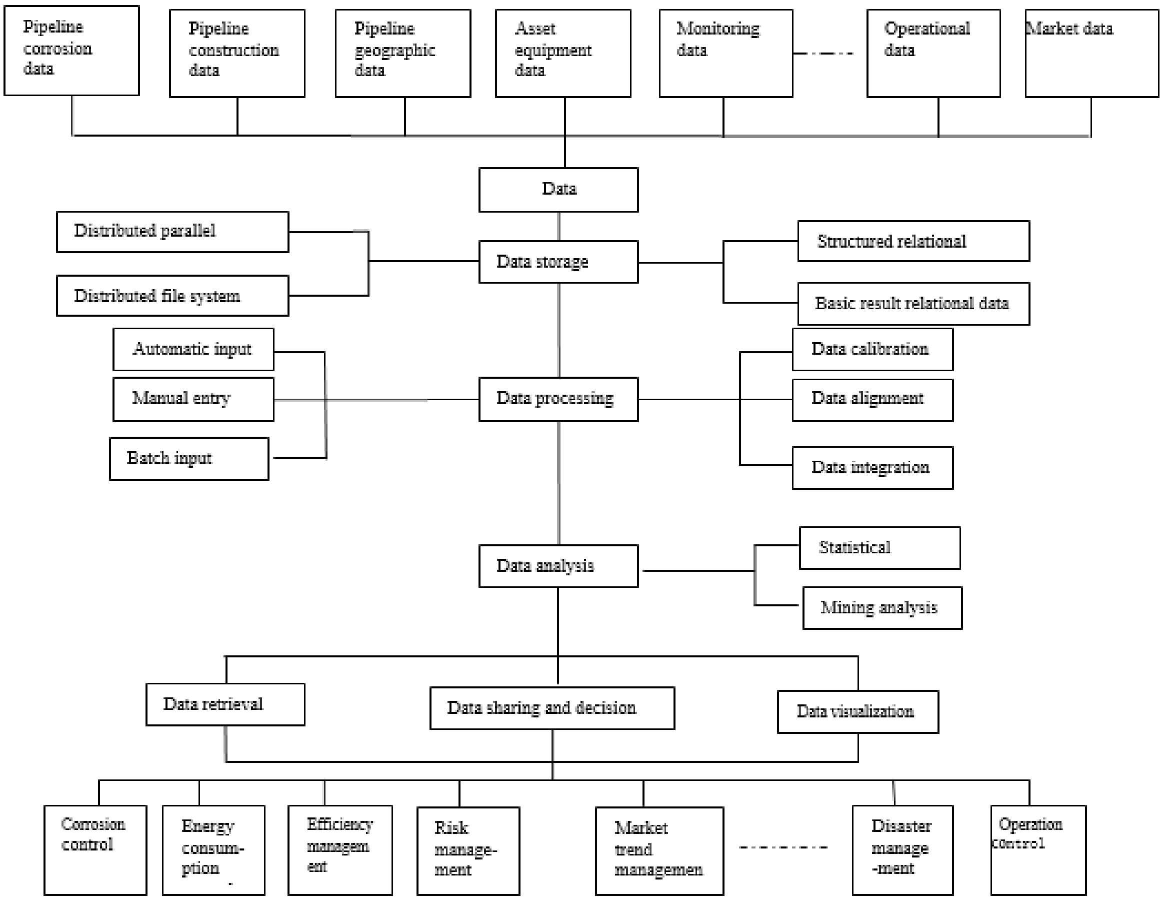

Figure 7: Schematic diagram of big data-based decision support systems.

Big Data Risk Analysis of Weld Seam

Weld seam is an important characteristic of a pipeline and its quality directly impacts the essential safety of a pipeline. Since 2010, more than 10 pipeline weld seam failures occurred in China. The defects of weld seams were mainly caused by the tie-in of pipeline, disqualified weld seam radiographic film, hidden defects, and mismatch between weld seam radiographic films and weld junctions. Through big data analysis, the weld defects and other hidden problems can be found and all negative films around the location of tie-in can be obtained [26].

Based on X-ray images of the weld seam, characteristics of the defect can be extracted and automatically identified: the weld image can be pre-processed via a combination of mean filtering and median filtering. By comparing the two types of image enhancement algorithms, the histogram equalization method was used to enhance images, while the iterative threshold image segmentation method was used to segment the weld seam area. The characteristics of weld seams are extracted and selected and then, the SVM classifier method and Mathematical Morphology method based on binary image was carried out to classify and identify with the edge of weld seam defects. The cracks, Inadequate penetration, Incomplete fusion, pores, spherical slag, and slag inclusion were screened, as shown in (Figure 8~Figure10).

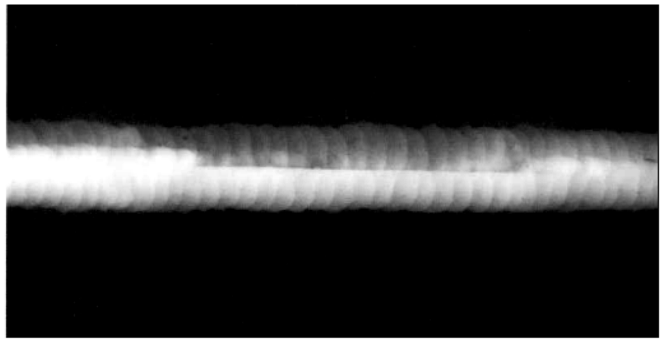

Figure 8: X-Ray Pipeline Weld with Defect of Incomplete fusion.

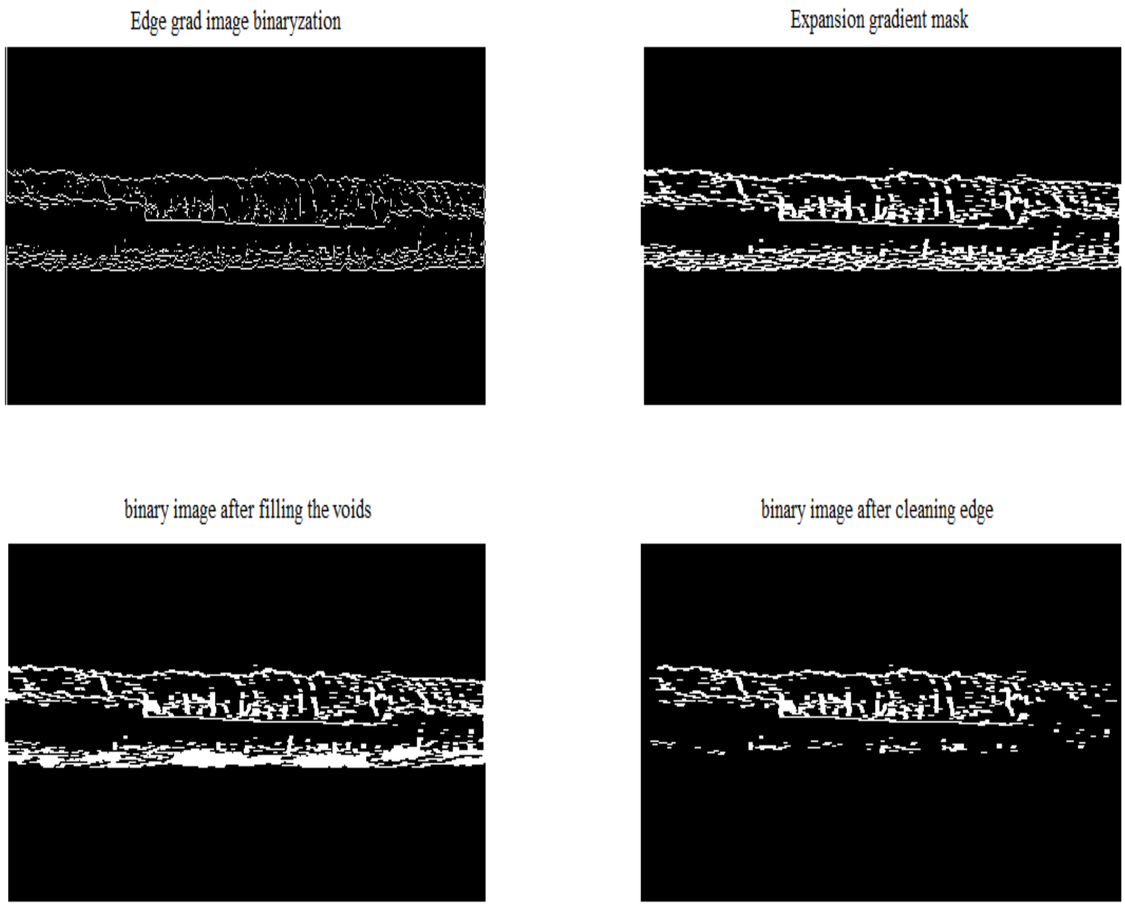

Figure 9: Edge grad image binaryzation.

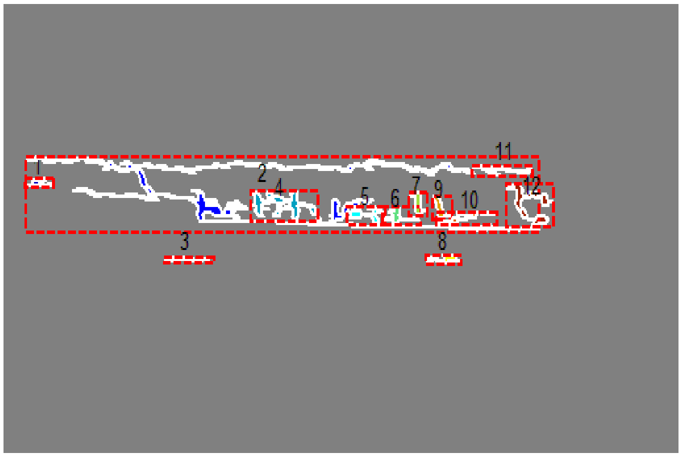

Figure 10: Mathematical Morphology of Defects Edge.

Early-Warning for Disaster Based on the IOT Monitoring

The monitoring system for a pipeline geological disaster was developed and consists of sensors, collectors, transmission modules, and assessment systems, which can overcome difficulties such as extreme weather and system power supply, thus achieving continuous real-time monitoring and automatic alarm management. The system can monitor stress and strain state of the pipeline in real-time in the areas where geological disaster of high consequence may occur. The system includes strain monitoring, temperature monitoring, displacement monitoring, and earth pressure monitoring; therefore, it can perform strain alarm, stress alarm, and displacement alarm in time, and form a pipeline-monitoring network.

Real-Time Monitoring for Pipeline Leakage

Based on the real-time data collected by monitoring sensors such as the SCADA system or the negative pressure wave, secondary wave, optical fiber, and other real-time monitoring sensors, the monitoring system for pipeline leakage will examine these abnormal data and analyze whether the data represents a leakage. After the monitoring system detects a leakage, it will immediately initiate an alarm and display data such as leakage location, leakage time, leakage speed, and total leakage [27].

Remote Equipment Maintenance and Visual Inspection Training for Faults and Hidden Problems

Disassemble and maintenance training encompasses the disassembling and assembling of the equipment's parts and components in the correct order; thus, we can intuitively view the overall expansion and sectional structure of the equipment, or we can view the appearance of each part and component, respectively. The procedure can help personnel master composition, structure, and operating principle of the equipment, and be familiar with the correct disassembling tools, disassembling process and precautions, laying a solid foundation for facility maintenance and repair.

Through accumulating typical faults and hidden problems for long-distance pipelines and stations, a database of hidden problems can be established, which can utilize three-dimensional visualization technology to implement three-dimensional reconstruction of the station. Students in the virtual environment can inspect the faults and hidden problems designed by the system and familiarize themselves with typical failure points and treatments. In addition, the system can provide analysis and evaluation by the end of training, so that the leader can periodically master the personnel's training status for risky faults and hidden problems.

Mobile Application

With the introduction of 4G and 5G network environments, mobile applications have become an important part of the development and management of the pipeline. Mobile applications (Figure 11) can form a close combination between administrator and system, ensuring to carry out emergency handling, file processing, and online management as soon as possible. Mobile applications also help the administrator to timely understand the operating condition of the pipeline and to guarantee the pipeline's safety operation as much as possible.

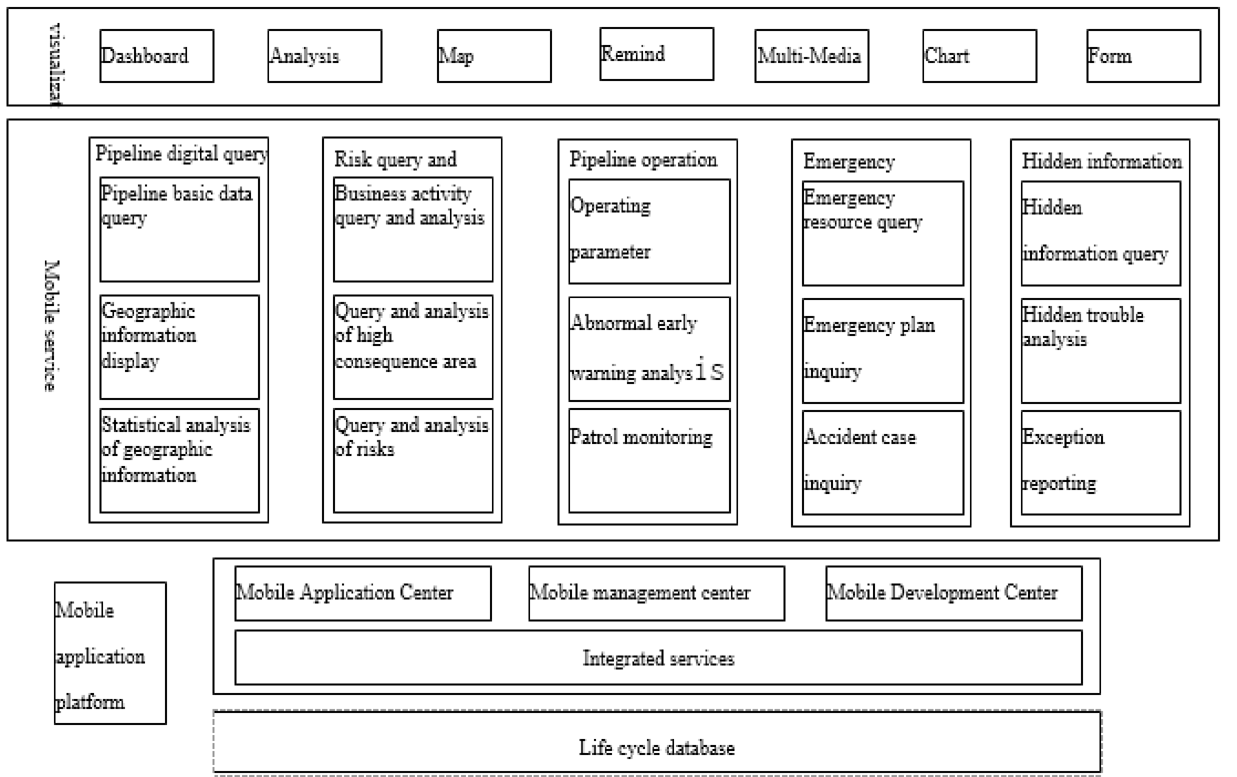

Figure 11: Designing block diagram of pipeline mobile applications.

Conclusion and Advice

(1) The integrity decision support area has become an important developmental direction for pipeline operation. Aimed at applications in oil and gas pipelines, the area intelligently assembles modern communication and information technology, computer network technology, intelligent control technology, and relevant advanced technology of the pipeline industry, finally achieving remote and real-time control, as well as real-time data acquisition based on the Internet of Things. In future, the integrity decision support area will closely integrate modeling and analysis of big data and artificial intelligence, and then serve safe, reliable, optimized, highly efficient and environmentally friendly operation of oil and gas pipelines.

(2) During the construction and development of integrity decision support systems, the digitalized level during the construction period and the implementation depth during the operation period are the foundations; the precision and accuracy of the data and analysis model are decisive factors and the self-adaptive control and feedback is the way to achieve this goal.

(3) Mobile applications supported by an integrity decision system are the mainstream developmental direction of pipeline enterprises; nevertheless, the personalized setting and maintenance mechanism of mobile applications need to be particularly considered to overcome issues in operational speed, data security, early-warning, and alarm mechanism settings.

(4) During both development and construction of the integrity management decision support system for the life cycle of a pipeline, it is most important to solve difficulties in the process from data acquisition to data application. Big data models and applications in the pipeline industry are certain to advance into the cloud computing area. Finally, intelligent network management can be migrated to the cloud so that all users can share data and models.

(5) We advise that future pipelines should consider the construction of integrity management decision support platforms since they can reduce the duplication of data entry, avoid duplicate construction of application systems, and increase the applicable scope of the data.

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Name of Innovation

Life Cycle-based Decision Support Solution Plan of Pipeline Integrity Management. The contents of innovation:

(1) The paper presents the life cycle decision support plan for pipeline integrity management. The plan solved problems in the process from data acquisition to data application, developed a big data model and an application for the pipeline industry, achieved application of intelligent pipe network, and realized the sharing of data and model by all users.

(2) We studied and established the life cycle data standard of a pipeline, constructed a pipeline life-cycle database, and proposed the design framework of the life cycle decision support for pipeline integrity management, which includes three aspects: manage and control the asset facility during the life cycle of a pipeline, operation and management control, and controlling and decision support.

(3) We proposed a GIS-based integrity management decision support platform framework, which can achieve data acquisition during the construction period, the handover of digitalized database, and the visual management of construction quality. We achieved some integrity management cycles such as corrosion potential control during the operation period, online integrity assessment, risk assessment for high consequence areas and upgrading areas, and UAV inspection. The online decision support for the pipeline network was also achieved, including big data modeling, emergency decision support, big data risk identification for weld seams, the prediction and early-warning of disasters based on Internet of Things, the real-time monitoring for pipeline leakages, remote facility maintenance and personnel training, as well as remote visual inspection of faults and hidden problems and mobile applications.

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