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A FRAMEWORK FOR INTEGRATED SHIP STRUCTURE LIFECYCLE MANAGEMENT

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Key words: information integration, thickness measurement, ship structure, lifecycle management.

ABSTRACT

As the concept of ship structure lifecycle management has emerged, lots of endeavors have been made to apply computer-aided (CAX) technologies to various business activities in the whole lifecycle of ship structure. However, information integration or data exchange were barely considered in most of CAX systems development. Hence the systems produce masses of data in their own formats, generate many information islands, and reduce the overall efficiency. It often needs much work of data preparation when downstream systems start working. Information integration can reduce data redundancy, form unified data platform and provide data resource for marine structure lifecycle management. This paper presented an integrated ship structure lifecycle management framework based on these approaches. Requirements for the framework are discussed based on the features of ship structure lifecycle management process first. Based on data exchange mechanism and integration model, the proposed framework consists of several subsystems. The designed framework is embodied within a prototype system and its usefulness is examined through management practice of a 298,000 DWT VLCC.

I. INTRODUCTION

In the global market competition of the current era, all the enterprises are facing with many different challenges, the enterprise must transfer and share product information quickly and effectively with worldwide customers, manufacturers, distributors and suppliers. In this aspect, product lifecycle management technology has reflected its irreplaceable superiority, and has been widely used in batch manufacturing industry. However, due to the particularity of shipbuilding and related industries, general PLM solutions cannot be applied to ship structure. In recent years, to satisfy the requirements of speeding ship owner's response in design and construction, improving operation safety and upgrading the management ability, many organizations started the study on ship structure lifecycle management (Collette, 2011; Song et al., 2011; Sielski, 2012; Frangopol and Soliman, 2014; Frangopol and Soliman, 2016).

As an industry strategy plan, ship structure lifecycle management can change the current business pattern of each enterprise on the information chain, integrate the computer applications of each enterprise, and enable all the systems that process data operation, business decision and activity control can be interconnected, eliminate the segregation between enterprises, and enhance the collaboration between them. As application software system, ship structure lifecycle management is mainly to control and manage data processing in each stage of ship structure lifecycle based on ship structure lifecycle modeling and integration, which is an information system oriented to data integration, knowledge base management and process optimization.

Ship structure lifecycle management refers many Computer aided (CAX) technologies, since CAX technologies have been widely applied in shipbuilding industry for many years. Many systems such as computer aided design (CAD), computer aided manufacturing (CAM), and finite element analysis (FEA) have been used to support design, construction and analysis of marine structure for decades. While these systems work and perform respective functions, they also cause many problems. An objective fact is that these systems do not run on a unified and integrated data platform, for they are developed by different approaches. The data of a system usually cannot be directly used in another one, which cause problems such as breakdown of information flow, repeated data processing, masses of redundant data, and decreasing the overall benefits of CAX technologies. With the increasing of CAX systems applied in shipbuilding industry, it becomes more difficult of interoperability among them. Fig. 1 shows typical CAX system applications through the entire lifecycle of ship structure, such as CAD/CAM system in design phase, FEA system in design/construction/operation phase, production management system in construction phase and TM system in operation phase.

Another problem is that the activity of inspection, maintenance and repairing (IMR) of in-service ship and offshore structures have not been benefited from CAX technologies. Take the most typical inspection activity, thickness measurement (TM), as ex-

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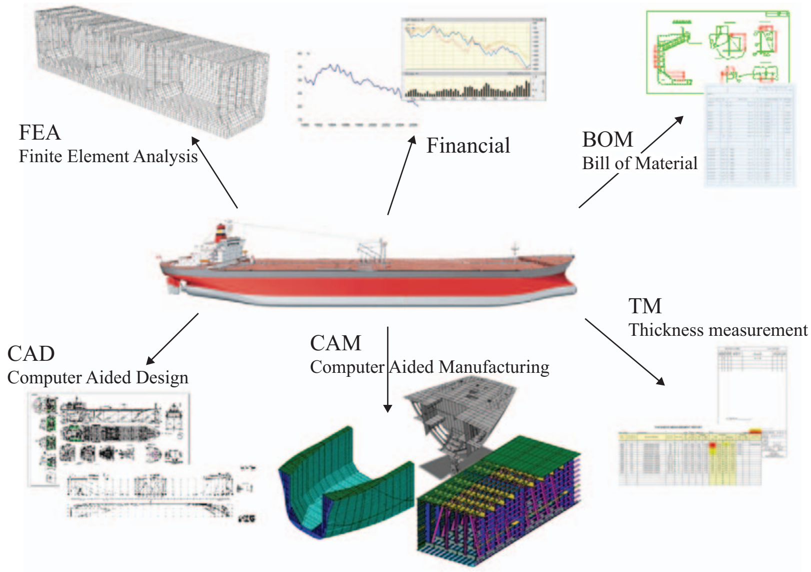


Fig. 1 Typical CAX system applications through the entire lifecycle of ship structure.

ample. The common process is onsite personnel measure the thicknesses of structural members by using thickness according to classification society rules, record the measured data and form the TM report. However, in fact, operators have to write the measured data on draft with a pen after obtaining a group of measured points, which cause the entire process very troublesome, time-consuming, and even prone to error.

The TM data is very critical to structural safety assessment, especially for aging ship and offshore structures. But the documented TM data cannot be directly used for FEA modeling, modelers have to read the TM report page by page and assign the latest plate thicknesses and stiffener sections, so the overall response is slow and this maybe dreadful when accident occurs.

In recent years, many classification societies and ship companies started studying on effective maintenance methods based on 3D model (David, 2006; Duperon, 2008). Many other industries have the same challenges as shipbuilding industry, and it is well accepted of using information integration approach to solve problem (Camba et al., 2017; Cavka et al., 2017; Herrmann et al., 2018; Marra et al., 2018). The advantages of information integration technology can be summarized as follows:

(1) Unified data resource can be formed as the basis of marine structure lifecycle management.
(2) Redundant data can be removed according to concrete application circumstance.
(3) The efficiency of data processing in each application can be improved noticeably.

This paper presents an integrated ship structure lifecycle management (SSLM) framework based on unified data model. The unified data model is the kernel of the framework, which is named as ship structure lifecycle management model (SSLMM). Retrieving and representation of structural member attributes with different levels of details are taken into consideration in development of data structure. On the basis of SSLMM, an integrated approach of recording TM data and importing TM data to FEA software is proposed.

In Section 2, a comprehensive analysis on requirements of ship structure lifecycle management is performed. Based on these business requirements, Section 3 then proposes a basic framework for ship structure lifecycle management system satisfying these requirements. Section 4 describes the background and data structure of SSLMM. An implementation of a pilot project is introduced in Section 5. The applicability of the designed framework is verified through the pilot project, and conclusions are presented in Section 6.

II. REQUIREMENTS OF SHIP STRUCTURE LIFECYCLE MANAGEMENT

On the level of industry strategy development, ship structure lifecycle management system (SSLMS) refers to satisfying requirements, integrating data and application systems, but not only computerizing the businesses involved in the stages during the whole lifecycle. SSLMS is the basis of realizing comprehensive informatization of ship structure lifecycle transactions. Table 1 shows the main user role types and definitions.

Requirements of business activity for each user role in SSLMS are summarized as below.

1. Requirements of Classification Society Headquarter Business

In classification society headquarter, users may login simultaneously to access the same database from different terminals, and perform query and editing of data. The main business requirements of classification society headquarter subsystem include:

Table 1. User role types in SSLMS.

Role code	Role name	Definition	Workplace	Internet connection
A	Modeler	Technical staff who create various models and configure attribute data for SSLMS	Modeling center	Stable and high speed
B	Administrative personnel in classification society	Administrative personnel who is responsible for data maintenance and management of SSLMS business in classification society	Classification society headquarter	Stable and high speed
C	Surveyor	Technical staff who perform onsite inspection in classification society	Unfixed	Irregular
D	Administrative personnel in ship company	Administrative personnel who is responsible for ship maintenance management of SSLMS business in ship company	Ship company	Stable and high speed
E	Ship crew	Technical staff who perform the concrete ship inspection and maintenance work onboard	Onboard	None
F	TM operator	Technical staff who perform TM work commissioned by ship company	Unfixed	None

(1) Accessing IMR records
Administrative personnel should be able to access all the inspection and repairing records of ship, all the maintenance records submitted by ship company voluntarily, and the historical TM data, from terminals on the local area network (LAN) in classification society headquarter. These works should be performed in the environment supporting 3D model browsing so that when user viewing records, user also should view the corresponding location and shape of the related 3D model entity.

(2) Analyzing ship current state
User should be able to do statistical analysis of ship current state, such as obtaining detailed statistics of inspection, repairing and TM data. User can annotate, measure length, area, or volume in 3D model, and save annotation. User should be able to cut the 3D model, observe the cutting section and export to print. User also should be able to evaluate repairing engineering quantities by selecting structural members and generate detailed BOMs.

(3) Auditing the data reported by surveyor
Administrative personnel should audit the IMR record and related files reported by surveyor and mark the records according to whether the records pass auditing or not, so that when the surveyor synchronizes the data online next time, he/she should be able to find the records that failed to pass auditing and the reasons, then he/she can continue edit the records and resubmit.

(4) Checking and releasing 3D model and attribute data
When the 3D model and attribute data of a ship is prepared, administrative personnel should check the model to confirm. If the information is correct, administrative personnel should mark the model and data as "validated", package them, and release to the web pages that can be accessed by surveyor, ship company, and TM company. When relevant personnel downloads the data package successfully, the download records can be saved from the web page.

(5) Determining whether to revise 3D model
If the ship structure had greatly changed due to conversion or significant repair, administrative personnel should determine whether to revise and re-release the 3D model and attribute data. Remodeling should be forward compatible so that the historical record can still be accessed.

(6) Determining whether to revise definition of key areas
Through analysis on historical inspection and repairing records, including the historical key area inspection records reported by surveyors, administrative personnel should determine whether to revise definition of key areas. Generally the revision of key areas will cause revising and re-releasing the 3D model and attribute data.

(7) Downloading the data package of ship maintenance records submitted by ship company
On the web page of external website of classification society, ship company should be able to query the ship information, download related files and upload the data package of ship maintenance records. When ship company uploads new data package of ship maintenance records, administrative personnel should download them and import to system database for SSLM.

2. Requirements of Onsite Surveyor Business

Basically, onsite surveyors participate SSLM process in the state of single person, single terminal, and offline. Only when submit data to the system database in headquarter, multiple concurrent sessions would take place. The main business requirements of onsite surveyor subsystem include:

(1) Filling in the inspection and repairing records offline
Surveyor should be able to fill in the inspection, repairing and finding records, view the historical inspection and repairing records, and the basic attribute data offline within 3D model browsing environment on personal computer. When conducting compartment coating inspection, surveyor should

be able to print compartment coating unit schematic containing coating unit IDs as the worksheet onboard. The worksheet can assist surveyor enter records conveniently in system.

(2) Submitting the inspection and repairing records to headquarter database online
When surveyor can access the private network of classification society, surveyor should be able to submit the inspection and repairing records to headquarter database online, and check whether the historical submitted records are approved.

(3) Downloading ship model data package online
When surveyor accepts new inspection project, surveyor should download the 3D models, attribute data to the personal computer online. Or when surveyor receives the notification of model revision, surveyor also should download the new data package. Surveyor should decide whether to execute these operations. Once the operation is started, the downloading process should be run automatically without interaction. If any error occurs during the downloading process, then the local data should be recovered to the pre-upgrade state.

(4) Distributing TM plan and checking TM data
When new TM task is issued, responsible surveyor should be able to download the TM data package including TM drawings and data tables from server, and distribute the data packages to TM company. After TM project is finished, TM operator should package the TM data and send to the responsible surveyor. Surveyor should be able to view the TM data in system, and check the TM data in contrast with 3D models. If the TM data are problematic, surveyor should directly inform TM operator to revise. If the TM data are approved by surveyor, surveyor should mark the TM data as "ready to submit" in local system, and the TM data will be submitted automatically to the server the next time that it connects. If the TM data fails in headquarter examination, the surveyor will be informed in the local system the next time that it connects to the server, then should revise the data and resubmit.

3. Requirements of Modeling Center Business

In order to build a 3D model environment for supporting classification society administrative personnel, surveyors, ship company, modeling center should provide ship 3D models in high quality. For enhancing the efficiency in use and transmission and saving storage space, the file size of models should be as small as possible under the precondition of satisfying 3D browsing function, so that this kind of model should be lightweight model, but not the source CAD model produced in design stage.

Modeling center should be composed of multiple high performance workstations within a LAN. The workstations should share model files and collaborate to complete modeling work. When the modeling work is finished, the models should be examined by classification society headquarter before releasing. The main business requirements of modeling center subsystem include:

(1) Completing modeling work requested by classification society
Use appropriate software to complete modeling work requested by classification society, and generate the lightweight models and attribute data package.

(2) Basic requirements of modeling
Generally, the models required in SSLMS should include compartment model, coating inspection model, equipment model, hull structure model and key area model. These models should reflect geometry shape precisely, and configure accurate attribute data for all management units. The structure models should contain properties such as location, weight, length, area, section, material.

4. Requirements of Ship Company Business

The operation mode of ship company subsystem is similar with that of classification society subsystem. Users may login simultaneously to access the same database from different terminals, and perform query and editing of data. The main business requirements of ship company subsystem include:

(1) Viewing ship basic information and IMR records
Administrative personnel should be able to access all the ship inspection and repairing records released by classification society, all the maintenance records submitted by ship crew, and the historical TM data, from terminals in a LAN of the ship company. These works should be performed in the environment supporting 3D model browsing so that when user viewing records, user also should be able to view the corresponding location and shape of the related 3D model entity.

(2) Analyzing ship current state
User should be able to do statistical analysis of ship current state, such as obtaining detailed statistics of inspection, repairing and TM data, and obtain reports of current state quantitatively. User should be able to annotate, measure length, area, or volume in 3D model, and save annotation. User should be able to cut the 3D model, observe the cutting section and export to print. User also should be able to evaluate repairing engineering quantities such as coating cost, sludge-cleaning cost, and steel replacing cost by selecting structural members and generate detailed BOMs.

(3) Making, revising and releasing maintenance rules and special orders to ship terminal
Administrative personnel should be able to make maintenance rules, and release the rules to ships. After receiving the rules, ship crew should be able to initialize maintenance record sheets in accordance with the rules. Administrative personnel also should be able to make special orders and send to ship terminal.

(4) Downloading ship model data package and send to ship terminal
When classification society releases ship model data package on the Web pages, administrative personnel should download the data package and import to database of ship company subsystem, meanwhile send the data package to ship via optical media.

(5) Viewing, downloading and uploading through the Web pages provided by classification society
Through the private Web pages provided by classification society, administrative personnel should be able to view the relevant information of the ships of the company, download data packages such as new models, attribute data, inspection and repairing records and TM data, and upload the maintenance data.

5. Requirements of Ship Crew Business

The crew who is responsible for ship maintenance should perform the business on the onboard computer offline, and exchange data online when necessary. At the same time only one user is permitted to log in ship crew subsystem, and there is no any other simultaneous access. The main business requirements of ship crew subsystem include:

(1) Viewing ship basic information and IMR records
Responsible crew should be able to access all the ship inspection and repairing records released by classification society, all the maintenance records, and the historical TM data, from terminals in a LAN of the ship company. These works should be performed in the environment supporting 3D model browsing so that when user viewing records, user also should be able to view the corresponding location and shape of the related 3D model entity.
(2) Evaluating repairing engineering quantities
User should be able to evaluate repairing engineering quantities such as coating cost, sludge-cleaning cost, and steel replacing cost by selecting structural members and generate detailed BOMs.
(3) Initializing maintenance record sheets and filling in records
Ship crew should initialize maintenance record sheets according to the maintenance rules released by ship company, execute maintenance tasks as defined in maintenance plan and fill in maintenance records in ship crew subsystem. When executing coating unit inspection of tank, deck and shell, ship crew should be able to print checklists for onsite inspection. The checklists should contain inspection items, inspection unit IDs, and 3D model graphs of inspection units. During inspection, ship crew writes the records on the checklists. When inspection is done, ship crew should enter the records into system.
(4) Receiving the orders from ship company and submitting records automatically and periodically
Through network connecting onboard and onshore terminals, ship crew subsystem should receive the data package including various orders from the ship company by email. And also ship crew subsystem should send the maintenance package to the onshore terminal of the ship company, and ship company subsystem should update the database automatically.
(5) Updating the model data package
When ship crew receives the model data package from the ship company, ship crew should copy the package to the onboard computer and execute model update process.

6. Requirements of TM Company Business

The TM company subsystem should be a stand-alone application that independent of above subsystems, and it doesn't need to perform data exchange or transmission with other subsystems. The main business requirements of TM company subsystem include:

(1) Viewing and revising TM plan
User should be able to receive the TM plan sent by surveyor, and open the files, view TM plan in TM company subsystem. If there are some minor mistakes in TM plan, user should edit the TM plan. If there are some big error, user should send the TM plan back to the surveyor. User should be able to print the right TM plan.
(2) Customizing TM data report form
User should customize TM data report form according to the TM point type and number of TM points.
(3) Filling in TM data with intelligent support
Refer to the TM plan graphs, system should check the rationality of entered data when user is inputting by structural member, remind or warn user the error, and calculate the average value of thickness automatically. When user is inputting, system should highlight or mark the graph corresponding to the entered data, and locate the table cell in edit area corresponding to the selected graph.
(4) Generating TM report automatically
After all the TM data are filled in and checked, system should generate TM report automatically in accordance with classification society rules.

III. FRAMEWORK OF SHIP STRUCTURE LIFECYCLE MANAGEMENT

1. System Architecture Design

According to the requirement analysis results of ship structure lifecycle management business activities, the system architecture is designed, which is shown in Fig. 2. The system is composed of several subsystems for all user roles, such as modeling subsystem, classification society headquarter subsystem, surveyor subsystem, ship company subsystem, ship crew subsystem, and TM operator subsystem. Usually these member companies in the whole SSLM information chain do not belong to each other, these subsystems wouldn't run in a public network. Basically, all the subsystems should be database management system for data security and data exchange. Modeling subsystem and classification society headquarter subsystem share a network within classification society. Surveyor subsystem, ship crew subsystem, and TM operator subsystem mainly use stand-alone database because there usually may be not stable internet connection in their working environment. Ship company subsystem can exchange data with ship crew subsystem.

2. Data Flow

Fig. 3 depicts the data flow among these subsystems. The

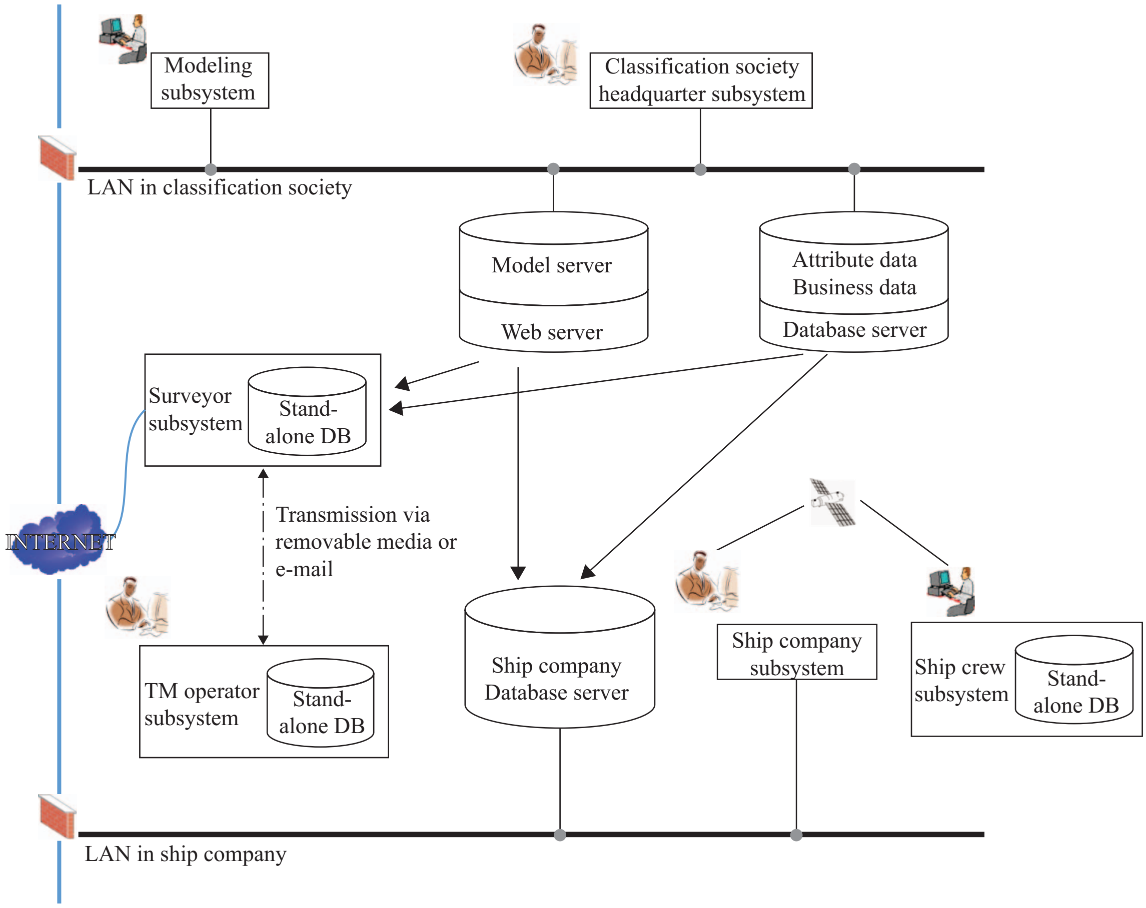


Fig. 2. Architecture design of SSLMS.

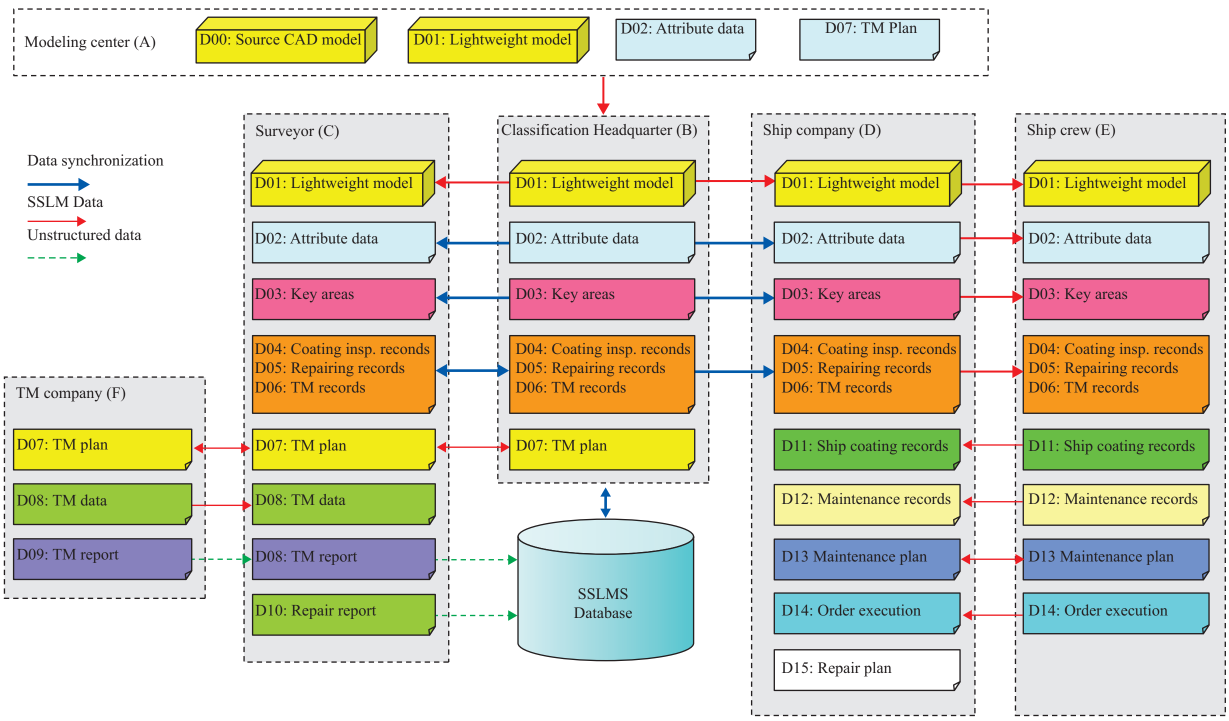


Fig. 3. Data flow in ship structure lifecycle management.

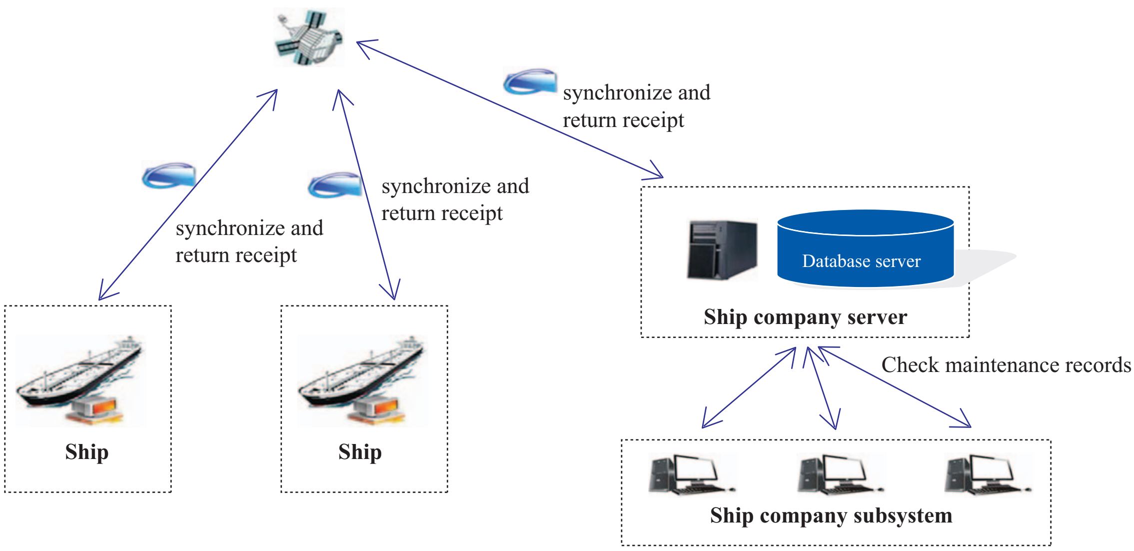


Fig. 4. Data exchange mechanism by using automatic transmission via email.

referred data are marked by using different colors. Modeling center generates four kinds of data: source CAD model, lightweight model, attribute data and TM plan. The lightweight models and TM plans should be stored in model server while the attribute data should be stored in database with structured format. Then classification headquarter subsystem should distribute lightweight model, attribute data, and managing data such as key areas, coating inspection records, repairing records and TM records to ship company subsystem and surveyor subsystem. And ship company subsystem should send these data to ship crew subsystem, while surveyor subsystem should send TM plan to TM operator subsystem. When ship crew performs maintenance work according to the maintenance plan, ship crew should record the relevant data such as ship coating records, maintenance records, and order execution in ship crew subsystem, and these data should be transmitted back to ship company subsystem. Similarly, when the TM work is finished, TM operator should send the TM data and TM report back to surveyor subsystem for approval.

Note that there is only a limited data connection via maritime satellite between ship company subsystem (onshore) and ship crew subsystem (onboard), hence it is necessary to develop an effective data exchange approach under resource-constrained condition.

3. Data Exchange between Ship Company Subsystem and Ship Crew Subsystem

Data exchange is the foundation of assigning and adjusting maintenance plan, filling in and checking maintenance records, which is a necessary guarantee to obtain the operation and maintenance status of ship structure. Ship can contact with the outside world only by maritime satellite, hence automatic transmission via email is the best option of data exchange between ship company subsystem and ship crew subsystem. Fig. 4 shows the data exchange mechanism.

The whole data exchange process can be divided into sending process and receiving process. Both the two ends can access specified mail server to send and receive data automatically. The data media is XML formatted document, and it should be compressed into RAR file for transmission so that some bandwidth can be saved during transmission. The file is transmitted as email attachment. Note that the data flows on the two ends are different. And data exchange operation for the two ends should be independent process.

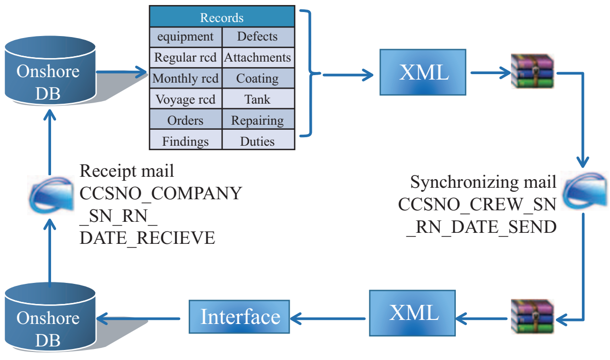
Fig. 5 depicts the synchronization content and process on the two ends. As shown in Fig. 5(a), after finishing maintenance work, ship crew should fill in and submit relevant maintenance records. Then ship crew subsystem application extracts the records that need to be uploaded, encapsulates them as XML format document, compresses the document, generate the RAR file with unique identifier in certain coding format, and upload the data via maritime satellite.

Fig. 5(b) shows the synchronization content and process of ship company subsystem. Ship company subsystem should check the submitted maintenance records form ship crew subsystem, and adjust the maintenance plan by editing job cards and equipment cards. After checking and adjusting, the generated data should be sent to ship crew subsystem in the same way.

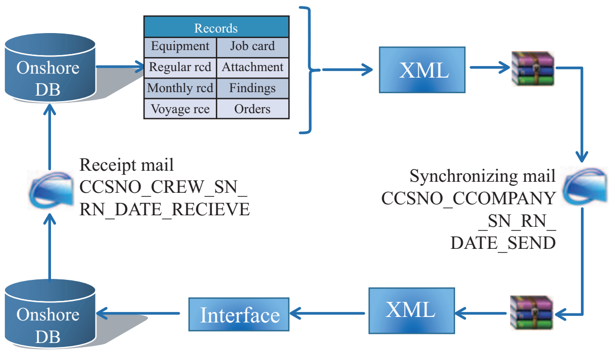
IV. SHIP STRUCTURE LIFECYCLE MODELING

1. CAX Models in Ship Structure Lifecycle

The objective of SSLM is to obtain the latest and accurate status of ship structure for preventing from any emergency and enhancing the security. Implementation of SSLM must be based on model construction and performance analysis, which mainly depend on four types of CAX models in ship structure lifecycle: CAD model, CAM model, IMR model and FEA model. Fig. 6 shows the relationships between these models. These models complement each other within the whole lifecycle of ship structure.



(a) Synchronization content and process at onboard terminal



(b) Synchronization content and process on the two ends

Fig. 5. Synchronization content and process on the two ends.

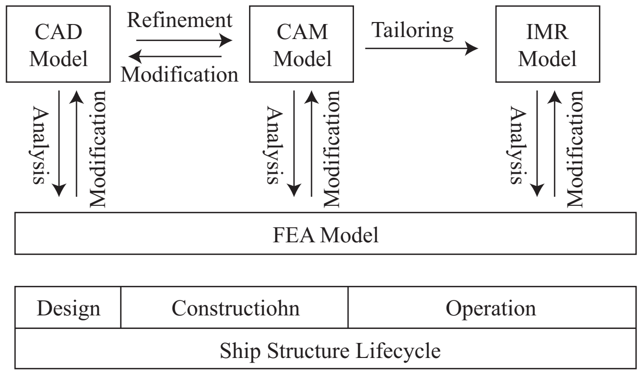


Fig. 6. The relationship among CAX models.

In design stage, CAD model is used to express the main characteristics and general information of ship structure. Usually only primary structural members are described in this stage, but small machining features are omitted. The designed model is to check whether the scantlings can satisfy the requirements of classification society rules, which indicated that CAD model should be converted into FEA model, and may be modified according to FEA results. CAD model also can be used as the foundation of downstream works such as evaluating the structural weight for general performance checking, ordering materials, refining machining features, arranging machinery equipment, and so on. This means that CAD model should be able to evolve to CAM model, and also may be modified according to the constraints from manufacturing considerations. The role of CAM model is to convert the general information in CAD model into detail process information. In construction stage, process information should be classified and grouped to form various information sets according to stage requirements and types until every area is decomposed into the lowest level, and then all the process work instructions, control charts and documents can be determined. CAM model also needs to be converted into FEA model and be modified according to FEA results to ensure the safety during various processes such as hoisting, launching, floating in incomplete condition, and so on.

The main task of IMR model is to record the status data of ship structure in the whole operation stage, and provide foundation of structure safety evaluation and repairing planning. IMR model should contain basic data, inspection requirements and implementations, global and local structure status assessment, and repairing plan and implementations. In order to reflect the real state of structure, IMR model generation must be based on CAM model, but CAM model should be tailored according to the ship company's requirements or inspection requirements. With the inspected data, usually the TM data, structure safety can be evaluated by using FEA, and repairing plan can be made according to FEA results.

2. SSLMM

In order to improve the quality of SSLMM and efficiency modeling work, more standardized and parametric modeling must be developed to replace manual operation. Many researchers have obtained good achievements on improving data exchange of ship structure modeling (Li, 2010; Shin, 2012; Nam, 2016). It is well accepted that neutral file such as text file, XML is an effective approach for data exchange among multiple systems.

The basic concept of SSLMM is to store the structured data in XML format. XML has shown its advantages of data structuring and application extensibility in many application fields. It can be conveniently parsed and hence suitable to development. XML is adopted to save all the integrated information. As for the multimedia information generated in the whole lifecycle, XML can also save them by using pointer.

The chosen XML-based approach ensures extensibility in future versions of the data model, which will need to be adapted to new available methodology for ship structure inspections, new regulatory requirements as well as to innovations in information technology in both software and hardware that will have an impact on the process. Fig. 7 shows a fragment of XML expression of integration model, including a plate and a stiffener.

In fact, redevelopment is well supported in current main CAX systems, which enables reading and writing CAX models by interface development. XML interface of CAX system contains two parts: preprocessor and postprocessor. Preprocessor converts CAX model into XML file, whereas postprocessor proceeds contrarily. Fig. 8 shows the technical route of CAX data exchanges using XML. There are many different CAD/CAM sys-

```xml
<?xml version="1.0"?>
- <ShipStructure>
  - <assembly>
      <name> ShipCure </name>
    </assembly>
  - <Plates>
    - <Plate thickness="16" group="Deck" name="Deck2114" id="2134">
      - <Outline>
          <Point z="12500" y="16000" x="82400"/>
          <Point z="12500" y="10000" x="82400"/>
          <Point z="12500" y="10000" x="90400"/>
          <Point z="12500" y="12000" x="90400"/>
        </Outline>
      - <Photos>
          <Photo name="巡检发现1101" date="2015-11-01" pointer="iVBORw0KGgoAAAANSUhEUgAAABAAAAAQCAYAAAAf8" type="jpg"/>
        </Photos>
      </Plate>
    </Plates>
  - <Stiffeners>
    - <Stiffener group="HopLongStf" name="Stf1308" id="9308" type="L" webthickness="9" webheight="140" flangethickness="9" flangeheight="90" side="left">
      - <PolyLine>
          <Point z="10387" y="14827" x="82400"/>
          <Point z="10387" y="14827" x="92400"/>
        </PolyLine>
        <Orientation j="0.5" i="-0.866"/>
      </Stiffener>
    </Stiffeners>
</ShipStructure>
```


Fig. 7. Attribute expression of structural member using XML.

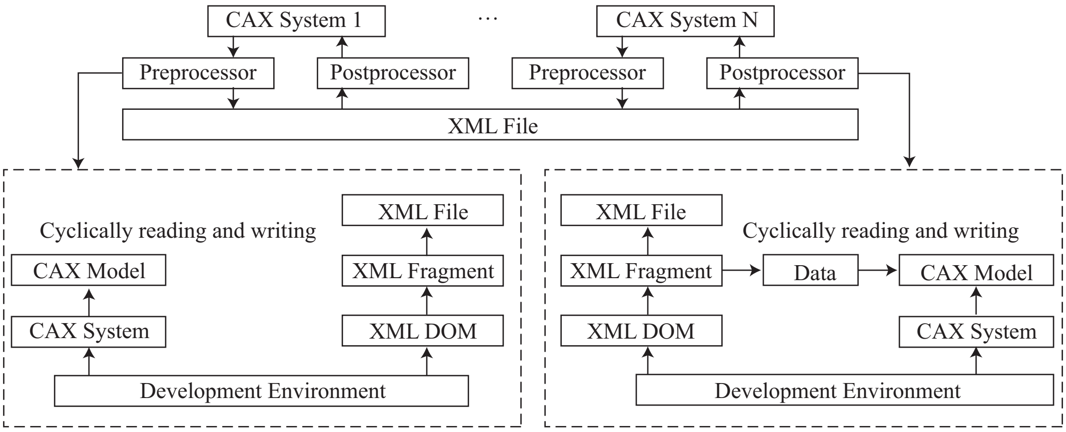


Fig. 8. CAX data exchange based on XML.

tems used in current new building ships, and these CAD/CAM data be transmitted through the proposed data exchange mechanism.

Fig. 9 shows the data structure of SSLMM, which mainly contain two parts: ship information and structural members. "Ship information" identifies which ship the managed data belong to. "Structural members" contain ID, basic properties, geography shape, process information, FE model data and inspection items. In this way the managed data in different stages can be integrated into one data model. "Basic properties" contain material, dimension, thickness, coating area and related compartments. "Geography shape" saves all the points, curves and surfaces that represent the shape of structural member, which can be parsed and converted into 3D model. "Process information" contains all the manufacturing details such as the locations and specifications of openings, joint types, end connection types, penetration types, locations and specifications of CM points and welding seams, and so on. "FE model data" save the element type, simplified shape, meshes and nodes, these data should be determined by several FEA trials. Once the FEA is performed successfully, these data can be stored and keep unchanged during whole life-cycle so that the FEA validity can be guaranteed and FEA efficiency can be improved. "Inspection items" refer to all the IMR records and data from TM company and ship crew, include measured thickness, scene photos, coating condition, rusting degree, crack shape and pitting degree, and so on.

For most in-service ships and offshore structures, the corresponding CAD/CAM system in design and construction stage may be invalid at present, and the information of CAD/CAM may be incomplete. In order to assist these ships and offshore structures be benefited from SSLMS, it is recommended that use the common CAD software to rebuild the 3D model and export the management information in accordance with the data structure of SSLMM.

V. APPLICATION RESEARCH OF SSLMS

Based on the proposed framework, a pilot project covering main functional modules was implemented and a 298,000 DWT VLCC was selected to provide the real data for structure life-cycle management, which can examine the benefits of the proposed framework prior to full implementation. Fig. 10 shows

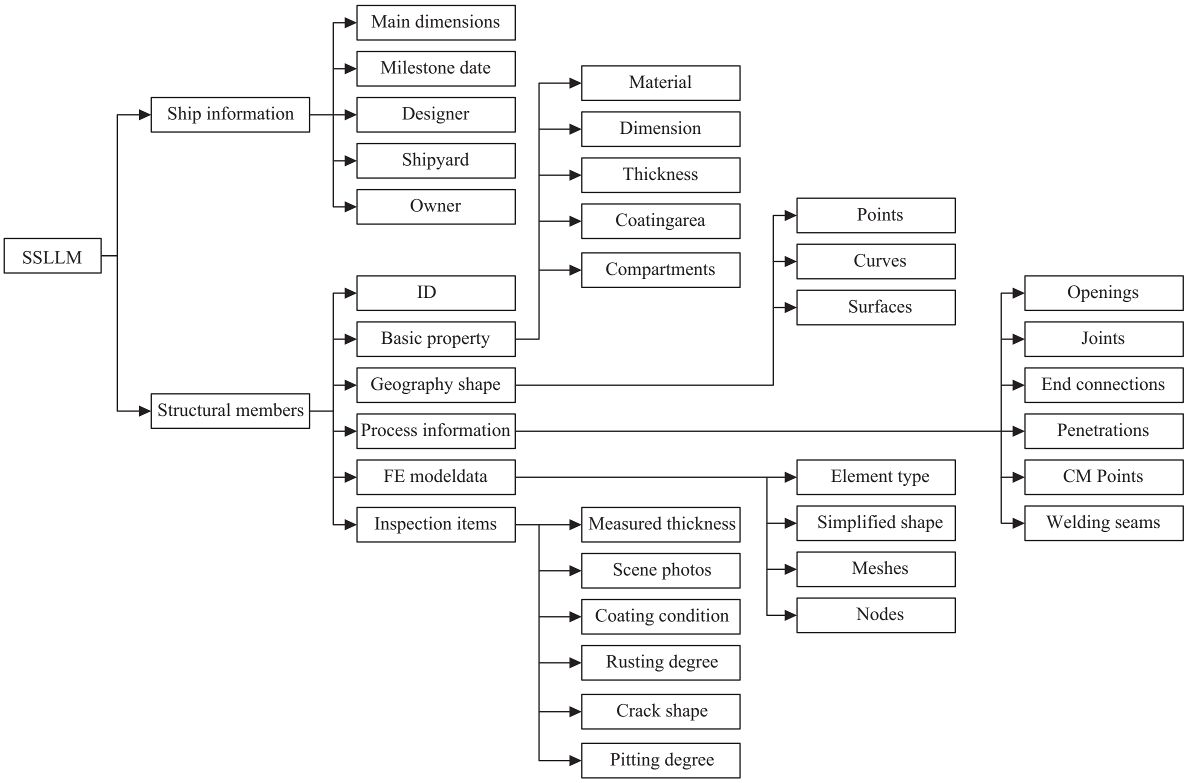


Fig. 9. Data structure of SSLMM.

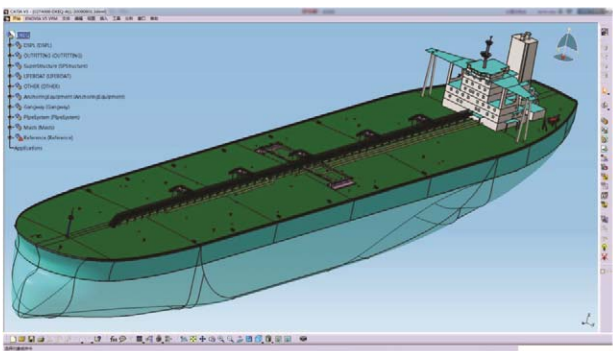


Fig. 10. Modeling environment of a 298,000 DWT VLCC.

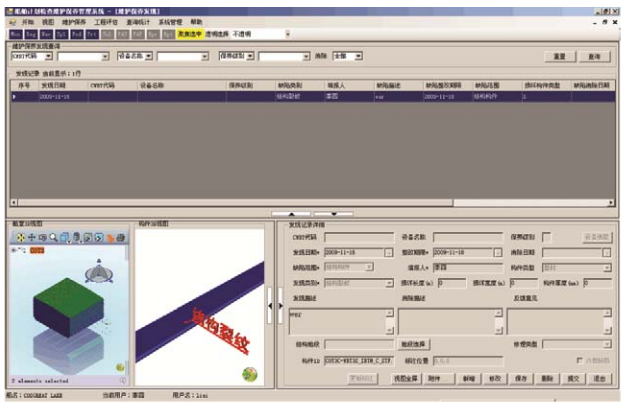


Fig. 11. Ship structure maintenance recording module.

the original modeling environment. Several application scenarios are selected to demonstrate the functions as follows.

1. Ship Structure Maintenance Management

Fig. 11 shows the function of filling in and submitting ship structure maintenance records. Ship crew can define the maintenance findings including finding date, CWBT code, maintenance level, equipment name, defect type, duty officer, defect description, repairing deadline, defect range, defect length, defect width, defect thickness, repairing date, defected member type, 3D model pointer, repairing description, repairing type, and defection ID.

Detailed records of structural defection can assist accurate evaluation of ship structure strength and repairing amount, but too much data entry work is tedious and will consume user's patience, and may decrease the accuracy of data source due to user's carelessness. Hence the definition of defect range such as length, width and thickness are not mandatory to fill in, but the related photos are required if the structural defects are not negligible.

Similarly, the maintenance results of ship structure coating can be recorded as shown in Fig. 12. To balance the management accuracy and data entry amount, coating management unit is simplified as a box composed of web plates, longitudinal girders, and bulkheads. Ship crew can view the 3D coating management model of a tank, and the related management units, enter the coat-

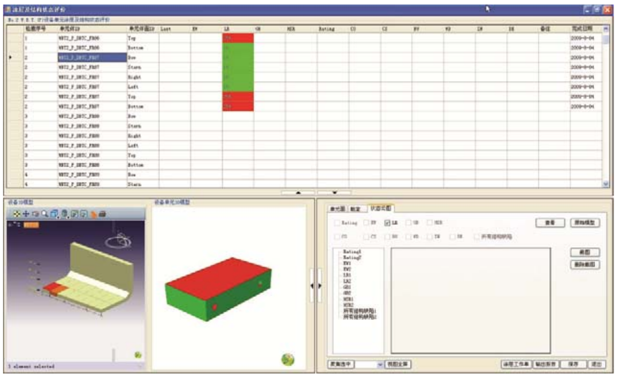


Fig. 12. Ship structure coating management module.

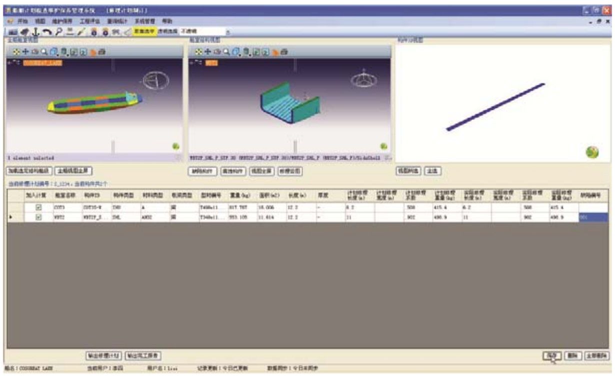


Fig. 13. Ship structure repairing management module.

ing inspection results for each surface of the box unit, evaluate the coating status of the whole tank automatically, view the colored model for indicating coating status distribution, and print the coating inspection report of the tank.

All the ship structure maintenance records should be sent to ship company subsystem. Based on the records of defected members and corroded members, ship repairing plan can be made and repairing amount can be evaluated by retrieving the coating area and weight of structural members from database, which is shown in Fig. 13. After ship structure repairing work is done, a full report containing real repairing range and amount can be printed automatically, and there is also a function of showing colored model for showing the repaired parts.

2. TM Management

TM work mainly refers primary structural members that can be categorized as plates and stiffeners. For determining the thickness, usually multiple points in one plane should be gauged to search the maximum and minimum value. Hence in TM subsystem, both plate and stiffener should be treated as plate member. In order to handle various types of structural members, structural members are classified as general member, expanded plate, and dissected member. Expanded plate means the planar member obtained by expanding the shell plate to a plane, which can assist TM operator marking results conveniently. Dissected member is formed by cutting existed structural member and extracting the outlines. Expanded plate and dissected member are defined for TM operation only, which don't exist in real structure.

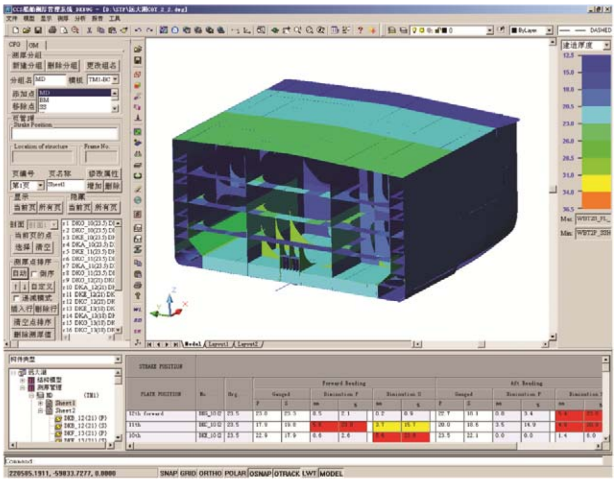


Fig. 14. User interface of TM subsystem.

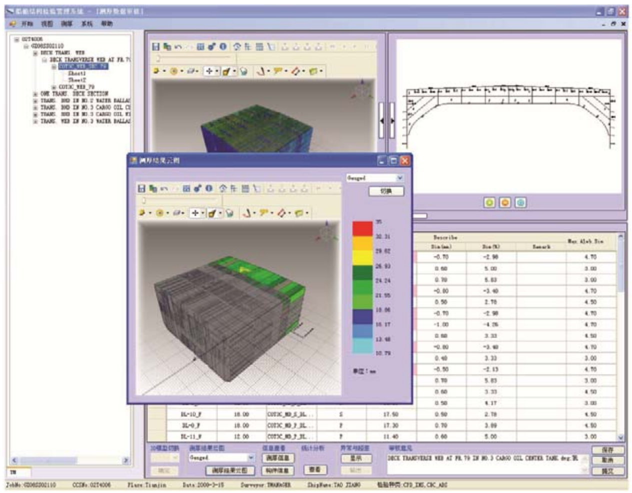


Fig. 15. User interface of surveyor subsystem.

In order to assist TM operator processing data and graphs conveniently, both 3D model and 2D drawing should be provided for viewing and editing. According user's habits, user can choose 3D mode or 2D mode. Fig. 14 shows the user interface of TM subsystem. In TM subsystem, TM data and ship information are managed by file. Each TM project has a dedicated folder. Definition of ship basic information, tanks, and frame spacings, are stored as files in the folder.

As shown in Fig. 15, surveyor can check the received TM data in surveyor subsystem. User can view the colored model of gauged thickness, corrosion value, and corrosion percentage according to current TM work. The TM data of a ship are organized in a tree structure. The levels of the tree structure are ship ID, TM work ID, TM area, TM plan, TM group, and pages. By choosing the levels, user can view TM data conveniently. Usually, there may be several different TM report formats in one TM plan, and therefore the TM data should be grouped. For example, the

Fig. 16. Data synchronization setting.

TM report formats of typical web ring, shell plate, and bottom plate are TM2(i), TM2(ii), TM(3). The members in 2D TM drawing may correspond to multiple 3D models, to avoid ambiguity the system will load the 3D model which contain the most structural members in current TM drawing. If user needs to view other model, user can switch the 3D model.

3. Data Synchronization

As shown in Fig. 16, both on ship company subsystem and ship crew subsystem, data synchronization setting contains three parts: External file operation, synchronization period operation and data synchronization type. In the function of setting external file operation, user can import and export the synchronized file or attachments. Both the synchronized file and attachments are in RAR compressed format.

In the function of setting synchronization period operation, user can define the synchronization period, the synchronization time and the deadline of receiving receipt. Synchronization period is the interval between two synchronizations. Synchronization time means the concrete time when system time achieves according to synchronization period. The deadline of receiving receipt is a value in units of days, which means that if the receipt of sent synchronization file is not received before deadline, then repeat sending the file. In the function of setting synchronization type, there are three options: receive only, send only, and receive and send. User can select synchronization type depending on circumstances. Whether manually or automatically, synchronization will perform by the user's selection. User also can set whether send attachment with the records.

All the records of sending and receiving can be viewed in data synchronization log, which is shown in Fig. 17. There are four statuses of synchronization records: waiting receipt, received successfully, sent successfully, and re-sent. User can select the record with status of "waiting receipt" and click the button of

Fig. 17. Data synchronization log.

"re-send" to re-send the file, then the fourth code of the file version will become the old value plus one automatically. Meanwhile, user can delete the local synchronization file.

VI. CONCLUSION

This paper focuses on designing the framework for a system to support the ship structure lifecycle management process through unified data platform and data synchronization. The system is designed to reflect a management environment preventing human error and unexpected delay under complex interactions between divided user roles. The feature of mutual dependence among subsystems is also taken into account in the framework design.

This paper also makes an analysis of modeling problem in current ship structure lifecycle and proposes an information integration method for CAX models using XML. The core of solution is using an integrated information model to record, save and manage data of structural members based on a unified and extensible data structure.

The application service platform is realized by adopting exertion-oriented programming solutions and 3D graphic programming technologies. Through the pilot project, the designed framework proves to be applicable and effective to actual structure lifecycle management practice. The system can assist different user roles in recording maintenance data, analyzing performance and monitoring status of ship structure.

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