A New Approach to Ship Design Automation: Vertex Expert System for Shipboard Equipment Layout

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Abstract. The impact of expert systems is widely spread in various industrial fields. They are also considered as a key technology to build up CIMS (Computer Integrated Manufacturing System). Ship design automation is discussed from the expert system approach as one of problems in the design stage of shipyard CIMS. Layout design is chosen from various ship design works, because it seems to contain many interesting points from the viewpoint of knowledge engineering. A layout expert system for shipboard upper deck equipment named "VESSEL" (Vertex Expert System for Shipboard Equipment Layout) has been developed. It has been certified that technology of expert system and picture perception are much effective to support layout design works.

Keyword. Artificial intelligence; Computer-aided design; Computer applications; Ships; Expert system; Layout design; Computer-integrated manufacturing.

INTRODUCTION

In the Japanese shipbuilding industries, computerization such as CAD or CAM has been progressed since 1960s and 1950s respectively, and nowadays, major shipbuilders have already developed their own CAD/CAM systems and used them for their daily industrial activities.

Generally speaking, these CAD/CAM systems can computerize design work and manufacturing to a certain level. However, their functions or performances are not yet satisfactory in respect of the inherent meaning of CAD or CAM. We should further pay efforts to revise them and complete them to shipyard CIMS and ship design automation.

The following problems are still remaining in the today's CAD systems:

1. Modelling of design objects is insufficient as a total model through design stage to manufacturing stage. It has been recognized important that a unified model should express and process both design and manufacturing information (data). Geometrical information is necessary but insufficient for modelling of design objects.

2. CAD systems are huge and complex, therefore their functions are not flexible. As a result of frequent requirements of upgrading CAD systems, they have become huge-size software consisting of several millions of steps, and in addition, they are generally written in FORTRAN.

It is very hard to add new functions or improve old functions, so the performances of the systems are inevitably limited.

3. Naturally, CAD systems have easy-to-use man-machine interface such as a mouse and a tablet. But it is still not friendly to designers. We need more flexible communication interface.

4. Modelling of design processes is insufficient. Modelling of design objects should also correspond to actual design processes. Modelling of design processes includes generation, modification of design objects. Present CAD systems can not support these design processes.

To advance ship design automation, we should solve these problems first. Next problem is how to deal with designers' intent. Considering recent innovation in knowledge engineering, expert system technology seems to be the nearest answer for that. At the same time it may also be able to represent design processes or design objects.

Layout design is one of the typical design works in ship design, and automation of layout design seems to include not only CAD features but also expert system features. We had better investigate automation of layout design from both CAD system and expert system. In this paper, we will deal with layout design in respect of how to use expert system technology and how to match it with CAD system.

LAYOUT OF EQUIPMENT

In this chapter, we will, first of all, analyze layout of equipment in ship design and extract their features, focusing our attention on shipboard upper deck equipment layout. Then we will discuss how to implement expert system to such design work.

Layout of Equipment in Ship Design

Reviewing ship design work, there are many kinds of jobs to determine equipment arrangements, such as main engine/auxiliary machinery arrangement in engine room, pump/piping arrangement in pumproom, piping and outfitting arrangement in tank or on upper deck, cabin arrangement, furniture arrangement and so on.

Ship designers synthesize many kinds of design objects and determine their layouts in accordance with various design methods, some of which are established as shipyard's design standards and some of which are owned by designers themselves.

In such design processes, designers usually use many kinds of design knowledge, rules, formulae, criteria and sometimes designers' know-how or sense, some of which are peculiar to the design objects.

But as a whole, they can be classified into following three categories as shown in TABLE 1, and their features are summarized as listed below.

1. Designers synthesize many kinds and large amount of design objects at a time and so-called "topdown strategy" is used to determine equipment layout. For instance, as to machinery and piping arrangement on upper deck, following procedure is applied.

- To arrange machinery first and in succession, piping follows.
  (Layout proceeding from upstream jobs to downstream jobs is applied.)

- To arrange mooring winch first and after that, relevant mooring fittings such as stand rollers, bollards, chocks etc. follow.
  (Layout proceeding from more important design object to less important one is applied.)

- To assume rough arrangement of design objects according to their functions and usages respectively, modify it step by step by checking the performance globally, and finally settle them to satisfactory positions.
  (Step by step approach using assumption, check and rearrangement is applied.)

- To rearrange design objects by synthesis from macroscopic point of view.
  (Layout proceeding from designers' sense is applied.)

TABLE 1 Typical Layout in Ship Design

Category	Contents	Example
A	Machinery arrangement inside compartment	Machinery arrangement in engine room Furniture arrangement in cabin Machinery arrangement in steering gear room
B	Compartment arrangement	Cabin arrangement in accommodation
C	Piping arrangement inside compartment	Piping arrangement in tank/on deck/in pumproom Piping arrangement in steering gear room

2. One design change causes another change. By the degree of importance of each design object, it is governed how far the change influence expands.

3. Layout design is situated downstream of functional design and upstream of production design. Design objects are arranged in accordance with the results of functional design but some modifications may be forced from production design. The layout work carries design data to its downstream jobs or feedbacks it to upstream jobs, if needed.

4. There are two distinctly different design works in ship design, namely outfittings and piping design, and hull structure design. As both are closely related, layout design as one of outfittings design should be also carried out under good cooperation with structure design.

5. There are two ways to determine geometrical configuration of design objects, i.e., by their own specifications (such as in the case of machinery, valves and outfittings) and as a result of their arrangement (such as in the case of cabins, compartments).

Design Procedure of Shipboard Upper Deck Equipment

The design work for shipboard upper deck equipment layout includes following jobs as shown in TABLE 2. Functional design of equipment is defined as a design activity to decide functions, performances or quantity of the equipment using relevant data or conditions given from upstream design stage, and to fix geometrical and relational design data which are necessary for layout design.

Layout design of equipment is defined as a design activity to decide layout of design objects in a given fixed space, considering their required functions, performances and working spaces without any difficulties in their installation, operation and maintenance. The job flow is shown in Fig.2.1.

TABLE 2 Design Jobs of Upper Deck Equipment Layout

Functional design of equipment	Layout design of equipment
Determination of legal equipment - Calculation of equipment number - Determination of legal equipment	Determination of layout of anchoring equipment - Hawse pipe - Windlass - Chain locker
Estimation of external force acting on hull - Mooring forces - Berthing forces	
Determination of mooring arrangement - Functional mooring arrangement - Mooring rope	Determination of layout of mooring winches and fittings - Mooring winches - Mooring fittings
Determination of mooring rope, windlass, winches and fittings	

Concept of Expert System for Equipment Layout Design

From the analysis and considerations described in previous sections, it is found to be essential for expert system of shipboard equipment layout design to support totally from functional design to layout design, and such expert system should have the following basic functions.

Functional design should have the capability

- To determine specifications of design objects based on shipyard standards, practices and design data of ships designed and/or built previously.

- To indicate summary of design work to designers

- To define geometrical, structural and relational data for design objects in accordance with their specifications determined.

- To modify determined specifications by designers' choice.

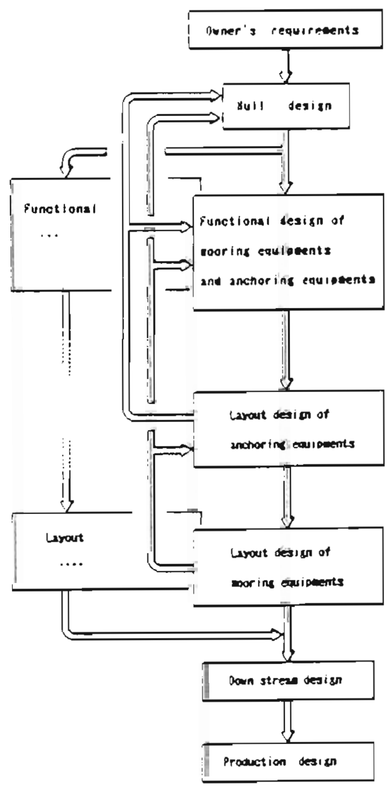


Fig.2.1. Design flow of shipboard mooring system

Layout design should have the capability

- To display equipment layout so that designer can perceive layout results with their eyes.

- To check and rearrange the initial result of arrangement by the system itself. Satisfactory equipment layout may be deduced efficiently by hypothesizing and poisoning the alternative arrangement.

In addition the system should be able

- To select best layout from several satisfactory equipment layouts.

- To modify determined equipment layout by designers' choice.

In the next chapter, we will introduce a prototype expert system named **VESSEL** (Vertex Expert System for Shipboard Equipment Layout).

EXPERT SYSTEM FOR SHIPBOARD EQUIPMENT LAYOUT VESSEL

System Outline and Function

The system outline of **VESSEL** is shown in Fig. 3.1. Design condition and initial input will activate **VESSEL**. Such data as ship's principal particulars, upper deck side line, living quarters are determined in the upstream of design stage, and in **VESSEL** they are treated as design condition and initial input. Operator will communicate with **VESSEL** through user interface and graphic display, if necessary or required.

Rule base is composed of three subsystems as shown in Fig.3.1. Specification subsystem determines specifications of mooring equipment and fittings. Anchoring subsystem determines hawse pipe location at upper deck level and at side shell level, using anchor type, size, chain diameter and those determined by specificaton subsystem. Then, arrangement subsystem determines the layout of mooring equipment and fittings according to their specifications.

Function of ART

ART is used to build this system. ART is one of the second-generation expert system tools having various expressions and functions (cf. APPENDIX).

The functions mainly used in **VESSEL** are as follows;

- *Schema* expression for objects
- *Production rule*
- Incremental loading
- *Action*
- *Viewpoint* (hypothesize and sprout)
- LISP.

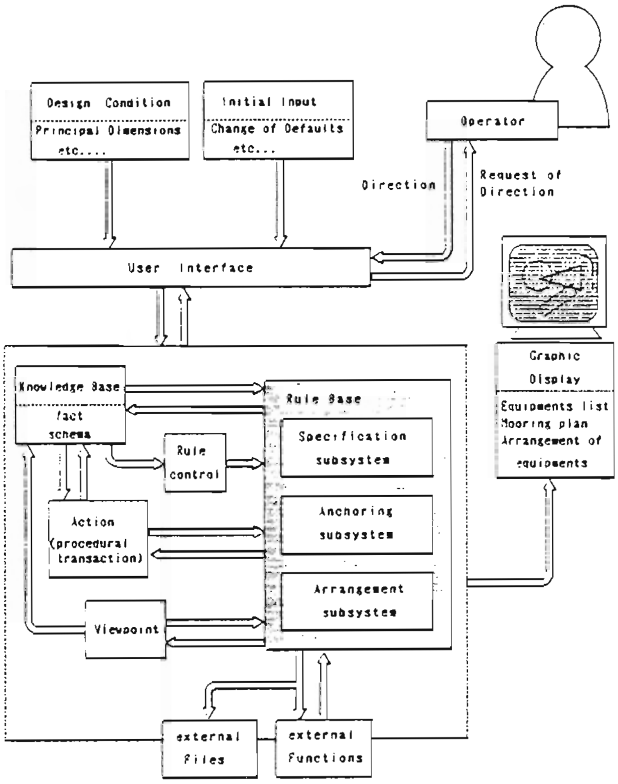


Fig.3.1. System outline of "VESSEL"

Representation of Knowledge

In the expert system, it is important how to represent the knowledge contained in the object. The knowledge used for determining specifications and arrangement of mooring equipment and fittings are grouped into the followings:

- Static knowledge : Knowledge regarding specification, intended services and geometrical shape of objects, and relations between objects

- Dynamic knowledge : Knowledge regarding handling of objects (such as arranging objects, determining specifications of objects, etc.), and knowledge to judge state of objects

- Procedural knowledge : Knowledge mainly regarding calculation (interference check between objects and movement, rotation, display, etc. of objects)

In **VESSEL**, the above knowledge is represented in the following functions of ART;

- Static knowledge : *Schema*
- Dynamic knowledge : *Production rule*
- Procedural knowledge : *Action* and LISP.

Objects Modelling

Object model(Ueno, 1988) is defined as a method to represent objects and is used for solving problem. It is expected to upgrade the capability and flexibility of expert systems. *Object model* should have the following abilities;

- To represent structure and function of objects
- To represent objects in hierarchical data structure
- To represent data in uniform and plain expression with good modularity.

Schema in ART is suitable for this purpose. In **VESSEL**, the objects are the mooring equipment and fittings on upper deck, and in their modelling, they are represented using the *schema* of ART. Fig.3.2 shows the object model represented by hierarchical structure.

The objects are basically represented by "is-a hierarchy" using the *schema*, and their common features are inherited from top to bottom. And also such an object that is composed of some objects (drum, engine and warping end), like a mooring winch, is represented as an object by the relation (has-part and has-child slots). Fig.3.3 gives an example of definition of such relation.

In a layout task, there are relations of superiority and inferiority among these objects. They are due to the functions or usages of the objects. In **VESSEL**, these relations are expressed as follows:

- Between mooring equipment and mooring fittings

  mooring equipment >> mooring fittings

  where the symbol ">>" denotes the left-hand side is superior to the right-hand side.

- Among mooring fittings

  stand roller >> shipside fittings >> bollard.

- Between other fittings and mooring equipment

  class A >> mooring equipment
  class B = mooring equipment
  class C << mooring equipment.

For example, fittings of each class are as follows:

class A: Accommodation house, cargo hatch, accommodation ladder, etc.
class B: Fore mast, small hatch, etc.
class C: Air pipe head, spare anchor, etc.

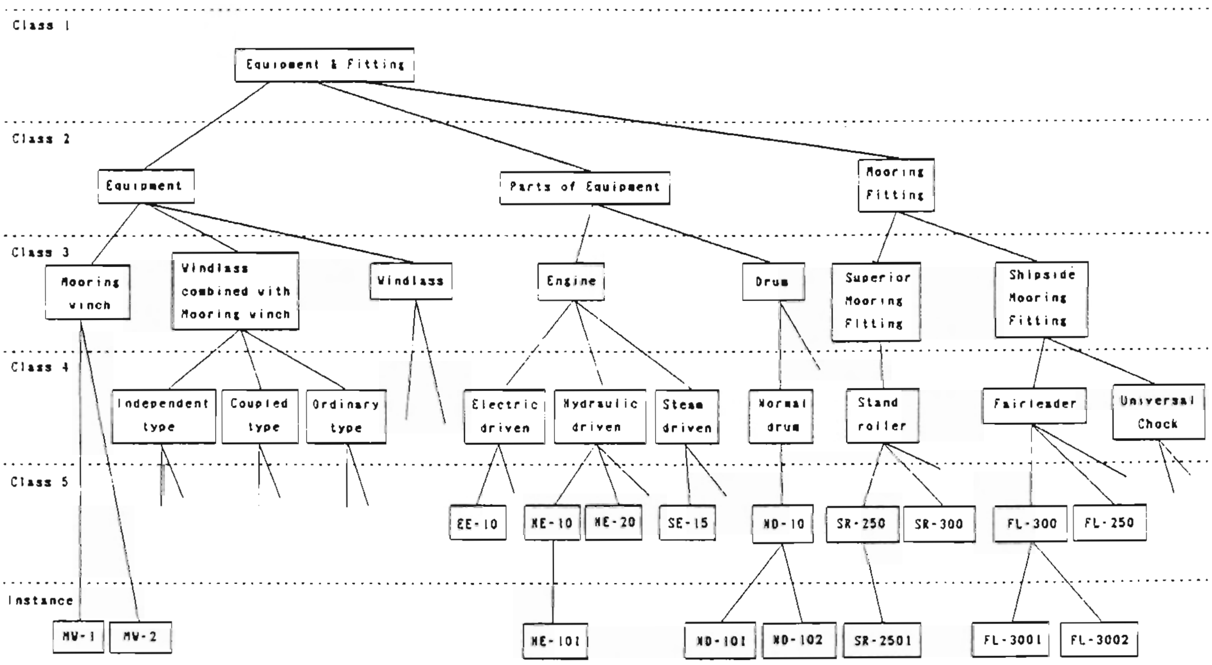
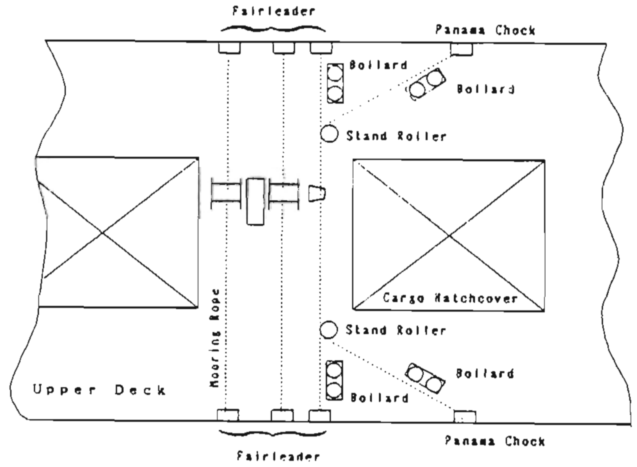
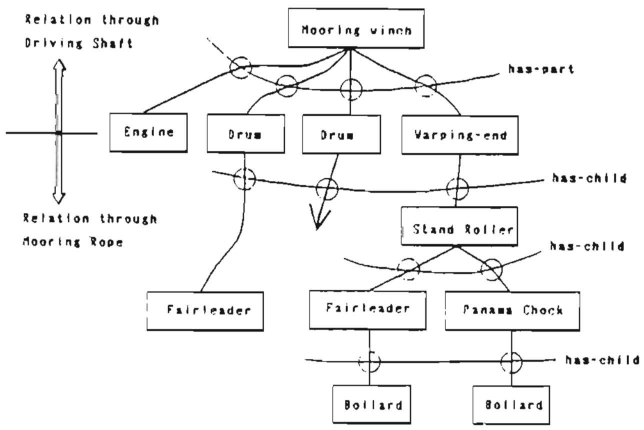


Fig.3.2. Hierarchical structure of object model



a. Arrangement of mooring equipment and fittings



b. Relation between mooring equipments and fittings

Fig.3.3. An example of the relation among objects

Strategy of arrangement

Arrangement of mooring winches and fittings is done in a trial-and-error manner. First, location of the main ones - mooring winches is fixed, and later location of mooring fittings are determined. In **VESSEL**, *viewpoint* is used for this purpose. The outline is explained below.

Arrangement of mooring winches.

a) Generation and abandonment of hypothetical *viewpoint* (first phase)

- Generation of initial hypothetical *viewpoint* for each mooring winch

Initial location of each mooring winch is determined based on its service and preliminary rough position, and in the vicinity of the initial location, at most five hypothetical *viewpoints* are generated.

- Abandonment of *viewpoint*

The following states are prohibited in any *viewpoint*. Those *viewpoints* which involve either of them are abandoned.

* Excessive fleet angle
* Physical interference between class A fittings and mooring winches
* Functional interference between mooring ropes and class A fittings

b) Generation and abandonment of hypothetical *viewpoint* (second phase)

- Re-generation of hypothetical *viewpoint(s)* in a same group of mooring winches

Mooring winches having the same preliminary location such as "fore", "mid-for", "aft", etc. determined by specification subsystem are grouped. Then one or more hypothetical *viewpoints* are re-generated by combining those generated in a) for each group of mooring winches.

- Abandonment of *viewpoint*

The following state is prohibited in any re-generated hypothetical *viewpoint*. Those *viewpoints* which involve it are abandoned.

* Physical interference between mooring winches

Arrangement of mooring fittings. Mooring fittings are arranged in the order of superiority using the *production rule* of *if-then* form based on their parent-child relations with respective mooring equipment (drum and warping end). After that, their interference with other fittings on upper deck are checked, and if any inconvenience is found, they are rearranged by the *production rule* based on parent-child relations and superiority-inferiority relations in arrangement among these mooring fittings and other related fittings.

Representation of Objects' Shape and Judgement of Physical Interference of Equipments

Strictly speaking, the arrangement of equipment is a three-dimensional matter, but it can be handled approximately as two-dimensional. In **VESSEL**, the geometrical shape of each object is represented by a polygon data (Hasegawa and others, 1989).

The physical interference between objects is judged using LISP functions which check the various relations among polygons, lines and points. For more detail, refer to Hasegawa and others(1989) and APPENDIX.

Picture Handling of Objects

During the system operation, graphic information of the objects is important, because designers can confirm the results by their eyes. In **VESSEL**, a polygon represents the geometrical shape of each object and it is treated as list structure of vertices data. On the other hand, data for graphics are represented by hierarchical structure of *graphic schema* in the corresponding *schema* of objects.

The control of *graphic schema* of objects is done as follows. First, a graphic object name is set to a *slot* value of a *schema* of the concerned object. Next a *production rule* refers the *graphic schema* name by its left-hand side. Then it changes the *slot* value (data of location and/or rotation angle) of *graphic schema* name in its right-hand side.

ARRANGEMENT OF MOORING EQUIPMENT ON UPPER DECK BY VESSEL (EXAMPLE)

Design Ship

130,000 DWT Bulk Carrier (Horyu-maru)

Principal dimensions

Length overall	: 270.0 m
Length between perpendiculars	: 260.0 m
Breadth moulded	: 43.0 m
Depth moulded	: 23.8 m
Deadweight	: abt.132,600 M.T.

The functional arrangement of mooring equipment in this ship is shown in Fig.4.1.

As explained in System outline and function, **VESSEL** determines specifications of mooring equipment and fittings, and arranges them on the upper deck. In this case, the following conditions are assumed.

- Specifications are to be determined for all mooring equipment and fittings. However, arrangement is to be determined for those only in the fore part.

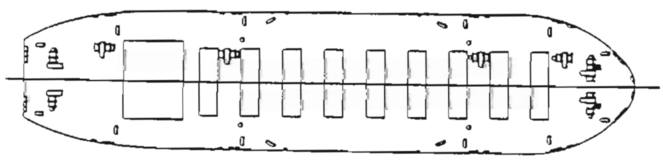


Fig.4.1. Functional arrangement of mooring equipment (design ship)

- Location of the hawse pipes is to be previously given.

- The upper deck side line is to be previously given.

Determination of mooring equipment and fittings

Determination of specifications of mooring equipment and fittings. First, the equipment number is calculated, and specifications of legal equipment are determined (cf. Fig.4.2a).

In the column of "Legal Equipment", classification society's requirements for each of anchor, anchor chain, tow line, and mooring line are displayed as "Required by Classification". Then, their specifications determined by **VESSEL** are displayed as "Proposed by Shipyard". In the column of "Design Information" on this screen, the equipment number is displayed.

Mooring forces are calculated, and an outline of mooring lines is determined (cf. Fig.4.2b). In the column of "Design Information", the head-on wind area, broadside wind area, wetted surface area, design wind velocity, current velocity, and calculated mooring forces are displayed. Then, a mooring plan suitable for this ship's deadweight is loaded into **VESSEL** from the standard design data file, and in the column of "Mooring Layout", required mooring specifications including outline arrangement of the mooring winches and fittings are displayed.

Subsequently, **VESSEL** determines kinds and types of mooring lines (wire, synthetic fiber rope, etc.) according to the ship kind, and finds a required breaking force, diameter, etc. of mooring lines. They are displayed in the column of "Legal Equipment".

After the required number, diameters, kinds and types of mooring lines are determined for each of their intended services, required specifications of mooring equipment and fittings are determined according to these mooring lines' breaking forces, diameters, and services (cf. Fig.4.2c). These specifications are displayed in the columns of "Deck Machinery" and "Deck Fittings". By the information in the columns of "Mooring Layout" and "Design Information", the designer makes a final decision of specifications of mooring equipment and fittings. Change of these specifications is possible through a key-in operation in the command window.

Arrangement of mooring equipment and fittings. First, the upper deck side line, accommodation part and class A fittings such as cargo hatches, which should be considered in arranging the mooring equipment and fittings, are fixed to their positions and displayed. This screen is divided into two windows showing a mid-aft and a mid-fore part of upper deck equipment arrangement respectively.

By utilizing the hypotheses using *viewpoints*, the first possible arrangements where mooring equipments do not interfere with each other nor with other class A fittings on the upper deck is obtained as a solution. Under this arrangement, related mooring fittings are located. This is a candidate of solutions (satisfactory solution). If there is a plural candidates of solutions, the designer calls them one by one and finally judges a most desirable one. Fig.4.3. shows one of such candidates of solutions.

EVALUATION

Through the development of expert system **VESSEL**, following conclusions are obtained:

1. It is important for equipment layout expert system to have following functions, and these should be taken into account in case of expert system design and expert shell selection.

<u>Flexible knowledge expression.</u>

- Expert shell can easily express design knowledge, rule, design know-how and geometrical data in their suitable form.

- Expert shell can have good linkage with external data base, because expert system needs to refer a lot of design data such as geometrical and relational data of machinery, hull structure and so on.

<u>Establishment of trial-and-error design.</u>

- At layout design, expert shell can abandon useless hypotheses efficiently using *contradictions*.

- Expert shell has good user interface to communicate with a designer. Through such interface, a designer can evaluate and modify layout plans easily and smoothly.

<u>Easy picture handling on a computer.</u>

- Expert shell can handle pictures in a form closely related to expert knowledge.

2. It is comparatively convenient to extract expert's knowledge by separating the design work into input, process and output parts and analyze each of them. But in general, extraction of knowledge from domain experts seems to be difficult, especially for works based on a lot of know-how or experiences.

3. A proto-typing procedure should be applied to the development of expert system, because it is impossible to remove uncleared part of expert system specification to be developed at an initial stage of system development.

4. Concept of *object model* is much useful in modelling design objects on a computer. To get suitable modelling of design object, it is necessary to analyze design work deeply and consider knowledge processing on a computer.

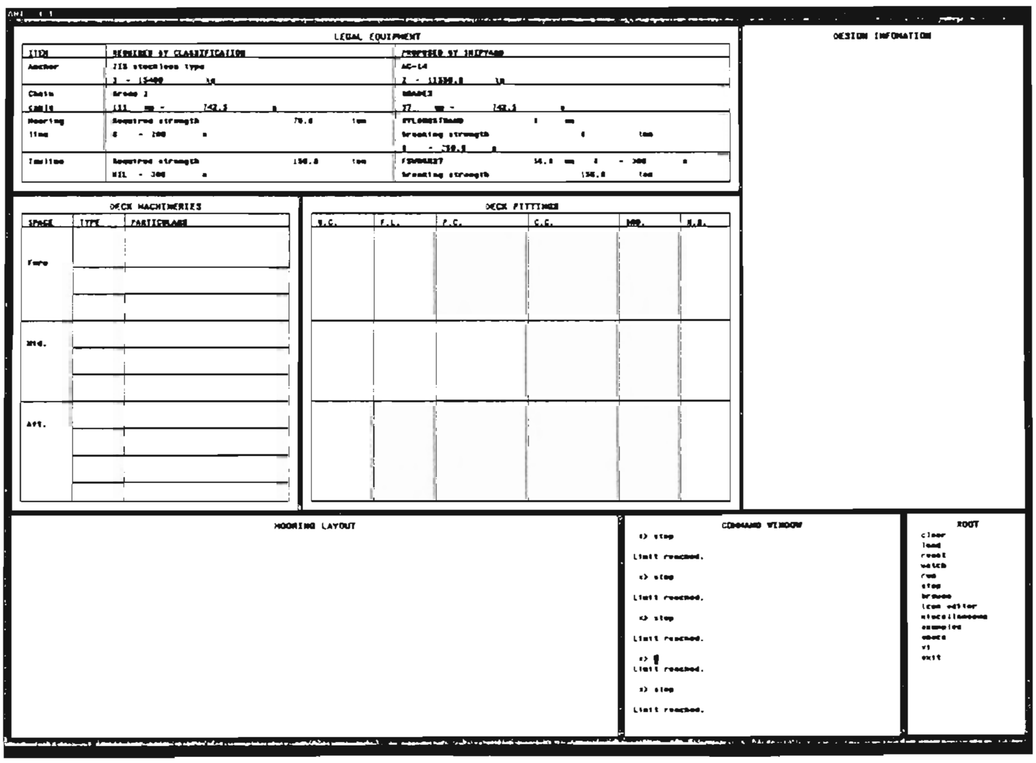


Fig.4.2a. An example output of specification subsystem (phase 1)

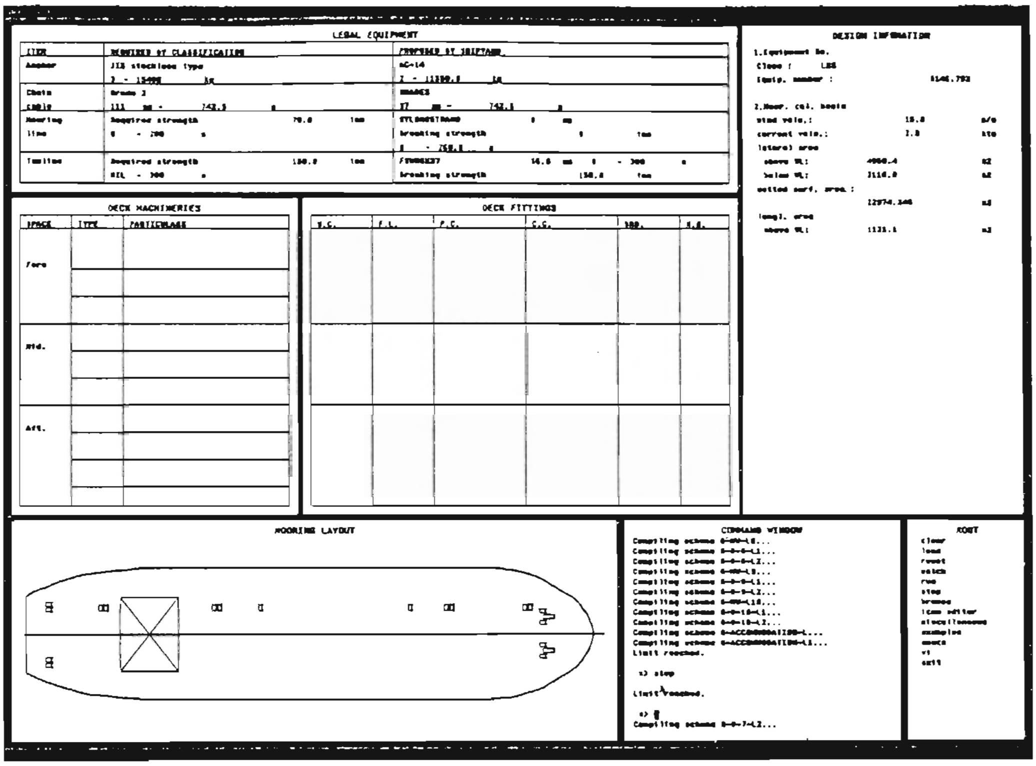


Fig.4.2b. An example output of specification subsystem (phase 2)

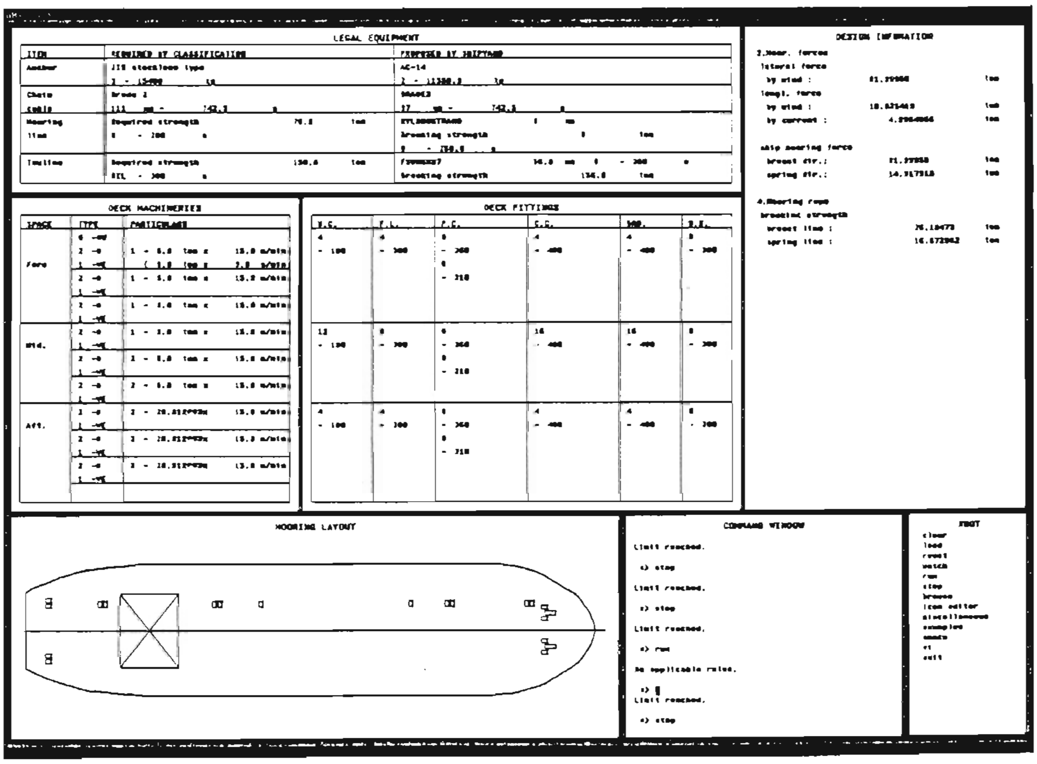


Fig.4.2c. An example output of specification subsystem (phase 3)

5. In layout design, it is important to analyze functions, performances and design knowledge deeply, to define location dependency among design objects and to apply "topdown strategy" and "generation and testing" method properly.

CONCLUDING REMARKS AND SCOPE FOR THE FUTURE

It is said that about 500,000 parts are assembled and about 10 gigabytes of information are handled to construct a whole ship. Besides, each ship is ordered separately. How can we manufacture various kinds of products efficiently, each of which is ordered a few and is assembled by thousands of parts? One of the solutions is to use low-cost labours. However, recent trend of a rise in labour costs and a fall in international competition cause the rapid requirement to the development of CIMS in Japanese shipbuilding industries.

The main aim of CIMS is to avoid unnecessary movement of things, men and information. The former two items are already reduced by new layout and automation of shipyards and by quality control movement etc. Reduction of information is believed to be very difficult. Similar but different sets of information (data) are used in different sections to handle the same thing. Men are necessary to the interface between them. They are converters or a kind of filters of information.

By the way, designing is a creative work and thus belonging to human-oriented activities. This paper showed an ability to replace some part of designer's judgement with picture handling to a computer. Especially in the initial design or in the tender estimation, our system will be of great worth. We should, of course, refine the system more and more, but it is certified that expert systems can be applicable even to the design works.

As we can establish the way to a kind of visual perception, many other applications, in which pictures must be handled, are replaceable by a computer. In the reference (Hasegawa and others, 1989), we have proposed a concept of *spacious distance* between two pictures. This concept must be one of the key to understand the beauty of layout and other human visual perception. As well as the basic functions for picture perception described in Appendix, we can develop the interface between an operator and CAD systems. We can call it an intelligent CAD system. In a usual CAD system, an operator must specify the definite point to put every element such as lines, circles etc. However, in an intelligent CAD system, an operator can instruct in several ways. Here are some examples: the element is put just touching to the specified picture, or it is put so as to be seen the equivalent distance between two other pictures, etc.

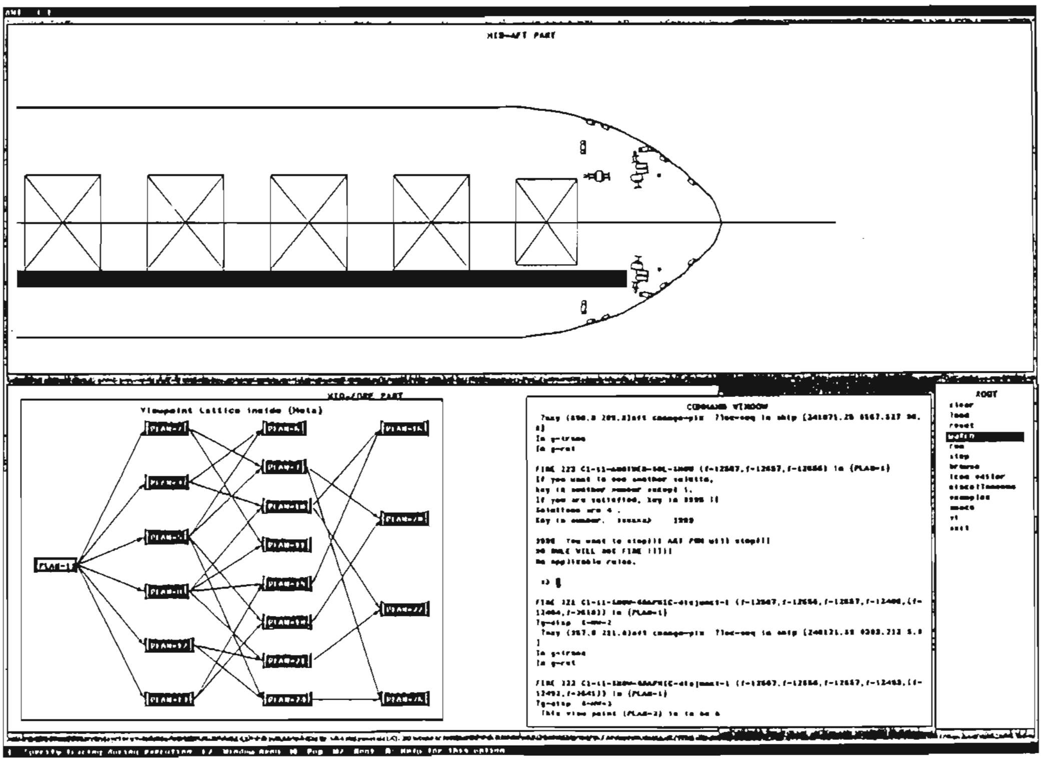


Fig.4.3. An example output of arrangement subsystem

Lastly, we would like to conclude this paper. Through the development of **VESSEL**, the essential and requirements of the layout expert system, developing procedure of the expert system, and modelling of the design objects were investigated. Expert systems and functions of picture perception are essential and useful for layout design and other picture handling applications.

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APPENDIX

FEATURE OF ART

ART is a second-generation expert system tool which stands for Automated Reasoning Tool. ART has many functions, such as *schema*, *rule*, *hypothesis*, *action*, *viewpoint*, and so on. Here, we explain some functions of ART mainly used in **VESSEL**.

Schema

Schema system is based on the *frame* theory, and it is a method to express objects to be treated with expert systems. An object may have its own name, own function, own characteristics and relations with other objects. Such attributes and relations can be expressed in a *schema*. Objects in an expert system are sometimes related in inheritable hierarchy. *Schema* system maintains the inheritance automatically.

For example, a definition of *schemata* as shown below expresses a part of hierarchical objects actually used in VESSEL;

```
(defschema mooring-winch
   (is-a equipment))

(defschema MW-1
   (is-a mooring-winch)
   (has-part HE-101 ND-102)
   (usage breast-line))

(defschema HE-10
   (is-a engine)
   (capacity 10 tons)
   (type hydraulic-driven))

(defschema HE-101
   (instance-of HE-10))
```

where the last *schema*, HE-101, is called an *instance object* and others are called *class objects*. Though there are no characteristic expressions in the *instance object*, the *schema* system of ART will refer following expressions from *class objects* to it;

```
(part-of MW-1)
(usage breast-line)
(capacity 10 tons)
(type hydraulic-driven).
```

Rule

The architecture of expert systems has been developed with the methodology of *production rules*. *Rules* expressed with the *if-then* form are activated with such objects that satisfy their if-clause. If there are plural *rules* activated, the inference engine selects a certain *rule* by so called conflict resolution. The selected *rule* may change or add some objects. Then, other *rules* may be activated with the changed or added objects again.

ART can express *rules* in various ways. This feature is useful to reduce coding troubles and to maintain *rule base*.

Hypothesis and Viewpoint

There are a few methods to explore the problem space. One of them is "Generation and Testing". *Hypothetical rules* can provide this method.

The *viewpoint* mechanism provides hypothetical plans. Using this function, ART can easily explore in terms of path-finding or process a system restricted by time.

Object-oriented Functions

ART can also express object-oriented functions. Sometime, an attribute of schema must be changed with other attributes. Such attributes may be declared as *active-value*, and connected with the certain function called *action*. *Action* can maintain the related attributes of *schemata*. Also graphic indication may be done with it.

User Interface

When an engineer develops an expert system, he writes source codes of *rules* or *schemata* with a text editor, compiles them and tests the behaviour of the system. If an unexpected behaviour is happened, he seeks what is wrong in source codes, and corrects it. Such procedure or developing cycle continues.

ART is designed considering such style of the system developing. The environment called *ART Studio* helps an engineer to continue such developing cycle. Also graphic routines have been included in the environment called *ARTIST*.

FUNCTIONS TO CHECK INTERFERENCE

In our system, VESSEL, we have implemented several functions to check picture interference, as shown in TABLE 3. For the detail of these functions refer to Hasegawa and others (1989).

All functions are written with LISP, because ART is well matched with LISP, and it allows flexible data structures.

TABLE 3 List of the Functions for Picture Perception

Name	Function
radian	To convert unit from degree to radian
degree	To convert unit from radian to degree
degrade	To degrade effective digits of floating-point number
line-length	To calculate length between two points
line-cross-point	To calculate a crossing point of two lines
line-cross-angle	To calculate angle between two vectors
check-point-on-line	To check whether a point is on line segment or not
check-line-parallel	To check whether two lines is parallel or not
check-line-cross	To check whether two line segments are crossing or not
check-line-touch	To check whether two line segments are touching or not
check-point-on-polygon	To check whether a point is on a edge of polygon or not
check-point-include	To check whether a point is including in a polygon or not
check-polygon-cross	To check whether two polygons are crossing or not
check-polygon-touch	To check whether two polygons are touching or not
check-polygon-include	To check whether a polygon is including in the other or not
check-interfere	To check spacious distance between two objects