A Study on Human Factors in Engine Room [1]

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Abstract

A study aimed at characterizing the human factors that affect machinery failure in engine room has been carried out, using damage data reported periodically and occasionally by surveyors of Nippon Kaiji Kyokai. The results of this study show that major failures, (those after which a ship is towed by tug or operates at reduced navigation speed), are mostly attributable to human factors for ships less than about ten years of age. On the other hand, constructive defects such as degradation in system performance due to wear and tear or corrosion, among other factors, may have a greater impact than human factors on the occurrence of major failures in the case of ships over about ten years of age. It may be concluded that human errors occur as the result of the chain of mistakes caused by human factors due to these constructive defects.

1. Introduction

Recently many discussions have been held on human factors and man-machine systems at various meetings at all levels throughout the world, aimed at decreasing the number of ship casualties and incidents of environmental pollution caused by ships. Several high-profile environmental and human disasters caused by oil leakage from tankers or the sinking of passenger vessels in recent years have resulted in introduction of new regulations as well as amendments to existing regulations following detailed investigation and discussions. Since a number of these major disasters were found to be the consequence of human errors, considerable research and discussion on measures for preventing of human error has already been carried out around the world.

It is generally recognized that 60~80% of accidents or problems are directly or indirectly attributable to human errors. There are still, however, only a limited number of reports which have examined machinery and electrical systems related failures or accidents onboard ships from the viewpoint of human error. Therefore almost all related discussion continue to be carried out more on the basis of theoretical perceptions rather than on actual circumstances onboard ships at sea.

In order to address this need, a study aimed at characterizing the human factors that affect machinery failure in engine room has been carried out using damage data reported periodically and occasionally by surveyors of Nippon Kaiji Kyokai(hereinafter, referred as ClassNK). The results compared data compiled from ninety-six cases of failures and associated problems which occurred to machinery on board the ships, and was provided by shipowners in Japan in response to a questionnaire.

2. Definition and Occurrence Process of Human Error

Before starting any study or analysis of human error, it might be helpful to review the process of how human error occurs based on a theory by Mr. A. Shoda, described briefly below [1)], and the definition of human error shown in Fig.1.

(1) Defects in a system, plant, industrial process, industrial method, or work procedure will become a source of the occurrence of human error in respect of machinery and hardware. This source may normally not be recognized and is often only determined during the investigation process after trouble has occurred.

(2) Trouble occurs after a worker commits a chain of mistakes due to human factors under conditions in which several sources of human error are present. Fig.2 shows this "chaining" process of mistakes based on human factors. However, trouble will not occur if this chain of mistakes can be broken before errors in operation or behavior occur.

(3) Certain personal and environmental factors can induce mistakes as a background to the occurrence of human error. Such personal and environmental factors include human relationship in the work place, working time, personal characteristics, the health condition of the person, work characteristics and environment conditions around worker, etc. These might include, for example, the environmental condition or state of mind of the worker or sometimes a desire to omit certain work process in order to complete a task more quickly. These personal and environmental factors that act as backdrop to the occurrence of human error are directly related to human factors. It is already well recognized that improvement of such personal and environmental factors is

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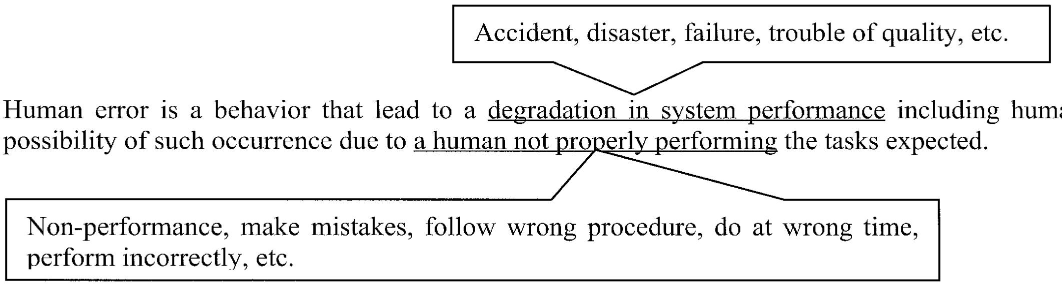

Figure 1 Definition of human error 1)

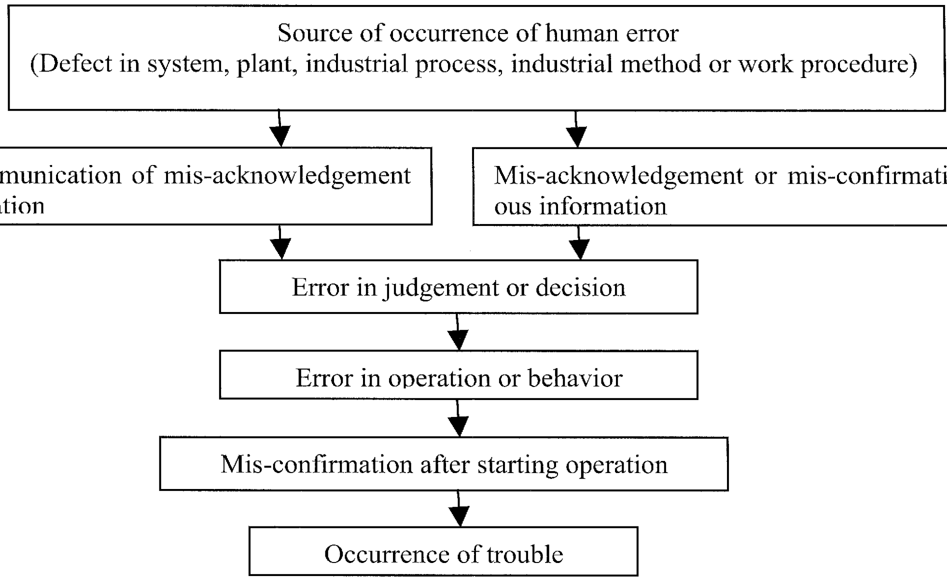

Figure 2 Chain of mistakes due to human factors

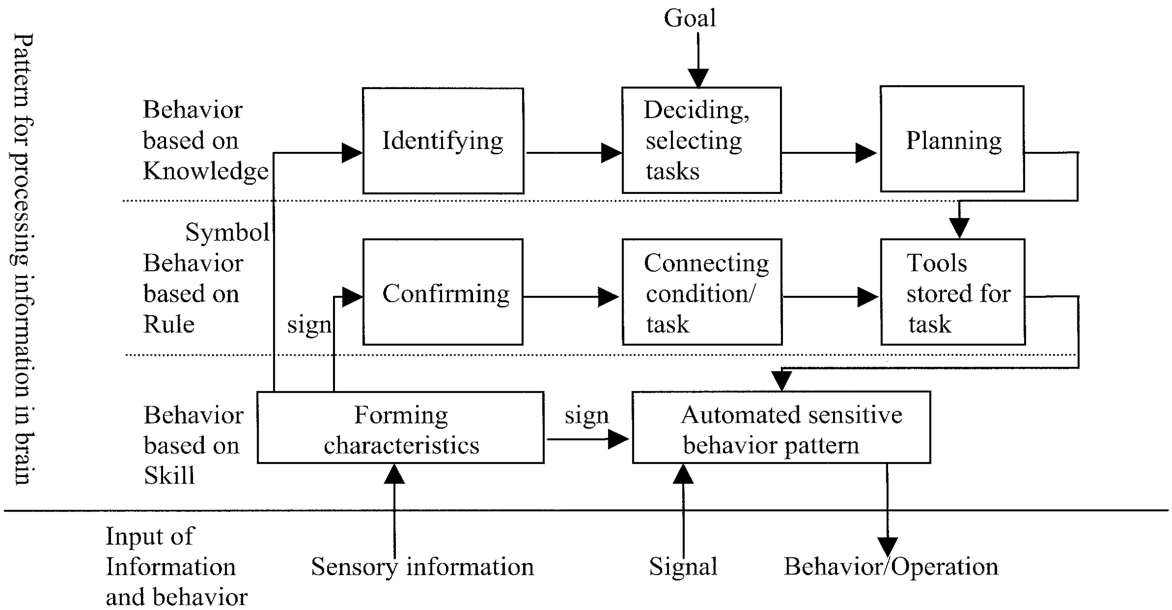

Figure 3 SRK Model advocated by Rasmussen 2)

very important to preventing the occurrence of human errors.

It is generally recognized that the human factors such as shown above normally differ between inexperienced and skilled workers. The SRK Model advocated by Rasmussen [2] shown in Fig.3 can assist in understanding these differences.

Rasmussen stated that human behavior can be categorized into three levels: behavior based on skill, behavior based on rules, and behavior based on knowledge. One of these three types of behavior will be selected depending upon the sensory incentive, knowledge obtained through education or training, work conditions requested, necessary action and so on. For example, a skilled worker can select his task immediately by taking short a cut to automated sensitive behavior pattern based on his memory of the relevant skill. However, the behavior of an inexperienced worker will be taken through identifying information, selecting and deciding task, planning task and behavior, selecting tool stored for task and sensitive behavior pattern. Moreover, a person who is undergoing training will take his behavior through the route of behavior based on rule.

These three categorized types of behavior are connected with three types of human error categorized by Reason [2] from the viewpoint of processing information in the brain;

(1) Mistake: Error that occurs in making the wrong link with external information
(2) Slip: Error that occurs in making the link with external information but reflects incorrect behavior or operation
(3) Lapse: Error which occurs as the result of incorrect or poor timing

Considering the relation between these different types of error and type of behavior shown in Fig.3, behavior based on skill or rule is easily prone to operative errors in which a slip and lapse occurs at the initial stage of the behavior. This is because the process of identification by forming characteristics of external information (checking mechanism) is often omitted. On the other hand, behavior based on knowledge will be easily susceptible to acknowledgement errors in which mistake occurs as a result of making the wrong link with external information [2].

Alternatively, the following categories of human error modes can be used;

(1) Omission error: Error resulting from the omission of behavior that should be undertaken (omitting/forgetting)
(2) Commission error: Error resulting from taking different behavior to that which should be taken (failing)
(3) Imperfection error: Error resulting from taking of imperfect behavior to be that which should be taken (missing)

3. Analysis to Identify the Characteristics of Human Errors

An analysis was carried out using data of major failures on machinery in engine room of ships registered with ClassNK, and reported by ClassNK surveyors during the period 1993 – 1998 as failures which resulted in the ship either being towed by tug or operating at reduced speed.

This major failure data contains 499 examples of main engine failure including failure of turbocharger, boiler, exhaust gas economizer, generator diesel, shafting equipment or the like that occurred during 1993 – 1998. In this study the cause of failure was categorized as resulting from assembling error, design error, fatigue, insufficient maintenance, fire etc., operation error, or vibration, as well as poor workmanship, taking into account the condition the failure itself and environmental conditions surrounding the failure. For example, “insufficient maintenance” was determined with an “omission error” when the failure could be considered as having been avoidable if sufficient maintenance and checks had been carried out regularly and properly prior to its occurrence, while “operation error” was chosen with “omission error” in cases where the failure could be considered as having been avoidable if sufficient checks of machinery such as lubricating oil pressure, cooling water temperature had been carried out regularly and properly, and sometimes “commission error” was selected in a case of unsuitable operation. With respect to the fracture of turbochargers, fracture due to intrusion of a foreign substance or wear and tear was determined as “insufficient maintenance” and “omission error”, while the fracture of turbocharger due to other causes was determined as “operation error”. Almost all of the failures concerned with the combustion chamber were judged to be due to “insufficient maintenance” and “omission error”. Failure of the crankshaft around a bearing was determined as “operation error” and “commission error”, or sometimes “omission error”. Propeller blade fractures were selected with “operation error” and “commission error”, however it is also assumed to be beyond our control.

Fig.4 shows the ratio of each cause for the total of all 499 major failures reported for 1993 – 1998. It can be seen that insufficient maintenance accounts for 53% of the total, while operational error accounts for 33%, assembling error 4%, fire etc. 3%, fatigue 3%, poor workmanship 2%, and so on. Fig.5 shows the ratio for each cause with each failed machinery or part of main diesel engine for the same 499 major failures. Cams and main diesel engine camshaft driving system were most generally effected by insufficient maintenance, while combustion chambers and turbochargers of main diesel engine have high percentage of operational error, as well.

Fig.6 shows the ratio of each human error mode for the total of all 499 major failures reported for 1993 – 1998. Here, omission error accounts for 48%, commission error 48% and imperfection error 4%. There is not a large a difference between omission error and commission error for these 499 major failures. It seems therefore that ship crews have the behavioral traits of omitting necessary work process, and of failing in work process, about the same rate.

Fig.7 shows the ratio of each error mode for these 499 cases of major failure during 1993 – 1998 together with the failed machinery and parts of main diesel engine.

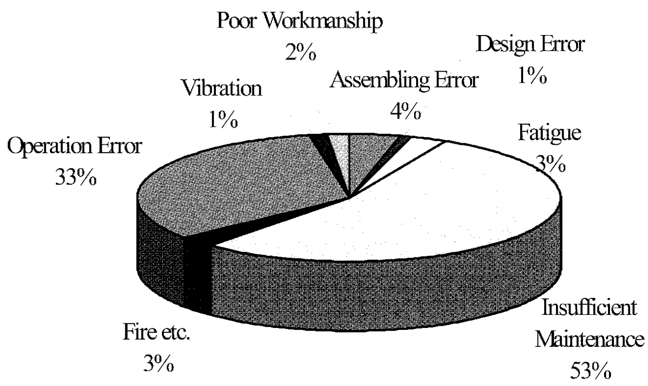

Figure 4 Ratio of each cause of major failure in engine room on 1993-1998

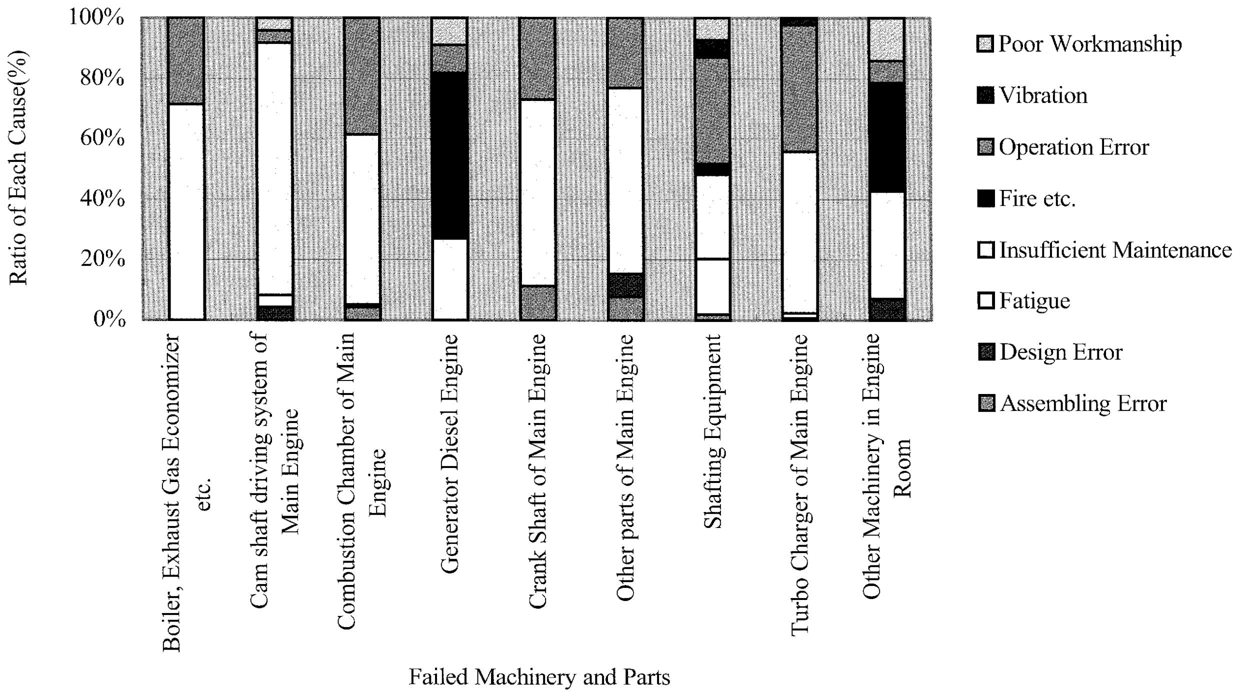

Figure 5 Failed machinery parts and their causes on major failures in Ships on 1993-1998

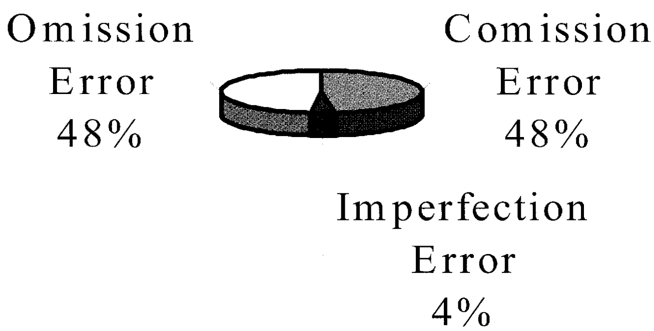

Figure 6 Ratio of each error mode on 499 major failures on 1993-1998

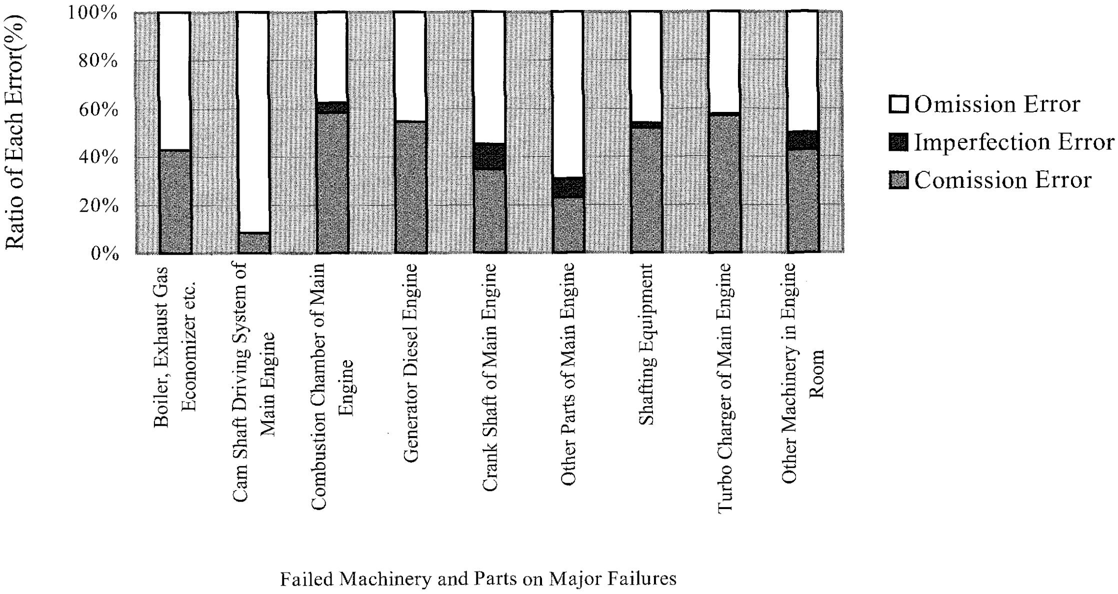

Figure 7 Ratio of each error mode with failed parts of 499 major failures on 1993-1998

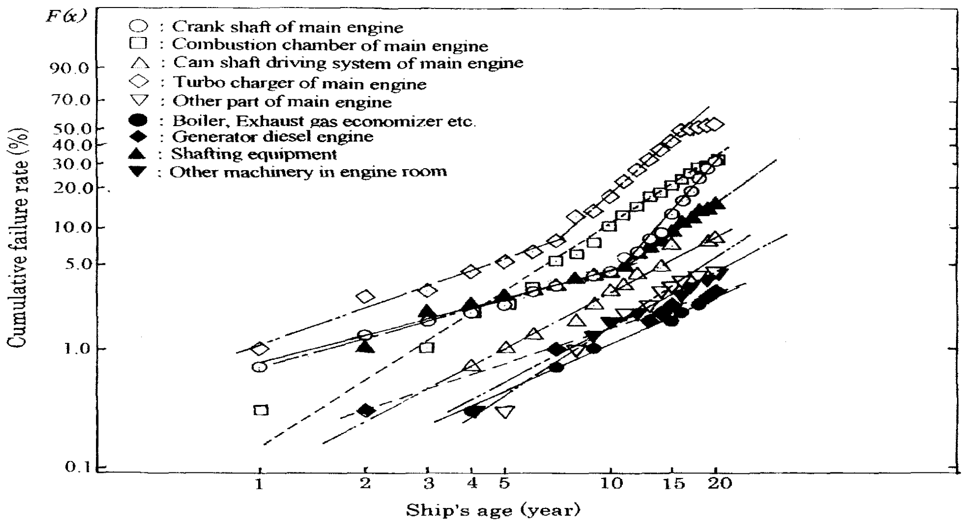

Figure 8 Cumulative failure rate of each major failure during 1993-1998 in Weibull Distribution

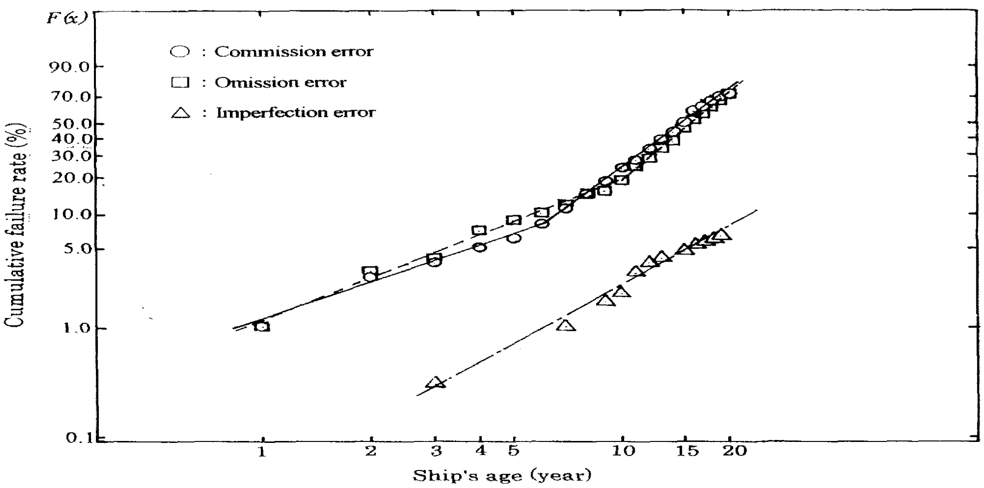

Figure 9 Weibull Distribution of each major failure categorized by error mode

Table 1. Shape parameters of Weibull Distribution of major failures during 1993-1998

Machinery & Parts of M/E		Shape parameter m	Failure Type
Main Diesel Engine	Combustion Chamber	1.8	Random Failure Type
	Crank Shaft	0.8 at ≦10 years old	Random Failure Type
		3.1 at ≧10 years old	Gradual Failure Type
	Cam shaft D. System	1.5	Random Failure Type
	Turbo Charger	1.0 at ≦7 years old	Random Failure Type
		2.4 at ≧7 years old	Gradual Failure Type
	Other Parts	1.9	Random Failure Type
Generator Diesel Engine		1.0	Random Failure Type
Boiler, Exhaust Gas Economizer		1.4	Random Failure Type
Shafting Equipment		0.9 at ≦10 years old	Random Failure Type
		2.0 at ≧10 years old	Gradual Failure Type
Other Machinery in E/R		1.4	Random Failure Type

Table 2 Parameter m of Weibull Distribution of each error mode on major failure during 1993-1998

Error mode	Parameter m	Failure Type
Commission Error	1.1 at ≦6 years old	Random Failure Type
	2.4 at ≧6 years old	Gradual Failure Type
Imperfection Error	1.7	Random Failure Type
Omission Error	1.1 at ≦10 years old	Random Failure Type
	2.6 at ≧10 years old	Gradual Failure Type

Although the ratio of omission error (omitting or forgetting a work process) is high for cams and camshaft driving systems, the main diesel engine combustion chambers and turbochargers as well as shafting equipment have almost same ratio of commission error (failed in work process) to omission error.

On the other hand, it may be concluded that the failures of machinery in engine rooms are caused not only by human errors but also constructive defects such as degradation of machinery due to wear and tear, corrosion, and fatigue cracking, for example, which can not be identified by daily or periodical checking or maintenance, may be related to these failures. In order to find some evidence of a relationship between human errors and constructive defects, analysis was conducted using Weibull Distribution.

The cumulative failure rate F(t), or the percentage of the total samples which can be expected to fail before a certain time t, can be derived from the following formula [3), 4)];

$$F(t) = 1 - \exp[-\{(t - \gamma)/\eta\}^m] \qquad (1)$$

$$t_0^{1/m} = \eta, \quad t \geqq 0$$

where:

t = Time

m = Shape parameter

t_0 = Scale parameter

γ = Position parameter

η = Mean time to failure, commonly defined as the time until 63.2% of the total will have failed

In a Weibull Distibution, the failure mode, which can generally be recognized by a large or small value for the shape parameter in the above formula (1), provides a good guide when examining the cause of failures and malfunctions, as follows;

$m < 1$: Decreasing failure rate, initial failure type

$m = 1$: Constant failure rate, random failure type

$m > 1$: Increasing failure rate, wear-out failure type

For example, it has been reported that the shape parameter, m, of marine diesel engine components is around 1.0, Hence, for example m = 0.6 ~ 1.5 in case of fuel injection valves, m = 0.9 ~ 1.8 in the case of exhaust valves, and m = 0.9~ 1.6 in the case of starting valves [4)].

It is also recognized that accidents or failure caused by human error will occur randomly, and it may be recognized that the failure caused by some defects in the construction of machinery, system or management etc. will have decreased failure rates for new ships and increased failure rates for old ships. Fig. 8 shows cumulative failure rates of each piece of machinery or main engine part, which were calculated using the data from the 499 major failures assuming that a total of 300 ships from 0 to 20 years of age would be navigating yearly. Shape parameters of each Weibull distribution in Fig.8 can be seen in Table 1.

Almost all of the shape parameters for machinery and main diesel engine parts considered range between 1.0 ~ 1.9, except for the case of crank shafts more than ten years of age, turbochargers more than seven years of age, and shafting equipment more than ten years of age. Although these shape parameters of 1.0 ~ 1.9 indicate that major failures occurred randomly, major failure of crankshafts more than ten years of age, turbochargers more than seven years of age and shafting equipment more than ten years of age can be understood to have occurred due to the influence of constructive defects such as degradation of machinery. It can be further concluded that the chain of mistakes caused by human factors, as shown in Fig.2, could not be broken under

Table 3 Causes of failures/malfunctions by type of human factor

Category	Human factor	No.	Total
Personal factors	Lack of knowledge, ability or experience of crew member	42	47 (21%)
	Work does not match personality or physical characteristics of crew member	0	
	Lack of motivation or morale	5	
Management factors	Insufficient education, training or instruction	23	94 (43%)
	Inadequacy of instructions, manuals, checklists, etc.	14	
	Non-fulfillment of inspection and repair	24	
	Insufficient information, communication, opinion exchange	10	
	Impractical work plans	4	
	Deficiency of directive order system	2	
	Bad custom on works	7	
	Bad teamwork	1	
	Indifferent attitude/insufficient attention to minor defects	9	
Work Characteristics & Environmental factors	Problem needed to be dealt with urgently (as an emergency)	9	65 (29%)
	Opinion from superior official or meeting required	4	
	Machinery needed to be shut down, stopped	3	
	Problem was difficult or dangerous to rectify	0	
	Difficult physical environment (due to noise, temperature, humidity, illumination or accessibility)	4	
	Time pressure	5	
	Crew preoccupied with other work	8	
	Working environment was carefree and thus conductive to careless or negligence	21	
	Aspects of the situation difficult to ascertain or predict	11	
Machinery factors	Lack of necessary machinery, valves, or indication devices	4	15 (7%)
	Difficult to understand meaning of signs, signals, etc.	2	
	Indication devices and gauges are dispersed, making effective handling and monitoring of machinery difficult	1	
	Indication devices and tools difficult to distinguish from each other	2	
	Unsuitable dimensions and placement of indication devices and tools	1	
	Valves, etc. are stuck or difficult to operate	1	
	Valves, etc. not conveniently arranged for effective operation	1	
	Spatial arrangement not adequate, effective, or well considered	1	
	Other causes	2	

conditions where the source of constructive defect could not be found through normal daily or periodically maintenance.

Fig.9 shows Weibull Distribution of each error mode for 499 major failures, it is generally understood that Weibull Distribution for human error should have shape parameter of about 1.0 because failure caused by human error may be assumed to occur randomly. Factors depending upon constructive defect are assumed to be stronger than human factors if the shape parameter has a different value from about 1.0.

Table.2 shows the value of shape parameters of each Weibull distribution categorized by error mode. It can be concluded from Table.2 that errors of commission at more than six years of age and errors of omission at more than ten years of age occurred in large part due to the strong impact of constructive defects. Such defects can be assumed to be a gradually increasing failure type caused by degradation of system performance due to such factors as wear and tear or corrosion, or the like.

However, Fig.9 and Table.2 show that major failures caused by errors of commission occurred randomly on ships less than six years of age while major failure caused by errors of omission occurred randomly on ships less than ten years of age. It can be concluded that preventing human error may be more effective in reducing the occurrence of majors failure in such cases.

A list of major human factors affecting failures and accidents onboard ship is shown in Table.3. This list was developed from a study done using a questionnaire to Japanese shipowners. Table.3 shows an analysis from the view of major human factors in order to prevent failures and accidents in the engine room which caused ninety-six actual cases of failures of machinery in the engine room.

It is generally recognized that human factors can be categorized into four types as summarized below [5];

(1) Personal factors: Cases where problems arise due to the failings of individual workers;
(2) Management factors: Cases where problems exist in management systems;
(3) Work characteristics & environmental factors: Cases where problems arise due to special characteristics of the work or environment conditions; and

(4) Machinery factors: Cases where defects or problems exist in machinery and equipment as a result of human error at the design or manufacturing stage.

For cases of failures or malfunctions which were thought to have been the result of human errors, the probable causes (in terms of the characteristics of each process and environmental factors) were classified in terms of the four different factor types described above, and are shown in Table 3. The table shows that failures and malfunctions caused by problems in management systems accounted for about 40% of the total number of cases, while work characteristics and environmental factors account for 30%, personal factors account for 20%, and human error related machinery factors represented less than 10% of the total number of cases. It can thus be seen from the Table.3 that about 70% of failures and malfunctions in engine rooms occurred either due to problems with the work management system or work characteristics and environmental conditions, and that problems arising from human-related machinery and equipment, and problems from personal factors are not nearly as prevalent. This suggests that it may be possible to prevent the majority of cases of failures or malfunctions caused by human error by improving the work management system and work characteristics/ environmental conditions of work onboard ships.

4. Summary

In a study using data from 499 major failures of machinery in the engine room of ships registered in ClassNK and reported by ClassNK's surveyors during the period 1993 – 1998 as failure after which the subject ship had to be towed by tug or operate at reduced speed, the cause of failure was categorized as assembling error, design error, fatigue, insufficient maintenance, fire etc., operation error, vibration and poor workmanship considering failed condition and environmental condition from the viewpoint that the failure had occurred after degradation of system performance as a result that crews did not carry out required tasks properly; for example, "insufficient maintenance" was classed as an "omission error" when the failure could be considered to be avoided if enough maintenance and check had been carried out periodically. The results were as follows;

(1) It can be concluded that 53% of the major failures reported occurred as a result of insufficient maintenance while 33% were due to careless operation.

(2) Given that human error occurs randomly; the shape parameter m of cumulative failure rate of failures caused by human error may be about 1.0. This may be understood to mean that major failures on ships less than about ten years of age may be due in large part to human error mainly. However, the occurrence of the major failures onboard ships over ten years of age can be assumed to be caused by constructive defects that resulted from degradation of system performance due to wear and tear, corrosion or the like. This is because all shape parameters are about 1.0 – 2.0 for ships less than ten years of age but over 2.0 for ships more than ten years of age in Fig.8 and Table.1.

(3) From this study on major failure, can be concluded that errors of both commission and omission occurred with same ratio, however these percentages may be subjected to modification in the event of a more detailed examination of the process of error.

(4) Cumulative failure rate of major failures caused by errors in commission as seen in Weibull Distribution tends to be of a random failure type for ships less than six years of age. Hence, it may be suggested that more attention should be paid to errors in commission in the case of ships less than six years of age. Moreover, attention must be paid to errors of omission for ships less than ten years of age because of the shape parameter of 1.1.

(5) It can be concluded that the source of constructive defects caused by degradation of system performance will disrupt the chain of mistakes caused by human factors for ships over about ten years of age and that are subject only to daily and periodical maintenance.

(6) Failures and malfunctions caused by problems in management systems accounted for more than 40% of the total number of cases reported, while work characteristics and environmental factors account for 30%, personal factors account for 20%, and human error related machinery factors represented less than 10% of cases. It can thus be seen from the Table.3 that about 70% of failures and malfunctions in engine rooms occurred either as a result problems with the work management system or with work characteristics and environmental conditions.

5. Conclusion

From the viewpoint of aiming to prevent failure of machinery in engine rooms, a study was carried out to determine the characteristics of human error which are assumed to occur daily. It can be concluded from the result of this study that major failures of machinery onboard ships are mostly attributable to human factors for ships less than about ten years of age. On the other hand, constructive defects may have a greater impact than human factors on the occurrence of major failures in the case of ships over about ten years of age.

Additional future study will be pursued in order to seek which characteristics of human factors and methods that can have the greatest impact on breaking the chain of mistakes caused by human factors caused by human factors under the existence of source of constructive defects.

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