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Corrosion Cost Survey in Japan
- Focusing on Transportation Industry -

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The Committee on the Cost of Corrosion in Japan was organized in 1999 jointly by the Japan Society of Corrosion Engineering (JSCE) and the Japan Association of Corrosion Control (JACC). Corrosion cost as of FY1997 was estimated based on the Uhlig and Hoar methods similarly to that conducted in 1974. The estimated corrosion cost of 1997 was compared with that reported for 1974 with speculation on the change in industrial environment. The overall costs estimated by the Uhlig and Hoar methods for 1997 were 3,938 billion yen and 5,258 billion yen, respectively, which were equivalent to 0.77% and 1.02% of the GNP of Japan. The process of organization formation, procedures for analyses and the results of cost evaluation were described by adjusting a focus on transportation industry.

Keywords *: corrosion cost, uhlig method, hoar method, railroad, shipping, shipbuilding, automobile industry*

1. Introduction

More than three decades have passed since the first analysis of the corrosion cost of Japan was reported. In the paper of 1974 it was reported that the corrosion loss in Japan without including the indirect loss was 1 to 2 percent of Gross National Product (GNP) 1). Since then Japan has experienced economic growth and drastic change in industrial structure. In consideration of the changing environments it was thought inevitable that the corrosion cost should be re-estimated based on new data and statistics. The present paper deals with brief summary of 1997 survey in general with the introduction of activities of and individual sector.

2. Corrosion cost survey in Japan as of 1997

National Research Institute for Metals (NRIM), currently National Institute for Materials Science (NIMS), which was affiliated formerly to Japanese Science and Technology Agency (STA) had been conducting a ten-year project of Ultra-Steels (STX-21). The project was governmental funded and aimed at developing innovative steels of hyper-performance for infrastructure, which would contribute to the conservation of environment and energy by minimizing the consumption of natural resources. In the process of R&D of corrosion resistant steels in the Project it was felt desirable to estimate corrosion cost that meets social demand in more quantitative manner. Thus a contract was implemented to Japan Society of Corrosion Engineering (JSCE) and the Japan Association of Corrosion Control (JACC) for the survey on corrosion cost. The Committee on the Cost of Corrosion in Japan was thus organized in 1999 jointly under the above two societies. The committee was headed by a chairman, Prof. T. Shibata and was composed of six subcommittees dealing with individual industrial fields plus a subcommittee dealing with general planning and analysis. Fifty seven specialists participated in the Committee from universities, governmental institutes, nonprofit organizations and private sectors. Because of the limited amount of funding most of the participants joined on voluntary basis. Cost of corrosion in 1997 was estimated based on the Uhlig[2] and Hoar[3] methods similarly to that conducted in1974. A preliminary study of Input/Output method[4] was also carried out. In the present paper the results of 1974 survey are only briefly introduced since they have been already published elsewhere[5),6)] in detail. Activities and organization of Transportation Sector will be introduced where details will be described regarding how specialty analyses were conducted.

2.1 Summary of survey by uhlig method

2.1.1 Methodology

By Uhlig method corrosion cost is evaluated by the sum of flows of materials and chemicals that are consumed

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for the purpose of corrosion protection. Also devices and the processes for corrosion protection are added to the total cost of corrosion. In the previous survey of 1997[1] the following six items were taken into consideration: surface coating, surface treatment (painting, plating, etc.), corrosion-resistant materials, inhibitors, cathodic protection, and corrosion research. The corrosion cost was separately evaluated for each item, but it should be pointed out that among the evaluated values paint cost occupies the majority; it extends to 60% of total anti-corrosion expenditure.

2.1.2 Survey results

Table 1 shows the estimation by Uhlig method of 1997 and 1975 surveys. Total cost of 1997 was 3.9 trillion yen, which is 1.54 times that of 1975 estimate, 2.6 trillion yen. Compared with the GNP growth rate of 3.0 fold during the same period, the corrosion cost ratio increase between 1997 and 1975 is somewhat smaller than expected. In table 1. surface organic coating accounts for major share in corrosion costs, approximately one half both in 1997 and 1975. Metallic coating and inorganic processing comprises about 25 % of total cost.

Fig. 2 shows one of itemized presentation, cost of metallic and inorganic coatings of both 1997 and 1975. One of the remarkable change is the growth of galvanized steel which is primarily due to the application of galvanized steel sheet in automobile bodies. Another innovative trend observed in Fig. 2 is the increased demand of tin-free steel in 1997 which has become popular as a can material. In the 1975 statistics the tin-free steel was classified as a miscellaneous surface treated steel.

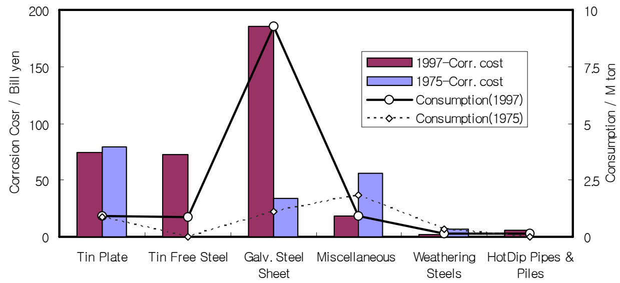

Fig. 1. Corrosion cost directed to metallic and inorganic surface finishings In comparison of total consumption

2. The hoar method

2.1 Methodology

By Hoar Method the Committee was divided into six subcommittees (sectors) where survey was conducted individually focusing the corrosion cost in the given industrial field in more detail. For this purpose each sector contacted industrial societies to obtain data or statistics, and circulate and collect questionnaires from their members. When it was thought necessary, sector members directly visited companies to have an interview to obtain detailed information necessary for more accurate analysis. However, some industries were reluctant to cooperate, leading to the deficit in data and under-estimation of corrosion loss. Under the present Committee following six sectors were organized, i.e., those specialized in energy, transportation, chemicals, machinery, metals and construction.

2.2 Summary of survey by hoar method

Corrosion costs as of 1997 and 1975 by Hoar method are shown in Fig. 5 for six industrial fields. The relative values of 1997 / 1975 are also shown for six fields. Results of Uhlig method are also given for comparison. The total of Hoar method is much higher than that of Uhlig method. This is owing to the fact that Uhlig method covers initial cost only while hoar method covers both initial and maintenance cost. As for the 1997 to 1975 ratio Hoar method gave higher value, indicating higher increase in corrosion

Table 1. Corrosion costs estimated by Uhlig method

Protective measures	1997		1975		Ratio of 1997/1975
	Anti-corrosion cost (Bill. yen)	Proportion (%)	Anti-corrosion cost (Bill. yen)	Proportion (%)	
Organic coating	2299.46	58.4	1595.48	62.5	1.44
Metal & inorganic processing	1013.52	25.7	647.62	25.4	1.57
Corrosion-resistant materials	443.24	11.3	238.82	9.4	1.86
Rust-preventing oil	63.68	1.6	15.65	0.6	4.07
Inhibitor	44.90	1.1	16.10	0.6	2.79
Electric anticorrosion	21.68	0.6	15.75	0.6	1.38
Corrosion research	41.65	1.1	21.51	0.8	1.94
Corrosion survey	9.56	0.2	-	0.0	-
Total	3937.69	100.0		100.0	

Table 2. Corrosion cost estimation by the Hoar in individual fields of industry.

Industrial Field	Corrosion cost (Bill yen)		Ratio of 1997/1975
	1997	1975	
Energy	456.8	59.8	7.64
Transportation	544.7	194.5	2.8
Chemicals	1070.0	154.3	6.93
Machinery	1561.5	427.8	3.65
Metals	27.6	26.5	1.04
Construction	1597.6	175.2	9.12
Total	5258.2	1038.1	5.07
Ratio to GNP (Hoar method)	1.02%	0.70%	1.46
Comparison (Uhlig method)	3937.7	2550.9	1.54
Ratio to GNP (Uhlig method)	0.77%	1.72%	

loss with time by Hoar method evaluation.

3. Corrosion cost survey in transportation

In the present paper focus is placed on the activities and analyses in Transportation Sector, where three branch fields of railroad, ship and motor vehicle were dealt with in more detail. In the Transportation Sector participated are eight members, two of whom are from governmental research institutes, two are from NGOs (Japan Ship-Owner's Assn., Japan Corrosion Engineers Assn), four are from private companies (iron and steel maker, shipbuilding, shipping, and paint production). To the survey we gained official support from marine transportation sectors both ship-builders and -owners societies. On the other hand land transportation societies and companies showed smaller interest in corrosion. In the latter case we collected necessary data from open statistics or by interview and visit to company and individuals.

3.1 Railroad transportation

Since the date of previous survey Japanese railroad transportation experienced drastic changes both in management and technology. In 1987 former Japan National Railway (JNR) was remodeled and split into eleven private companies that are collectively called Japan Railways (JR) group. Out of 27,268 km of railroads networking the country. JR controlled 20,135 km of the lines as of March 31, 1996, with the remaining 7,133 km in the hands of private local railway companies. Technological progress is seen in the expansion of high-speed "*Shinkansen*" lines, of which car body is prepared from aluminum alloy eliminating exterior corrosion problems. Other than the high- speed trains, many local and commuter trains have adopted bodies of aluminum alloy and stainless steel which reduced much in the corrosion cost in maintenance. Another social change observed in the two decades was a shift of freight from railroad to truck transportation. Obviously the majority of railroad freight cars have disappeared in these decades: Among the freight cars survived are tankers and container cars.

3.1.1 Survey methodology

Interviews and visits were conducted from selected major manufactures of railroad cars and repair factories of JR Group. The ratio of anti-corrosion costs to total manufacture and material costs was evaluated separately in production and maintenance. This ratio is hereafter called coefficient of corrosion cost and is denoted by γ. Cost of corrosion resistant materials such as stainless steels and aluminum alloys are classified as corrosion cost in production. The cost of painting including labor and paints occupies the major potion in maintenance cost of cars made of carbon steel body. For aluminum or stainless steel body cars, maintenance corrosion cost is assumed to be nil since there is no need of repainting.

3.1.2 Results of survey in railroad

Cost survey was conducted at selected sample factories, where the coefficients of corrosion cost (in %) were determined per unit of railroad car both for production and for maintenance. The coefficient was multiplied by nationwide production number and production cost of car units, yielding the nationwide corrosion cost in the production. Similarly by multiplying the coefficient of corrosion cost for maintenance, by the total number of cars in service, nationwide corrosion cost for maintenance was evaluated.

Table 3. Corrosion cost in the production of new railroad cars based on the statistics

Category	Production number (unit)		Amount of production (bill. yen / y)		Coefficient of corrosion cost (γ) in production (%)		Total corrosion cost (bill. yen / y)	
	1997	1974	1997	1974	1997	1974	1997	1974
Locomotive	4	322	1.8	19.7	-	0.57	-	0.81
Passenger car	1,425	2,113	141.6	73.9	3 to 19	2.14	8.66	1.55
Freight car	692	2,167	12.0	12.4	5	5.15	0.60	0.64
Total	2,125	4,602	155.4	106.0			9.26	2.30
1997/74 ratio	0.46		1.47				4.03	

Table 4. Corrosion cost in the maintenance of railroad cars in use

Category	Number cars in service (unit)		Amount of maintenance (bill. yen / y)		Coefficient of corrosion cost (γ) in maintenance (%)		Total corrosion cost (bill. yen / y)	
	1997	1974	1997	1974	1997	1974	1997	1974
Locomotive	1,996	4,826	19.6	26.24	-	0.57	0.98	0.81
Passenger car	50,902	45,116	135.0	129.25	3.3 to 10	2.14	7.94	12.67
Freight car	14,741	145,576	4.9	22.72	3	5.15	0.60	3.95
Total	67,639	197,517	159.5	178.20			9.07	17.45
1997/74 ratio	0.34		0.90				0.52	

Tables 3 and 4 are corrosion cost estimation for railroad cars in production, and in maintenance or repair, respectively. Coefficients of corrosion cost ranged 3 to 19% as shown in the tables.

The bottom rows of table 3 and 4 indicate cost ratio of 1997 to 1974. Owing to the diversification of transportation we see apparently a decrease in freight transport on railroads, and consequently a decrease in the production and maintenance number of locomotives and freight cars. On the other hand the coefficient of corrosion cost is soaring for passenger car. This corresponds to the more frequent use of stainless steel and aluminum alloys. We see a clear trend that increased anticorrosion measures decreased maintenance and repair cost. The use of corrosion-resistant materials in railroad is an excellent example of a case where the life-cycle cost(LCC) have worked effectively.

3.2 Shipping and ship building

Fig. 2 shows the statistics of tonnage expressed in dead weight ton (dwt.) and the number of ships in the Japanese merchant fleet. A clear trend is the reduced number of the ships of "Japanese flag" and the counter-balancing increase of the ships of "flag of convenience" (or "chartered foreign flags") and this trend still continues. A problem arises as to which degree the "Japanese ships" would be extended. If we included only those of Japanese flags, it would be detached too much from the actualities. In the following discussion we included ships of "flag of convenience" as Japanese ships as far as they were under Japanese ownership.

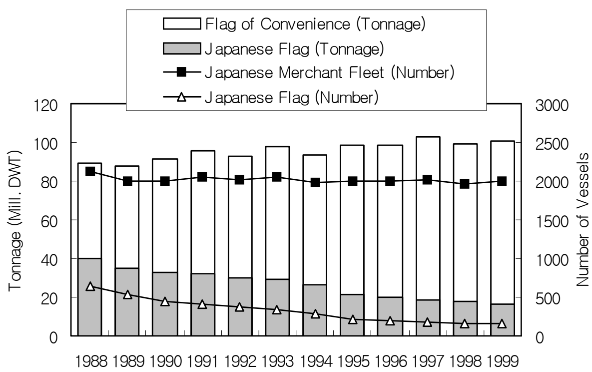

Fig. 2. Dead weight tonnage (dwt) and number of Japanese merchant fleet; based on the statistics by Japanese Shipowners' Association (JSA).

3.2.1 Corrosion costs for new ships

Corrosion cost estimation for new ships was carried out with the assistance of the Shipbuilders' Association of Japan by the following procedures: 1) To distribute to member companies a questionnaire regarding the ratio of expenditure in anti-corrosion measures to total costs of ship building (the ratio is hereafter referred to corrosion cost coefficient); 2) To multiply the building cost by the coefficient to yield the corrosion cost for each type of ship. The coefficient included coating, corrosion-resistant materials, cathodic protection, plating, etc. (including labor). Based on the above survey, we concluded that the coefficient of corrosion cost (γ) was 6.2%. Cumulative tabulations resulted in a total of 43.2 billion yen /year in corrosion costs in production of new ships.

The present coefficient of corrosion cost (γ = 6.2 %) was lower than that estimated previously, i.e. 9.0 % in 1975. The decreased coefficient is primarily due to the automation in painting despite the fact that painting area had increased by 1.5-fold after the double-hull structure was mandated for tankers by the regulation of International Maritime Organization (IMO) beginning from 1992.

3.2.2 Maintenance costs of ships in service

The Japanese Shipowners' Association (JSA) had been conducting questionnaires on the maintenance cost for ships that are actually in service to member companies, which were compiled in the form of annual statistical database. For the estimation of corrosion cost FY 1997, data beginning from April 1, 1997 to March 31, 1998 were provided to us. While the survey targeted ships of "Japanese flag" including both for "coastal shipping" (domestic) and "ocean-crossing" (international) use, it was converted nation-wide estimation by multiplying the tonnage ratio of flag of convenience to Japanese flag vessels

Table 5. Corrosion cost of repair and maintenance of ships in service (ships of "Flags of Convenience" not included)

	Dead weight tonnage (dwt) (x 1000)	Annual corrosion cost in maintenance (mill yen / year)					per dwt (yen/ton)
		Repair in dock		Offshore minor repairs* γ =0.50	Commodities for corrosion protection	Total	
		Hull* γ =0.75	Engine* γ =0.55				
Ocean-Crossing (Japanese Flag)	12,540	2,724	1,180	2,186	623	6,712	535
Coastal Shipping	775	1,733	1,189	590	263	3,799	4,890

*Corrosion cost coefficients indicated by γ are multiplied to original maintenance cost to give corrosion costs listed in the table.

(the ratio was 4.0 as of 1997 as shown in Fig. 2).

Items related to corrosion cost were extracted from the JSA data, to which appropriate corrosion cost coefficients were given: The pre-determined coefficients were 75% and 55% respectively for hull and engine repairs in dock, and 50 % for minor offshore repairs. Among commodities such items as paint and chemicals including inhibitors were included in the corrosion cost. In the cost of in-dock repair, major expense appeared in re-painting, surface finishing and the replacement of corroded steel parts.

Table 5 shows the summary of corrosion cost paid in the maintenance of ships in use. The total dead-weight tonnage (dwt) of ocean-crossing ships was 12,540 thousand tons, which required 6.71 billion yen annually for corrosion costs. In contrast the dwt of coastal shipping was 775 thousand tons, and 3.79 billion yen was spent annually to corrosion costs. The corrosion costs of "flag of convenience" ships were evaluated to be 4 times those of "Japanese flag", giving a total of 26.85 billion yen. The total corrosion costs of Japanese merchant fleet in service were thus estimated to be 37.35 billion yen.

3.3 Motor vehicles

According to statistics from the Japan Automobile Manufacturers Association, Inc. and other organizations, the total number of four-wheeled motor vehicles produced in Japan in FY1997 was 10,975 thousand as shown in Table 6 . Number of production, imported and exported motor vehicles (in thousand units) are also included in the Table6. Of this total, 4,553 thousand vehicles were for export. The total number of vehicles was used in the production costs. The total number of registered four-wheeled motor vehicles in Japan was 70,551 thousand as shown in Table 7.

3.3.1 Corrosion costs in automobile production

Based on publicly released statistics of materials shipped to the automobile industry, we attempted to evaluate the corrosion cost strictly from the point of materials transactions. The results are summarized in Table 8, where prices of 20,000 yen/ton and 200,000 yen/ton were allocated to galvanized steel and stainless steel, respectively as an excessive cost for corrosion protection. Using the statistics of the Japan Iron and Steel Federation (JISF) on local- and usage-categorized ordering of mild steel we determine the amount of galvanized steel sheets consumed in the automobile industry, while statistics of the Japan

Table 6. Number of motor vehicle production in Japan (as of FY1997)

	Four-wheeled vehicles (x 1000 units)				Motorcycle (x 1000 units)
	Passenger car	Truck	Bus	Sum	
Production	8,491	2,421	62	10,975	2,675
Export	3,579	919	54	4,553	1,459
Import	341	23		428	

Based on the statistics of Japan Automobile Manufactures Association (JAMA)

Table 7. Number of registered motor vehicles in use in Japan (as of FY1997).

	Four-wheeled vehicles (x 1000 units)						Motorcycle (x1000units)
	Passen-ger car	Truck	Bus	Special use	Light-weight car	Sum	
Registered No	40,477	8,819	242	1,430	19,584	70,551	1,225

Table 8. Corrosion cost estimation for motor vehicles by transactions of corrosion resistant materials between auto industries and material suppliers

Materials for corrosion prevention	Amount shipped (x 1000 tons)	Corrosion cost (billion yen)
Galvanized steel sheet	3618.8	72.4*
Stainless steel	93.4	18.7*
Paint	314.2	137.7
Total		227.8

*Estimation by the difference in price of resistant materials in comparison with carbon steel; i.e. 20,000 and 200,000 yen / ton for galvanized steel and stainless steel, respectively.

Table 9. Cost estimation of corrosion of a unit of compact car (1500 to 2000cc class)

Cost	Means of protection	Cost structure
Body 19,000 yen/unit	Surface treatment Pretreatment (degreasing, chemical conversion) Electropainting Anti-chipping coatings (stone-guard coat, undercoat) Sealing, anti-corrosion wax	Materials: galvanized steel, paint, resins, chemicals Labor: coating, sealing, waxing Energy: heating of baths of phosphating and electropainting Facilities: pretreatment and coatings, robots for painting
Parts 6,500 yen/unit	Exhaust system (muffler, exhaust system) Chassis component (radiator grill, suspension) Engine parts (oil pan) Transmission parts (propeller shaft)	Materials: stainless steels

The annual cost of corrosion in the production of automobiles was estimated as 25,500 yen/unit x 10.975 million units units/year = 279.9 billion yen / year

Stainless Steel Association were used for stainless steel. The statistics of the Ministry of International Trade and Industry (MITI) were used for the monetary transactions of coating materials. In terms of raw materials alone, corrosion costs were evaluated to be roughly 19,500 yen per vehicle.

For Japanese passenger cars of the 1500 to 2000 cc class, we received information from one of automobile manufactures on the per-vehicle basis. The figure was 19,000 yen per vehicle for chassis, plus 6,500 yen per vehicle for parts, making a grand total of 25,500 yen per vehicle. Compared with the 19,500 yen/vehicle value deduced from raw materials alone, it is somewhat expensive, but the difference is not excessive. Coating process been increasingly automated in the auto industry, resulting in the relative reduction in labor cost. Assuming an average price of 1.4 million yen per unit, the coefficient of corrosion cost to the price of unit in production is evaluated to be 1.8% ($\gamma = 0.018$). Multiplying total corrosion costs at production of 25,500 yen/vehicle by total number of vehicles produced of 10,975,000 gives us a total of 279.9 billion yen in annual production base.

3.3.2 Corrosion cost in automobile maintenance

Compared with production-related evaluations, corrosion costs for automobile owners depended widely on individual users, and it was difficult to conduct organized surveys to automobile users. Japan Automobile Service Promotion Association has been publishing reports on "Survey of Automobile Inspection Fees", which gave us unbiased data for automobile maintenance. Among the items reported in the survey we selected the chassis coating cost of 4,700 yen/vehicle as corrosion cost. Since in Japan the automobile inspection is mandated once every two years for private owned and one year for business use. In the evaluation of users' maintenance corrosion costs at the nation level, we multiplied the chassis coating cost of 4,700 yen/vehicle by 70,551,000 registered vehicles, and then divided by 2 because of the two-year cycle of the inspection, which gave an estimate of an annual figure of 165.8 billion yen.

3.4 Discussion on transportation sector

Summary of transportation sector is give in Table 10. For railroad cars maintenance-related corrosion cost decreased markedly compared with that in 1974, which is largely because an increase number of cars of which bodies were made either of stainless steel or aluminum alloys, eliminating coating costs. The use of corrosion-resistant materials in railroad cars helped to reduce lifecycle costs.

In FY 1997, the coefficient corrosion cost for new ships, 6.2%, was lower than the value of 9.0% for 1974. Despite the fact that during this period with double-hull structures

Table 10. Annual corrosion cost in the transport sector of Japan in 1997

	Corrosion Cost as of 1997 (billion yen)			Corrosion Cost as of 1975 (billion yen)			Ratio of 1997/1975
	Production	Maintenance	Subtotal	Production	Maintenance	Subtotal	
Railroad cars	9.3	9.1	18.4	2.3	17.4	19.7	0.93
Ships	43.2	37.4	80.6	23.0	34.2	57.2	1.41
Motor vehicles	279.9	165.8	445.7	117.1		117.1	3.81
Total			544.7			194.0	2.81

became mandatory for tankers and the coating area increased by 50%, decrease in the coefficient of corrosion cost was observed. This is attributed to the improved efficiency in coating processes, for example, use of advanced equipments and buildings exclusively for painting, outsourcing of labors, and automation.

Regarding ships in service, we should notice that corrosion costs increased only 9% since 1974, although dead weight tonnage increased to 103 million tons including the ships of "flags of convenience", which corresponded to the increase by 160%. Corrosion costs were maintained low through such measures as transferring docking yards from domestic to overseas ports where cheaper labor was available.

In FY 1997, the corrosion costs of automobiles in production, which were estimated to be 279.9 billion yen, were markedly higher than that of 1975, i.e. 97.5 billion yen. This was due to the increase in production (from 6.5 million vehicles to the 11 million level) and expensive measures that were taken for each vehicle. The increase in corrosion costs of automobiles in production should have led to a reduction in maintenance cost for users.

In shipping industry corrosion and its protection are still the major concern of owners and engineers. In the land transportation on the contrary by the adoption of corrosion resistant materials such as galvanized steel, aluminum alloy and stainless steel sheets in car bodies, major corrosion problems have been eliminated as far as exterior corrosion is concerned. We see a good example of reduced life cycle cost (LCC) at the expense of initial investment on materials.

4. Conclusion

Corrosion cost as of FY1997 was estimated based on the Uhlig and Hoar methods similarly to that conducted in 1974. The estimated corrosion cost of 1997 was compared with that reported for 1974 with speculation on the change in industrial environment. The overall costs estimated by the Uhlig and Hoar methods for 1997 were 3,938 billion yen and 5,258 billion yen, respectively, which were equivalent to 0.77% and 1.02% of the GNP of Japan. Under the committee six sectors specialized in industrial fields were organized. The transportation sector obtained the following conclusion.

The corrosion costs for transportation in Japan were as follows; 279.9 billion and 165.8 billion yen for production and maintenance, respectively in FY1997. In the land transportation by the adoption of corrosion resistant materials such as galvanized steel, aluminum alloy and stainless steel sheets in car bodies, the corrosion cost in the maintenance decreased relatively to the production despite the initial increase in the production. In shipbuilding and shipping, relative decrease in corrosion cost is apparent, despite the increased painting area owing to the regulation of double hull structure for tankers. The suppression of painting and repair cost is due to accelerated automation, improvement in facilities, outsourcing of labor and especially transferring docking to overseas yards.

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