Statistical Method for Deriving Standard Work Time of Refinishing Vehicles and its Application

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1 Introduction

1.1 Background and purpose

In recent years, the number of traffic accidents, casualties and fatalities has been declining in Japan. Nevertheless, the social loss incurred as a result of traffic accidents is still immeasurable. For example, in 2007, there were approximately 0.83 million traffic accidents leading to 1.03 million casualties in Japan. In terms of physical loss, the economic and environmental impact was also immense. For example, the cost of repairing damaged vehicles exceeds 1.0 trillion yen per year, even if the statistics are limited to insured accidents, as compiled by the Non-Life Insurance Rating Organization of Japan.

Refinishing is usually conducted in the final stages of the repair process, in order to restore the appearance and performance of the outer/inner panels of a damaged vehicle. In Japan, refinishing accounts for about one fourth of the total repair costs for damaged vehicles. In addition, refinishing technicians perform almost all of the processes manually. In other words, there is basically no automation involved in the refinishing of damaged vehicles.

We can assume, therefore, that it would be quite valuable if standard work times for refinishing damaged vehicles could be derived. This is because it would contribute to process management, cost accounting and training, or could provide as reference information for calculating the required number of man-hours.

The refinishing of damaged vehicles consists of many different processes. This is why the overall refinishing process involves many factors spread over a relatively long duration, such as the structure of the coats, the size of the panels, the height of the vehicle, and so forth. Therefore, it had been quite difficult to derive standard work times for refinishing based on statistically appropriate models because a large amount of data/time-studies had been necessary. On the other hand, the processes can be considered as being almost independent of each other. That is, the result of one process has little effect on the next.

Chapter 2 of this paper proposes a method for deriving standard work times based on statistically appropriate models developed from a relatively small amount of data/time-studies. The method involves two main elements: the classification of refinishing work into many processes, and the application of averaging or multiple linear regression analysis to each process. In addition, Chapter 3 presents an example of applying standard work times as obtained from actual refinishing work, according to the proposed method.

This method enables us to derive standard work times for refinishing not only with better accuracy, but also much more easily than ever before, given constant prerequisite conditions, such as procedures, worker's skills, working speed, and so forth. This is expected to lead to better process management, more efficient cost accounting, more effective training, more reasonable calculation of man-hours,

and so forth.

1.2 Processes constituting the refinishing procedure

The refinishing procedure varies according to the structure of the coat on the target vehicle. In concrete terms, refinishing 2-layer metallic color usually consists of more procedures than is necessary for single-layer solid color. Refinishing 3-layer white pearl color consists of even more steps. And, for some colors, a layer of scratch-resistant clearcoat may be required over the normal clearcoat. Regarding the repair of the damaged panels, there are two main methods, namely, replacement and shape correction. The refinishing procedure also varies depending on which of these repair methods is adopted.

As mentioned above, the refinishing of damaged vehicles inevitably involves varying the different procedures. These procedures depend on the working conditions, such as the structure of the coat, whether scratch-resistant clearcoat is to be applied, the repair method used, and so forth.

1.3 Target

This paper basically covers the refinishing operations that are applied after replacing a damaged outer panel with new one, or after restoring the shape of a damaged outer panel by panel-beating. The panel that is either replaced or "restored by panel-beating" is referred to as the "target panel" in this paper. The panel adjacent to the target panel, which is not replaced/restored but painted to blend with the new panel, is referred to as a "blended panel" in this paper.

Regarding the processes, this paper covers undercoating, such as primer-surfacer coating, topcoating including the colorcoat, clearcoat, and scratch-resistant clearcoat, and the final finishing process, including polishing. Hereinafter, these processes are collectively referred to as "refinishing" in this paper. Pretreatment process, putty process and mixing processes, which are necessary only for restoring the contours of a panel, are not covered in this paper.

2 Method

This chapter explains the details of the method for deriving standard work times for refinishing damaged vehicles. It is quite important to make the prerequisite conditions as constant as possible because variable conditions may lead to a considerable increase in the dispersion of the studied work times.

2.1 Classification

First, the refinishing work is broken down into shorter processes. In this paper, the refinishing work including the pretreatment and putty processes is classified into 168 separate processes. Table 1 lists these processes.

The number or content of the classification is not essential; meanwhile, it is important that each classified process consists only of simple operations.

2.2 Explanatory variable

Factors that appear to lead to a dispersion in the refinishing work time are arranged as options for the explanatory variables (independent variables) for multiple linear regression analysis. Table 2 lists the options obtained by interviewing refinishing technicians and observing actual refinishing work. These options are available for the multiple linear regression analysis conducted in section 2.4.

2.3 Time study and distribution of time

A time study of actual refinishing work is conducted. The prerequisite conditions, such as tools, equipment, workers' skill levels, speed of working, and so forth, should be constant throughout the work.

All the studied times are divided and distributed according to the panel and process classifications listed in Section 2.1. The distributed time is explained variable (dependent variable) for multiple linear regression analysis in Section 2.4.

2.4 Standard work time for each process

An average value or a regression formula is derived for each process classified in Section 2.1. It is derived from the explanatory variables obtained in Section 2.2 and the explained variables studied in Section 2.3.

Figure 1 is a flowchart that illustrates the process needed to derive the average values or regression formulae. The details are as follows:

1. Stage 2 and the subsequent stages are sequentially conducted in all processes.
2. One process is regarded as being one group. The values in one process, however, can be divided into multiple groups if the values of the divided groups are obviously different and the division is technically appropriate.
3. Stage 4 and the subsequent stages are performed in sequence for all groups.
4. The average value of a group is compared with a certain threshold. If the average value is less than the threshold, Stage 5 is conducted. Otherwise, Stage 6 and the subsequent stages are performed in sequence. The threshold magnitude affects the correlation between the total actual work time and the derived total standard work time, that is, the coefficient of determination of this method. The magnitude can be set depending on the situation. In this paper, the threshold is set to 6 minutes. This is because the refinishing of damaged vehicles requires a few hours or more on average, and it is expected that 6 minutes (1/10 hour) would be within the allowable range. As a consequence, a good coefficient of determination is obtained in this paper.
5. The average value of the group is regarded as being the standard work time for the group. If the application of a regression formula to the group is technically appropriate and the coefficient of determination is good, Stage 6 and the subsequent stages can be conducted for the group.
6. Multiple linear regression analysis is conducted for the group. Explanatory variables have to be selected as adequately as possible from the options obtained in Section 2.2. In addition, the result has to fulfill a certain statistical requirement, which can be set depending on the situation. In Chapter 3, the requirements are set as follows: the adjusted R-squared must be 0.7 or more, and the significance level of the analysis of variance (ANOVA) must be less than 0.05 ($p < 0.05$). If there are no appropriate options for fulfilling this requirement, Stage 7 is conducted.
7. The average value of the group is regarded as being the standard work time for the group. Multiple average values for multiple conditions in the group can also be considered as being standard work times for the respective conditions if the p-values of the t-test/Welch's test (for differences in the population mean among the separated conditions) are less than 0.05. This separation can make the dispersion of each condition smaller, and contribute to better correlation between the total actual work time and the derived total standard work

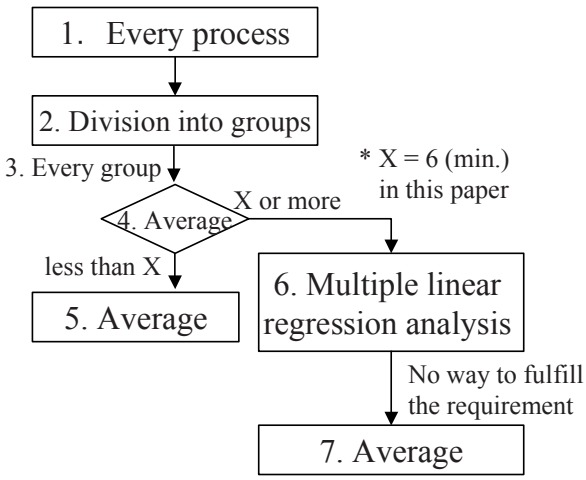

Figure 1: Flowchart to derive standard work time values/formulae

time.

The average values or regression formulae (standard work time values/formulae) for all processes can be obtained using this flowchart.

2.5 Merger

Refinishing work is also classified into multiple conditions so that the procedure for refinishing under each condition can be constant. In this paper, refinishing is classified into the following 12 (= 2 × 3 × 2) conditions:

- Structure of coat: single-layer solid, 2-layer metallic/pearl, or 3-layer pearl
- Scratch-resistant clear: applied/not applied
- Repair method: replacement or shape correction

Based on the classification, the procedure to be applied for each condition is determined. Table 3 lists the procedures determined in this paper.

The standard work time values/formulae for all the processes have already been obtained as mentioned in Section 2.4. Therefore, the total standard work time for refinishing for a target condition can be derived by summing all the standard work times of the processes included in the target condition, as shown in Table 3.

3 Application

The method, proposed in Chapter 2, for deriving standard work times for refinishing damaged vehicles was applied to actual work. Time studies for refinishing 71 target panels of 24 models were performed. In each of the time studies, the target panel was refinished in case of solid colors; the target panel and two adjacent blended panels were refinished in the case of the other colors. One technician performed all the work, to eliminate the dispersion caused by variations between the technicians. The condition of the workshop, including the initial positions of the tools and equipment, was assumed to be constant for all the work. Color was not adopted as an explanatory variable in this application because it would be extraordinarily difficult to properly classify the many different vehicle colors.

3.1 Example

This section shows an example of the processes involved in deriving standard work time values/formulae for the "Spraying colorcoat in the work area (#61)" refinishing process. Process #61 involves the spraying time only. It does not include any preparation of the spray guns and hoses, the time needed to mix the colorcoats and hardener, and so forth. These values are included in #62.

The points shown in Figure 2 indicate time-studied data, that is, the actual work times. Based on the stage 2 of the

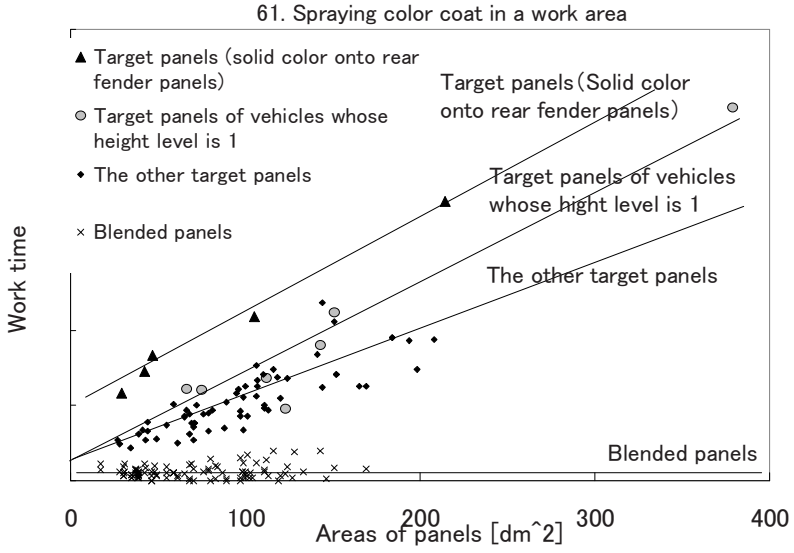

Figure 2: An example of studied data (points) and regression formulae (lines)

flowchart, the target panels and blended panels were classified into two different groups because the values varied considerably. Based on the stage 4 of the flowchart, the average time was adopted as the standard work time for the blended panels because the average time was less than six minutes. Based on the stage 6 of the flowchart, multiple linear regression analysis was conducted on the target panels. This is because the average time is over six minutes and it is clear that as the size of the target panels increases, more time will be needed for spraying. In multiple linear regression analysis, the following three options were used.

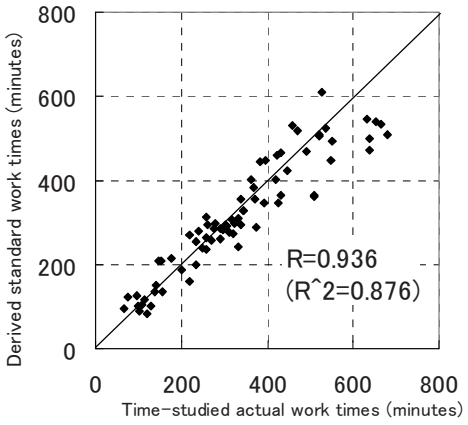

Figure 3: Derived standard work times and time-studied actual work times

A) Area of the panel (numeric value: units are dm^2)
B) Height level (dummy variable: 1 in case that the height is over a certain value, otherwise 0)
C) Single-layer solid color onto rear fender panel (dummy variable: 1 when single-layer solid color is sprayed onto a rear fender panel, otherwise 0)

Using these three options, four explanatory variables, A, A × B, A × C, C, were adopted. As a consequence, regression formulae were derived to fulfill the abovementioned requirement, adjusted R-squared >= 0.7, and p of ANOVA < 0.05. The lines in Figure 2 show the average value and the regression formulae (standard work time values/formulae).

All the standard work time values/formulae for the other processes were derived by the same method. This enabled us to derive standard work times for refinishing damaged vehicles under any conditions.

3.2 Results

The total standard work times for all panels under the 71 time-studied conditions were derived. Figure 3 shows a comparison of the derived standard work times with the actual time-studied work times. The correlation coefficient (R) is 0.936 (R-squared is 0.876). We are sure that this result proves that the method proposed in this paper contributes to the derivation of significant standard work times for refinishing damaged vehicles under constant prerequisite conditions.

4 Conclusions

This paper has explained, in Chapter 2, a method for deriving standard work times for refinishing damaged vehicles from a relatively small number of time studies, based on a statistically appropriate model. In addition, this paper has shown, in Chapter 3, an example application for deriving standard work times from actual refinishing work. In consequence, we have ascertained that the correlation between the derived standard work times and time-studied actual work times is quite high.

As a subsequent step, we have to attempt to determine how the quality of the original vehicle coats and the colors of the coats affect the refinishing work time. Any solution could be a breakthrough for obtaining more appropriate/significant standard work times for refinishing damaged vehicles in a wide range of situations.

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Table 1: Refinishing process classifications

Process	No.	Explanation	*
Pretreatment, etc.	1	Preparation before refinishing, such as curing	1
	2	Feather-edging	2
	3	Anti-corrosion primer application on bare metal surfaces	2
	4	Polyester-puttying	2
	5	Sanding of polyester putty	2
Undercoating	6	Reversing panels for sanding before spraying primer-surfacer	
	7	Curing for sanding before spraying primer-surfacer for welded panels	
	8	Curing inside for sanding before spraying primer-surfacer for welded panels	4
	9	Sanding before spraying primer-surfacer	
	10	Sanding inside before spraying primer-surfacer	4
	11	Masking before spraying primer-surfacer for welded panels	
	12	Masking inside for primer-surfacer and topcoating	
	13	Degreasing after spraying primer-surfacer	
	14	Work in work area other than spraying while spraying primer-surfacer	
	15	Spraying primer-surfacer in the work area	
	16	Flash-off time while spraying primer-surfacer in the work area	3
	17	Time taken for concurrent work with flash-off time, such as filling spray-guns, while spraying primer-surfacer in the work area	3
	18	Time that cannot be classified into flash-off time or others because of concurrent work	3
	19	Work other than spraying while spraying primer-surfacer inside a vehicle	4
	20	Spraying primer-surfacer inside a vehicle	4
	21	Flash-off time while spraying primer-surfacer inside a vehicle	3,4
	22	Time taken for concurrent work with flash-off time, such as filling spray-guns, while spraying primer-surfacer inside a vehicle	3,4
	23	Time that cannot be classified into flash-off time or others because of concurrent work	3,4
	24	Touch-up puttying	
	25	Curing before wet sanding of primer-surfacer for bolt-on panels	
	26	Wet sanding of primer-surfacer	
	27	Reversing panels for sanding before topcoating	
	28	Curing for sanding before topcoating	
	29	Additional curing of rear-fender panels for sanding before topcoating	5
	30	Sanding before topcoating	
	31	Additional sanding of rear-fender panels before topcoating	5
	32	Sanding reverse-side before topcoating	6
Topcoating	33	Sealing	
	34	Masking before topcoating	
	35	Additional masking of rear-fender panels before topcoating	5
	36	Additional masking before scratch-resistant clearcoating	7
	37	Degreasing after masking for topcoating	
	38	Degreasing after additional masking of rear fender panels for topcoating	5
	39	Degreasing after additional masking for scratch-resistant clearcoating	7
	40	Work in the work area other than spraying while spraying undercolor	8
	41	Spraying undercolor in the work area	8
	42	Flash-off time while spraying undercolor in the work area	3,8
	43	Time taken for concurrent work with flash-off time, such as filling spray-guns, while spraying undercolor in the work area	3,8
	44	Time that cannot be classified into flash-off time or others because of concurrent work	3,8

	45	Work in the work area other than spraying while spraying undercolor onto reverse-side	6,8
	46	Spraying undercolor onto reverse-side in the work area	6,8
	47	Flash-off time while spraying undercolor onto reverse-side in the work area	3,6,8
	48	Time taken for concurrent work with flash-off time, such as filling spray-guns, while spraying undercolor onto reverse-side in the work area	3,6,8
	49	Time that cannot be classified into flash-off time or others because of concurrent work	3,6,8
	50	Work in the work area other than spraying while spraying undercolor inside	4,8
	51	Spraying undercolor inside in the work area	4,8
	52	Flash-off time while spraying undercolor inside in the work area	3,4,8
	53	Time taken for concurrent work with flash-off time, such as filling spray-guns, while spraying undercolor inside in the work area	3,4,8
	54	Time that cannot be classified into flash-off time or others because of concurrent work	3,4,8
	55	Additional work for rear fender panels in the work area other than spraying while spraying undercolor	5,8
	56	Additional spraying of undercolor onto rear fender panels in the work area	5,8
	57	Flash-off time while additional spraying of undercolor onto rear fender panels in the work area	3,5,8
	58	Time taken for concurrent work with flash-off time, such as filling spray-guns, while additional spraying of undercolor onto rear fender panels in the work area	3,5,8
	59	Time that cannot be classified into flash-off time or others because of concurrent work	3,5,8
	60	Work in the work area other than spraying while spraying colorcoat	
	61	Spraying colorcoat in the work area	
	62	Flash-off time while spraying colorcoat in the work area	3
	63	Time taken for concurrent work with flash-off time, such as filling spray-guns, while spraying colorcoat in the work area	3
	64	Time that cannot be classified into flash-off time or others because of concurrent work	3
	65	Additional work for rear fender panels in the work area other than spraying while spraying colorcoat	5
	66	Additional spraying of colorcoat onto rear fender panels in the work area	5
	67	Flash-off time while additional spraying of colorcoat onto rear fender panels in the work area	3,5
	68	Time taken for concurrent work with flash-off time, such as filling spray-guns, while additional spraying of colorcoat onto rear fender panels in the work area	3,5
	69	Time that cannot be classified into flash-off time or others because of concurrent work	3,5
	70	Work in the work area other than spraying while spraying colorcoat inside	4
	71	Spraying colorcoat inside in the work area	4
	72	Flash-off time while spraying colorcoat inside in the work area	3,4
	73	Time taken for concurrent work with flash-off time, such as filling spray-guns, while spraying colorcoat inside in the work area	3,4
	74	Time that cannot be classified into flash-off time or others because of concurrent work	3,4
	75	Work in the work area other than spraying while spraying colorcoat onto reverse-side	6
	76	Spraying colorcoat onto reverse-side in the work area	6
	77	Flash-off time while spraying colorcoat onto reverse-side in the work area	3,6
	78	Time taken for concurrent work with flash-off time, such as filling spray-guns, while spraying colorcoat onto reverse-side in the work area	3,6
	79	Time that cannot be classified into flash-off time or others because of concurrent work	3,6
	80	Work in the work area other than spraying while spraying pearlcoat	
	81	Spraying pearlcoat in the work area	
	82	Flash-off time while spraying pearlcoat in the work area	3
	83	Time taken for concurrent work with flash-off time, such as filling spray-guns, while spraying pearlcoat in the work area	3
	84	Time that cannot be classified into flash-off time or others because of concurrent work	3
	85	Additional work for rear fender panels in the work area other than spraying while spraying pearlcoat	5
	86	Additional spraying of pearlcoat onto rear fender panels in the work area	5
	87	Flash-off time while additional spraying of pearlcoat onto rear fender panels in the work area	3,5
	88	Time taken for concurrent work with flash-off time, such as filling spray-guns, while additional spraying of pearlcoat onto rear fender panels in the work area	3,5
	89	Time that cannot be classified into flash-off time or others because of concurrent work	3,5
	90	Work in the work area other than spraying while spraying pearlcoat inside	4
	91	Spraying pearlcoat inside in the work area	4
	92	Flash-off time while spraying pearlcoat inside in the work area	3,4
	93	Time taken for concurrent work with flash-off time, such as filling spray-guns, while spraying pearlcoat inside in the work area	3,4
	94	Time that cannot be classified into flash-off time or others because of concurrent work	3,4
	95	Work in the work area other than spraying while spraying pearlcoat onto reverse-side	6
	96	Spraying pearlcoat onto reverse-side in the work area	6
	97	Flash-off time while spraying pearlcoat onto reverse-side in the work area	3,6
	98	Time taken for concurrent work with flash-off time, such as filling spray-guns, while spraying pearlcoat onto reverse-side in the work area	3,6
	99	Time that cannot be classified into flash-off time or others because of concurrent work	3,6
	100	Work in the work area other than spraying while spraying clearcoat	
	101	Spraying clearcoat in the work area	

	102	Flash-off time while spraying clearcoat in the work area	3
	103	Time taken for concurrent work with flash-off time, such as filling spray-guns, while spraying clearcoat in the work area	3
	104	Time that cannot be classified into flash-off time or others because of concurrent work	3
	105	Additional work for rear fender panels in the work area other than spraying while spraying clearcoat	5
	106	Additional spraying of clearcoat onto rear fender panels in the work area	5
	107	Flash-off time while additional spraying of clearcoat onto rear fender panels in the work area	3,5
	108	Time taken for concurrent work with flash-off time, such as filling spray-guns, while additional spraying of clearcoat onto rear fender panels in the work area	3,5
	109	Time that cannot be classified into flash-off time or others because of concurrent work	3,5
	110	Work in the work area other than spraying while spraying clearcoat inside	4
	111	Spraying clearcoat inside in the work area	4
	112	Flash-off time while spraying clearcoat inside in the work area	3,4
	113	Time taken for concurrent work with flash-off time, such as filling spray-guns, while spraying clearcoat inside in the work area	3,4
	114	Time that cannot be classified into flash-off time or others because of concurrent work	3,4
	115	Work in the work area other than spraying while spraying clearcoat onto reverse-side	6
	116	Spraying clearcoat onto reverse-side in the work area	6
	117	Flash-off time while spraying clearcoat onto reverse-side in the work area	3,6
	118	Time taken for concurrent work with flash-off time, such as filling spray-guns, while spraying clearcoat onto reverse-side in the work area	3,6
	119	Time that cannot be classified into flash-off time or others because of concurrent work	3,6
	120	Work in the work area other than spraying while spraying additives for colorcoat-blending	
	121	Spraying additives for colorcoat-blending in the work area	
	122	Flash-off time while spraying additives for colorcoat-blending in the work area	3
	123	Time taken for concurrent work with flash-off time, such as filling spray-guns, while spraying additives for colorcoat-blending in the work area	3
	124	Time that cannot be classified into flash-off time or others because of concurrent work	3
	125	Work in the work area other than spraying while spraying additives for pearlcoat-blending	
	126	Spraying additives for pearlcoat-blending in the work area	
	127	Flash-off time while spraying additives for pearlcoat-blending in the work area	3
	128	Time taken for concurrent work with flash-off time, such as filling spray-guns, while spraying additives for pearlcoat-blending in the work area	3
	129	Time that cannot be classified into flash-off time or others because of concurrent work	3
	130	Work in the work area other than spraying while spraying mixture of clear and pearlcoat for good blending of pearlcoat	
	131	Spraying mixture of clear and pearlcoat for good blending of pearlcoat in the work area	
	132	Flash-off time while spraying mixture of clear and pearlcoat for good blending of pearlcoat in the work area	
	133	Time taken for concurrent work with flash-off time, such as filling spray-guns, while spraying mixture of clear and pearlcoat for good blending of pearlcoat in the work area	
	134	Time that cannot be classified into flash-off time or others because of concurrent work	
	135	Additional work for rear fender panels in the work area other than spraying while spraying mixture of clear and pearlcoat for good blending of pearlcoat	
	136	Additional spraying mixture of clear and pearlcoat for good blending of pearlcoat onto rear fender panels in the work area	
	137	Flash-off time while additional spraying of mixture of clear and pearlcoat for good blending of pearlcoat onto rear fender panels in the work area	
	138	Time taken for concurrent work with flash-off time, such as filling spray-guns, while additional spraying of mixture of clear and pearlcoat for good blending of pearlcoat onto rear fender panels in the work area	
	139	Time that cannot be classified into flash-off time or others because of concurrent work	
	140	Work in the work area other than spraying while spraying mixture of clear and pearlcoat for good blending of pearlcoat onto reverse-side	
	141	Spraying mixture of clear and pearlcoat for good blending of pearlcoat onto reverse-side in the work area	
	142	Flash-off time while spraying mixture of clear and pearlcoat for good blending of pearlcoat onto reverse-side in the work area	
	143	Time taken for concurrent work with flash-off time, such as filling spray-guns, while spraying mixture of clear and pearlcoat for good blending of pearlcoat onto reverse-side in the work area	
	144	Time that cannot be classified into flash-off time or others because of concurrent work	
	145	Wet sanding of clearcoat before spraying scratch-resistant clearcoat	7
	146	Curing before wet sanding of clearcoat before spraying scratch-resistant clearcoat	7
	147	Work in the work area other than spraying while spraying scratch-resistant clearcoat	7
	148	Spraying of scratch-resistant clearcoat in the work area	7
	149	Flash-off time while spraying scratch-resistant clearcoat in the work area	3,7
	150	Time taken for concurrent work with flash-off time, such as filling spray-guns, while spraying scratch-resistant clearcoat in the work area	3,7
	151	Time that cannot be classified into flash-off time or others because of concurrent work	3,7
Finishing	152	Removal of dust nibs	

	153	Adjusting smoothness	
	154	Final polishing	
	155	Clearing masking materials	
	156	Clearing materials needed for additional masking for rear fender panels	5
	157	Clearing materials needed for masking inside	4
	158	Clearing materials needed for additional masking for scratch-resistant clear	7
	159	Clearing materials needed for additional masking for primer-surfacer onto welded panels	
	160	Touch up	
Others	161	Necessary work after refinishing	
	162	Time in which not only the color of the engine compartment/boot, but also the color of the surface are sprayed onto the reverse-side	
	163	Time in which black is sprayed onto side sill panels	
	164	Time for additional preparation work for *5 in the work area	
	165	Time for spraying engine compartment color inside boot on condition that target panel is rear fender panel and assuming that blending is conducted	
	166	Time for spraying black onto sashes of door panels	
	167	Time for masking and clearing before spraying primer-surfacer assuming that the shape of the target panel is modified	2
	168	Pre-work before refinishing, but not included in refinishing in this paper	2

* Processes without *4,5,6,7 are applied to surfaces. Primer-surfacer-spraying and polishing primer-surfacer of bolt-on panels are conducted with the panels off. The other work is conducted with the panels on the frames. *1 Not covered by this paper because this is preparation work. *2 Not covered by this paper because this work is necessary only for shape correction. *3 Not covered by this paper because it is not within the scope of refinishing as defined in this paper. *4 Work related to spraying inside vehicles when welded panels are replaced. *5 Work related to spraying panels hidden by door panels, such as rocker pillar panels, because the procedure for refinishing rear fender panels with adjacent blended panels is as follows. First, areas hidden by a closed door are sprayed with the doors open. Next, the surfaces of the target panels are sprayed with the doors closed and the adjacent panels blended. *5 refers to work performed on hidden areas. *6 Work performed on the reverse-side. *7 In this paper, the procedures for applying the scratch-resistant clearcoat are as follows: wet sanding after spraying the normal clearcoat, masking, spraying the scratch-resistant clearcoat, and then polishing. *8 Work related to the spraying of additional undercolor before spraying a relatively transparent colorcoat.

Table 2: Optional explanatory variables obtained by interview and observation

Factors	Options	Main opinions obtained
Areas of panels	(Variables)	The larger the area of the panel, the longer it takes to spray and polish.
Metal-joining process	Bolt-on	Refinishing procedure varies depending on the metal-joining processes.
	Welded	
Types of panels	Hood panels	Difficulty of refinishing seems to depend on the type of the panel.
	Front fender panels	
	Door panels	
	Back door panels	
	Boot panels	
	Rear fender panels	
	Roof panels	
	Body lower back panels	
Position of panels	Vertical	It seems to take more time to polish vertical panels than horizontal ones because of difficulty in making the surface smooth.
	Horizontal	
Height	(Variables)	The higher the target vehicle, the more difficult the refinishing seems to be.
Projected area	(Variables)	The larger the projected area is, the better the quality of the coats seems to be.
Structure	1-layer coat	Refinishing procedure varies depending on the structure of the coats.
	2-layer coat	
	3-layer coat	
Type of spraying	Target panels	Refinishing procedure varies between target panels and blended panels.
	Blended panels	
Blending	With adjacent panels blended	Refinishing procedure varies between panels with adjacent blended panels and those without blended panels.
	No blended panels	
Number of dust nibs	(Variables)	The greater the number of dust nibs on the panels, the longer it takes to remove them.
Color	Red, blue, green, white etc.	Difficulty of refinishing, required smoothness, and gloss all vary with the colors.
Quality	Expensive, public, compact etc.	Required quality depends on the smoothness, gloss, etc. of original coats. Work time depends on the quality.

Table 3: Processes included in respective conditions assumed in this paper

	Normal clearcoat						Scratch resistant clearcoat					
	1-layer solid		2-layer metallic/pearl		3-layer pearl		1-layer solid		2-layer metallic/pearl		3-layer pearl	
Proc. No.	Rep.	Rst.	Rep.	Rst.	Rep.	Rst.	Rep.	Rst.	Rep.	Rst.	Rep.	Rst.
1	–	–	–	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	–	–	–	–	–	–
6	✔		✔		✔		✔		✔		✔	
7	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
8	✔		✔		✔		✔		✔		✔	
9	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
10	✔		✔		✔		✔		✔		✔	
11	✔		✔		✔		✔		✔		✔	
12	✔		✔		✔		✔		✔		✔	
13	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
14	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
15	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
16	–	–	–	–	–	–	–	–	–	–	–	–
17	–	–	–	–	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	–	–	–	–	–	–
19	✔		✔		✔		✔		✔		✔	
20	✔		✔		✔		✔		✔		✔	
21	–	–	–	–	–	–	–	–	–	–	–	–
22	–	–	–	–	–	–	–	–	–	–	–	–
23	–	–	–	–	–	–	–	–	–	–	–	–
24	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
25	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
26	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
27	✔		✔		✔		✔		✔		✔	
28	✔		✔		✔		✔		✔		✔	
29	✔		✔		✔		✔		✔		✔	
30	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
31	✔		✔		✔		✔		✔		✔	
32	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
33	✔		✔		✔		✔		✔		✔	
34	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
35	✔		✔		✔		✔		✔		✔	
36	✔		✔		✔		✔		✔		✔	
37	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
38	✔		✔		✔		✔		✔		✔	
39							✔	✔	✔	✔	✔	✔
40	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
41	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
42	–	–	–	–	–	–	–	–	–	–	–	–
43	–	–	–	–	–	–	–	–	–	–	–	–
44	–	–	–	–	–	–	–	–	–	–	–	–
45	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
46	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
47	–	–	–	–	–	–	–	–	–	–	–	–
48	–	–	–	–	–	–	–	–	–	–	–	–
49	–	–	–	–	–	–	–	–	–	–	–	–
50	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
51	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
52	–	–	–	–	–	–	–	–	–	–	–	–
53	–	–	–	–	–	–	–	–	–	–	–	–
54	–	–	–	–	–	–	–	–	–	–	–	–
55	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
56	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
57	–	–	–	–	–	–	–	–	–	–	–	–
58	–	–	–	–	–	–	–	–	–	–	–	–
59	–	–	–	–	–	–	–	–	–	–	–	–
60	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
61	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
62	–	–	–	–	–	–	–	–	–	–	–	–
63	–	–	–	–	–	–	–	–	–	–	–	–
64	–	–	–	–	–	–	–	–	–	–	–	–
65	✔		✔		✔		✔		✔		✔	
66	✔		✔		✔		✔		✔		✔	
67	–	–	–	–	–	–	–	–	–	–	–	–
68	–	–	–	–	–	–	–	–	–	–	–	–
69	–	–	–	–	–	–	–	–	–	–	–	–
70	✔		✔		✔		✔		✔		✔	
71	✔		✔		✔		✔		✔		✔	
72	–	–	–	–	–	–	–	–	–	–	–	–
73	–	–	–	–	–	–	–	–	–	–	–	–
74	–	–	–	–	–	–	–	–	–	–	–	–
75	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
76	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
77	–	–	–	–	–	–	–	–	–	–	–	–
78	–	–	–	–	–	–	–	–	–	–	–	–
79	–	–	–	–	–	–	–	–	–	–	–	–
80					✔	✔					✔	✔
81					✔	✔					✔	✔
82	–	–	–	–	–	–	–	–	–	–	–	–
83	–	–	–	–	–	–	–	–	–	–	–	–
84	–	–	–	–	–	–	–	–	–	–	–	–

	Normal clearcoat						Scratch resistant clearcoat					
	1-layer solid		2-layer metallic/pearl		3-layer pearl		1-layer solid		2-layer metallic/pearl		3-layer pearl	
Proc. No.	Rep.	Rst.	Rep.	Rst.	Rep.	Rst.	Rep.	Rst.	Rep.	Rst.	Rep.	Rst.
85					✔						✔	
86					✔						✔	
87	–	–	–	–	–	–	–	–	–	–	–	–
88	–	–	–	–	–	–	–	–	–	–	–	–
89	–	–	–	–	–	–	–	–	–	–	–	–
90					✔						✔	
91					✔						✔	
92	–	–	–	–	–	–	–	–	–	–	–	–
93	–	–	–	–	–	–	–	–	–	–	–	–
94	–	–	–	–	–	–	–	–	–	–	–	–
95					✔	✔					✔	✔
96					✔	✔					✔	✔
97	–	–	–	–	–	–	–	–	–	–	–	–
98	–	–	–	–	–	–	–	–	–	–	–	–
99	–	–	–	–	–	–	–	–	–	–	–	–
100			✔	✔	✔	✔			✔	✔	✔	✔
101			✔	✔	✔	✔			✔	✔	✔	✔
102	–	–	–	–	–	–	–	–	–	–	–	–
103	–	–	–	–	–	–	–	–	–	–	–	–
104	–	–	–	–	–	–	–	–	–	–	–	–
105			✔		✔				✔		✔	
106			✔		✔				✔		✔	
107	–	–	–	–	–	–	–	–	–	–	–	–
108	–	–	–	–	–	–	–	–	–	–	–	–
109	–	–	–	–	–	–	–	–	–	–	–	–
110			✔		✔				✔		✔	
111			✔		✔				✔		✔	
112	–	–	–	–	–	–	–	–	–	–	–	–
113	–	–	–	–	–	–	–	–	–	–	–	–
114	–	–	–	–	–	–	–	–	–	–	–	–
115			✔	✔	✔	✔			✔	✔	✔	✔
116			✔	✔	✔	✔			✔	✔	✔	✔
117	–	–	–	–	–	–	–	–	–	–	–	–
118	–	–	–	–	–	–	–	–	–	–	–	–
119	–	–	–	–	–	–	–	–	–	–	–	–
120			✔		✔				✔		✔	
121			✔		✔				✔		✔	
122	–	–	–	–	–	–	–	–	–	–	–	–
123	–	–	–	–	–	–	–	–	–	–	–	–
124	–	–	–	–	–	–	–	–	–	–	–	–
125					✔	✔					✔	✔
126					✔	✔					✔	✔
127	–	–	–	–	–	–	–	–	–	–	–	–
128	–	–	–	–	–	–	–	–	–	–	–	–
129	–	–	–	–	–	–	–	–	–	–	–	–
130					✔	✔					✔	✔
131					✔	✔					✔	✔
132	–	–	–	–	–	–	–	–	–	–	–	–
133	–	–	–	–	–	–	–	–	–	–	–	–
134	–	–	–	–	–	–	–	–	–	–	–	–
135					✔						✔	
136					✔						✔	
137	–	–	–	–	–	–	–	–	–	–	–	–
138	–	–	–	–	–	–	–	–	–	–	–	–
139	–	–	–	–	–	–	–	–	–	–	–	–
140					✔	✔					✔	✔
141					✔	✔					✔	✔
142	–	–	–	–	–	–	–	–	–	–	–	–
143	–	–	–	–	–	–	–	–	–	–	–	–
144	–	–	–	–	–	–	–	–	–	–	–	–
145							✔	✔	✔	✔	✔	✔
146							✔	✔	✔	✔	✔	✔
147							✔	✔	✔	✔	✔	✔
148							✔	✔	✔	✔	✔	✔
149	–	–	–	–	–	–	–	–	–	–	–	–
150	–	–	–	–	–	–	–	–	–	–	–	–
151	–	–	–	–	–	–	–	–	–	–	–	–
152	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
153	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
154	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
155	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
156	✔		✔		✔		✔		✔		✔	
157	✔		✔		✔		✔		✔		✔	
158							✔	✔	✔	✔	✔	✔
159	✔		✔		✔		✔		✔		✔	
160	✔		✔		✔		✔		✔		✔	
161	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
162	✔		✔		✔		✔		✔		✔	
163	✔		✔		✔		✔		✔		✔	
164	✔		✔		✔		✔		✔		✔	
165	✔		✔		✔		✔		✔		✔	
166	✔		✔		✔		✔		✔		✔	
167		✔		✔		✔		✔		✔		✔
168	–	–	–	–	–	–	–	–	–	–	–	–

✔ : Must or required　　- : Not studied in this paper　　Blank : Unnecessary processes

Rep. = Replacement　　Rst. = Shape-restoring