Quantitative Estimate of CO_2 Emission Reduction from Reuse of Automobile Parts in Japan

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***Abstract*—In general, reusing automobile parts reduces not only the cost of replacing the failed parts but also the environmental load of manufacturing new parts. However, these effects have not yet been quantified. The present study focuses on determining the emitted CO_2 during production and quantitatively evaluating its reduction by the reuse of automobile parts. First, CO_2 emissions are calculated during the reused parts production process at the factory site. Thirty-nine automobiles from 27 models prepared in Japan are examined to measure the amount of CO_2 emitted in the production of new parts. Furthermore, the CO_2 emission reduction effect for different automobile models is estimated through multiple regression analysis. The CO_2 emissions are assumed to be the objective variable, whereas the explanatory variables are derived from the data provided in the automobile inspection certificates. The presented quantitative estimate of CO_2 emission reduction owing to the exploitation of reused parts is expected to promote policies for further reducing CO_2 emissions and arouse public awareness regarding the benefits of recycling automobile parts.**

Keywords*—*CO_2 emissions, reuse, life-cycle assessment, multiple regression analysis, automobile

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1. Introduction

As world population increases, more natural resources are being consumed to satisfy customer demand, leading to more generated waste [1]. At present, approximately 3.5 million automobiles are discarded every year in Japan [2]. Therefore, when all of the discarded automobiles are simply scrapped, they result in about 3.5 million tons of annual waste, which corresponds to approximately 8% of the total volume of waste per year in Japan (45 million tons) [3]. From the viewpoint of environmental issues such as the depletion of natural resources and reduction of CO_2 emissions, closed-loop product supply chains are essential for achieving a sustainable society [4]. Approaches to implement a green supply chain include efforts to minimize the negative impact on the environment [5]. Promotion of the three Rs, i.e., “reduce, reuse, and recycle,” is one of the approaches for realizing a sustainable society. Recycling and reusing involve the recovery of materials from the scrap of end-of-life products [6].

A 2005 legislation, which governs automobile recycling in Japan [7], has imposed fees on the purchasers of automobiles to attempt enforcing the recycling of end-of-life vehicles by using their parts or resources to repair other vehicles. The reused and rebuilt parts, which can promote the effective use of parts themselves rather than the recycled material and automotive shredder residue, have been given more attention since the legislation came to effect. Reused parts are recovered from end-of-life vehicles and commoditized after visual checking and cleaning without maintenance or repair. On the other hand, rebuilt parts are recovered from end-of-life vehicles and commoditized by disassembling, exchanging the worn or degraded components for new ones, and then reassembling. In general, the reuse of automobile parts can reduce material consumption and environmental load. In particular, it is effective in reducing the emission of CO_2, a greenhouse gas responsible for global warming. However, these effects have not yet been quantified. This study focuses on reused parts and quantitatively estimates the associated CO_2 emission reduction. This will prompt automobile-related businesses to promote the further reduction of CO_2 emissions. In addition, the higher visibility of CO_2 emission reduction is expected to make consumers more aware of the importance of parts recycling. As one of the methods of publicizing the reduction effect, businesses that sell reused parts can describe not only the part unit price but also the CO_2 emission reduction effect in the quotation.

The present study aims to quantitatively evaluate the effect of reused automobile parts on the reduction of CO_2 emissions. To this end, it is necessary to measure the amount of CO_2 emitted during the production of various automobile models and compare it with the corresponding amount for the production and recycling of reused parts. Because investigating all of the produced vehicle models would be unrealistic and impractical, the reduction effect is estimated through a multiple regression analysis.

2. Evaluation Method of CO_2 Emission Reduction Effect of Reused Parts

A conceptual diagram of the CO_2 emission reduction effect investigated in this study is presented in Figure 1. Life-cycle assessment (LCA) is a method of assessing environmental effects by calculating resource consumption and emissions, such as CO_2 and sulfoxides (SO_X), for the entire life cycle [8, 9]. LCA results are used for decision-

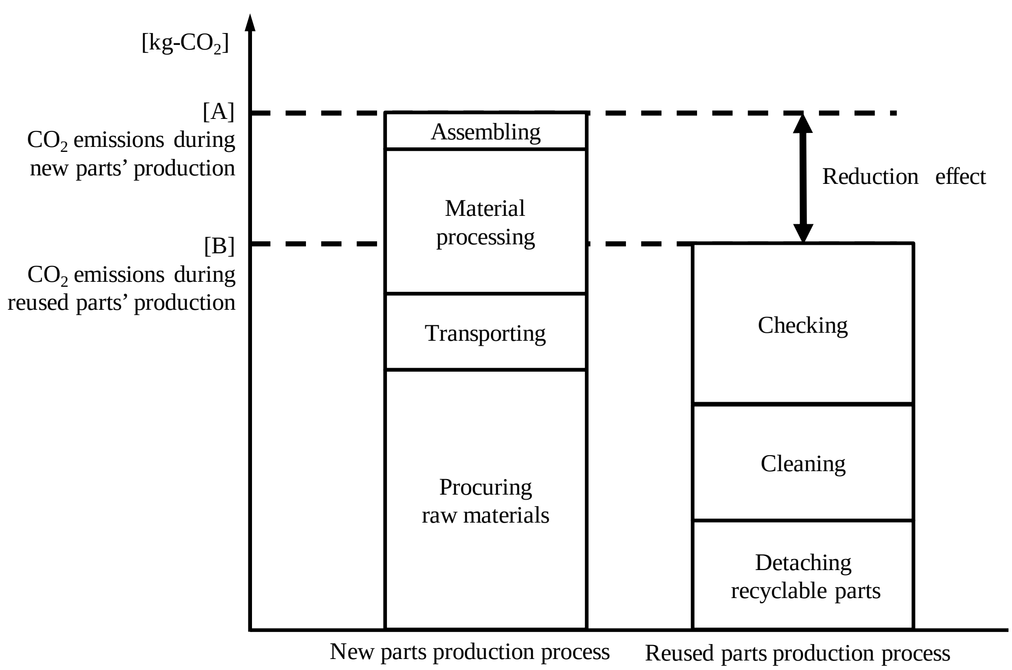


Figure 1. CO_2 emissions reduction effect by reusing automobile parts; [A] CO_2 emissions during the new part production process; [B] CO_2 emissions during the reused part production process

making to decrease the negative environmental impact of various human activities. In the present study, the LCA method is applied to determine the amount of CO_2 emissions in the production of automobile parts. The CO_2 emissions are calculated by converting the total exhaust amount, including six greenhouse gases, into CO_2. The global warming potential (GWP) is used for the conversion. GWP measures the degree, relative to CO_2, to which each gas participates in global warming.

If automobile parts are damaged or broken, the owner exchanges them for reused or new parts, the latter being produced by the automobile manufacturer. The hypothesis that the amounts of CO_2 emitted during reused and new part production differ is tested herein. In Figure. 1, [A] is the CO_2 emitted during the new part production process, which is calculated by adding the CO_2 emitted during raw material procurement, parts transportation, material processing, and parts assembly. In Figure 1, [B] is the CO_2 emitted during the reused part production process. The production process consists of detaching, cleaning, and checking the parts. In the present study, the CO_2 emissions during automobile operation are considered equal, regardless of whether they are equipped with reused or new parts. Consequently, the difference [A] − [B] corresponds to the CO_2 emission reduction effect offered by replacing failed automobile parts with reused parts. If [A] − [B] is negative, producing the reused parts will negatively affect the environment.

3. Results: CO_2 Emissions during Reused and New Parts Production

3.1 CO_2 emissions during reused parts production

To calculate [B], an onsite investigation was performed at a reused parts factory [10]. The production process was recorded using a video camera, and the working hours required for the entire procedure were counted (Figures 2, 3). From this information, the amount of CO_2 emitted during each distinct working process is calculated (Table 1). The CO_2 emissions in Table 1 are calculated on the basis of the working hours, power consumption, and amount of fuel consumed by each tool and machine that is used for the detaching, washing,

Figure 2. Checking an engine

Figure 3. Retrieving a front bumper

and checking of parts. The amount of CO_2 emissions C_t [kg-CO_2] produced by each tool is calculated using the following equation:

$$C_t = F_t \times P \times T_t , \quad (1)$$

where F_t [kg-CO_2/kWh] is the CO_2 emission factor, which is obtained from the literature on the carbon footprint of products [11] and corresponds to 0.55 kg/kWh. In this equation, P [kW] is the power consumption, and T_t [h] is the operating time of the tool.

If the engine and transmission are reused, their parts are checked by means of a warm-up operation, considering the abnormalities encountered during other activities, such as retrieving exterior components. The amount of CO_2 emissions C_w [kg-CO_2] from the warm-up is calculated using the following equation:

$$C_w = F_w \times T_w , \quad (2)$$

where F_w [kg-CO_2/h] is the CO_2 emission factor from the warm-up, and T_w [h] is the warm-up operating time. As previously reported, F_w is 0.54 kg-CO_2/h [12]. In Table 1, the CO_2 emissions

Table 1. CO_2 emissions from each tool, machine, and warm-up

Tool	Power consumption P [W]	Operating time T_t [s]	Emission of CO_2 [kg-CO_2]
Lift	1500	125	2.87×10^{-2}
Crane	650	22	2.19×10^{-3}
Flashlight	8	35	4.28×10^{-5}
Driver	40	10	6.11×10^{-5}
High-pressure washer	1300	900	1.79×10^{-1}
Air tool	1300	235	4.67×10^{-2}
Fuel use		Warm-up time T_w [s]	Emission of CO_2 [kg-CO_2]
Engine and transmission		2676	4.01×10^{-1}
		Total	6.58×10^{-1}

during the reused part production process [B] is approximately 0.66 kg per vehicle. Because checking exterior components is basically only a visual check, it is not considered in the calculation. Furthermore, the production of a total of 11 reused parts from one automobile was observed, including the engine, bonnet, front bumper, right and left headlamps, radiator, compressor, right and left front fenders, and transmission. Consequently, the CO_2 emissions during the production of only one part are smaller.

3.2 CO_2 emissions during new part production

Thirty-nine automobiles, including 27 models manufactured in Japan, were investigated to calculate [A]. The size of samples is sufficient to calculate CO_2 emissions within the error range of 20 %. The survey includes the engine, transmission, front and rear doors, bonnet, and back door. A disassembled engine is shown in Figure 4. The method of calculating CO_2 emissions is as follows:

1. Disassemble the parts as shown in Figure 4.
2. Measure each component's mass. ("component" refers to an individual part in Figure 4).
3. Confirm the raw materials used in each part.
4. Investigate methods of processing the raw materials.
5. Create and run the life-cycle model for new parts based on this information.

An example of the life-cycle model is presented in Figure 5, which reconstructs the new engine part production flow, including procuring raw material, transporting parts, and processing parts. In this figure, the ellipses represent various input resources and energy, the arrows represent the consumption of resources and energy, and the parts roughly enclosed within rectangles are processes in the new parts' life. The process of procuring raw materials has the most influence on CO_2 emissions during new part production. Meanwhile, the influence of the assembling process is much smaller. Furthermore, the assembly process is available in only a few databases and varies by manufacturer; therefore, it is difficult to understand sufficiently. For that reason, [A] in this study was calculated ignoring the assembly process. Consequently, a detailed understanding of the assembly process is one of the future challenges.

CO_2 emissions during new part production [A] is calculated by multiplying the resource consumption by the greenhouse gas emissions per unit using the carbon footprint for greenhouse gas emissions rate per unit [11]. Figure 6 shows a box plot of the CO_2 emissions for new parts. A box plot is a convenient graphical means for depicting groups of numerical data through their quartiles. In this figure, the

Figure 4. Disassembled engine

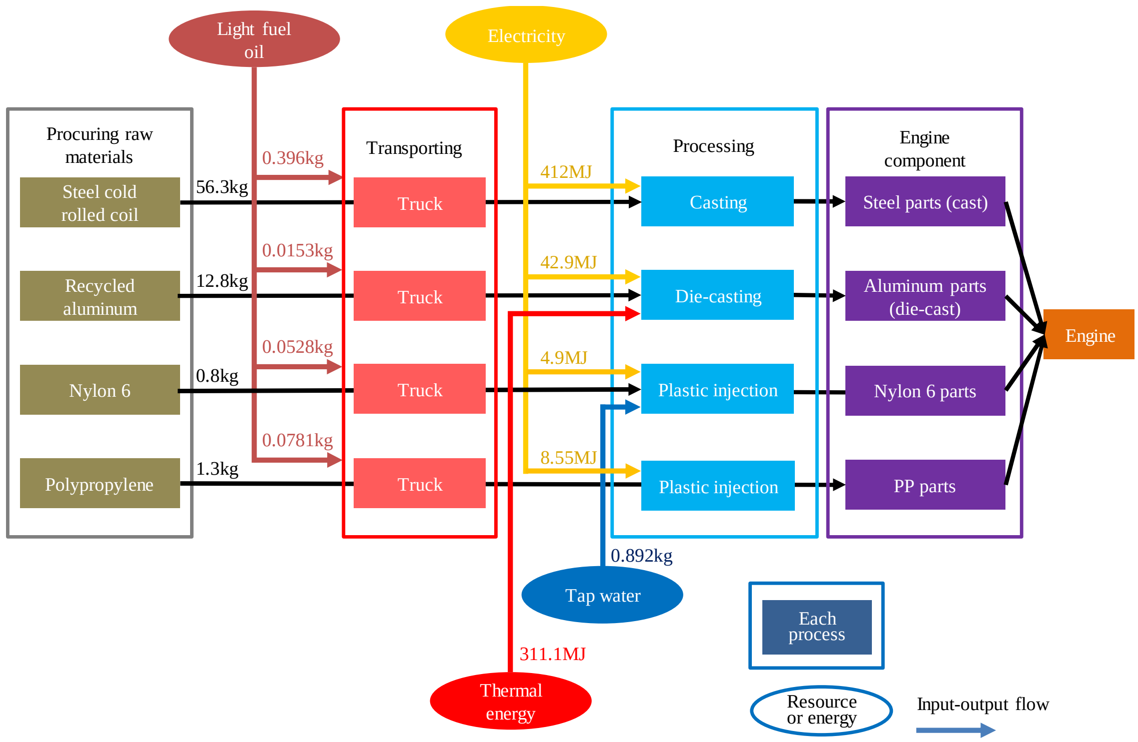


Figure 5. Example of the life-cycle model of an engine, including procuring raw material, transporting, and processing

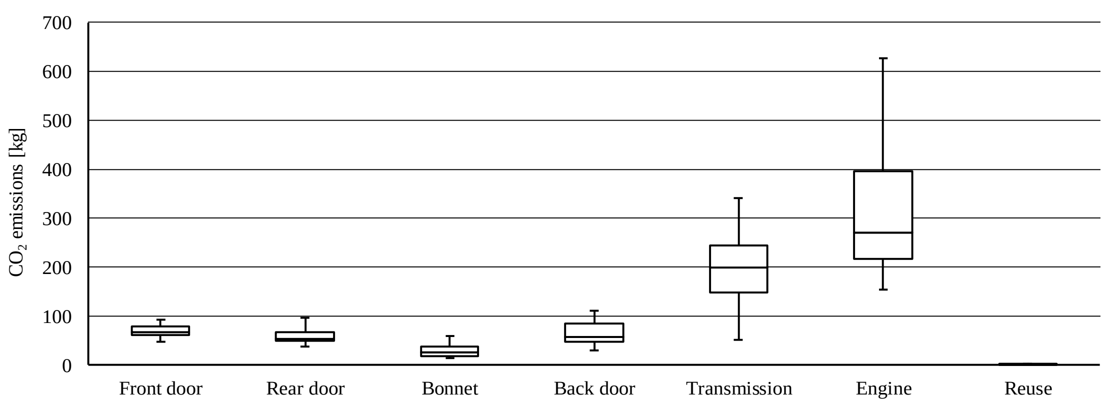
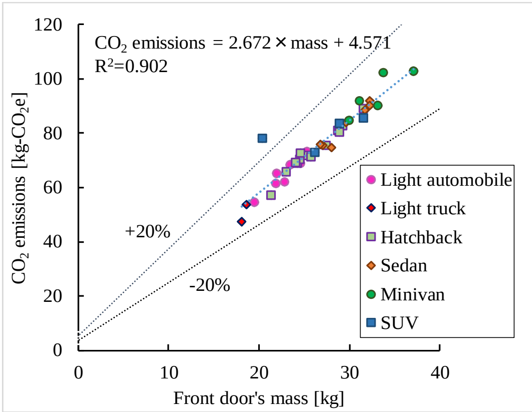


Figure 6. Emissions of CO_2 during new part production. The CO_2 emissions for each part can be visually compared. It is confirmed that CO_2 emissions can be greatly reduced using reused parts

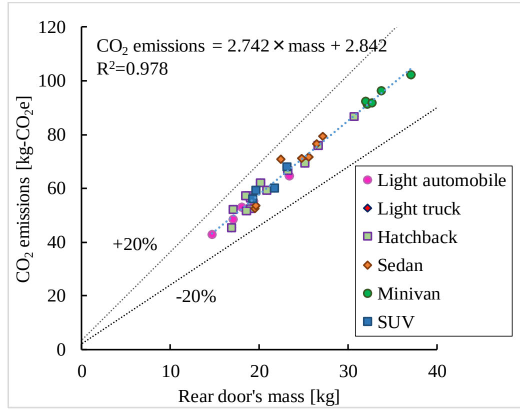
points at the ends of each line that extends from a rectangle show the maximum and minimum values. The line at the center of each rectangle is the median, whereas the lower side is the first quartile, and the upper side is the third quartile. The CO_2 emissions for each part can be visually compared in this figure. The value of [A] is greater than [B]. Therefore, it is confirmed that CO_2 emissions can be greatly reduced by using reused parts.

3.3 Estimation of CO_2 emission reduction

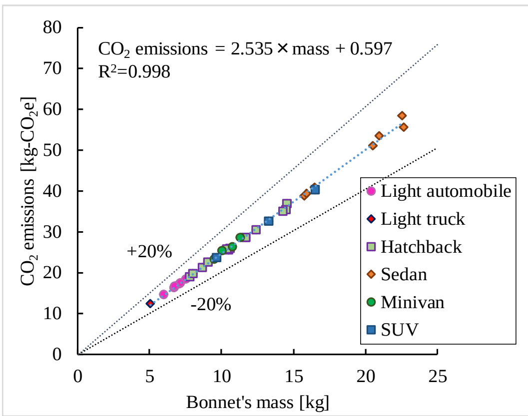
To estimate the total CO_2 reduction achieved by the customer when he or she purchases a reused part instead of a new part, the CO_2 emission reduction is calculated separately for each automobile model. However, it was not possible to investigate all models. Therefore, a multiple regression analysis was used as an estimation method. Because [B] is much smaller than [A], the



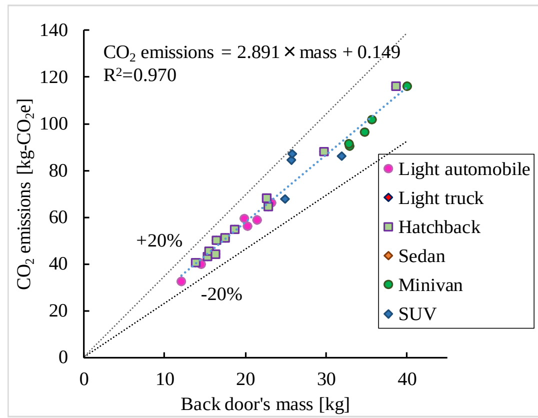
(a) CO_2 emissions of the front door mass



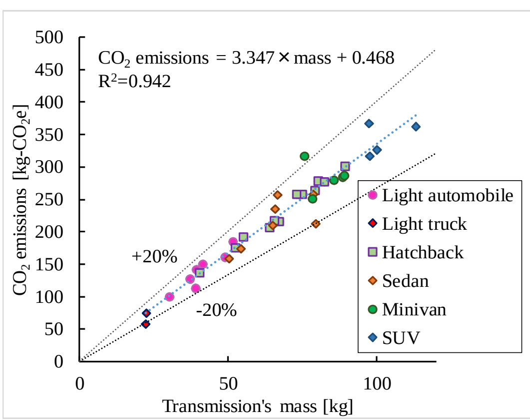
(b) CO_2 emissions of the rear door mass



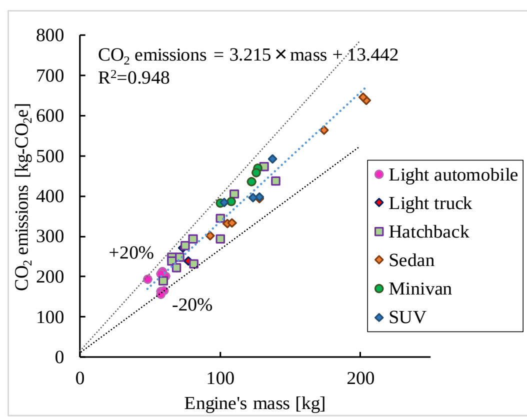
(c) CO_2 emissions of the bonnet mass



(d) CO_2 emissions of the back door mass



(e) CO_2 emissions of the transmission mass



(f) CO_2 emissions of the engine mass

Figure 7. Relationship between CO_2 emissions and mass of each part

reduction effect is considered equal to that of [A]. The relationship between the CO_2 emissions and the mass of each part is shown in Figure 7. This figure shows a strong correlation between the two variables. However, information on the masses of the parts could not be obtained without investigation. Therefore, we used data that could be easily obtained, such as automobile inspection certificates and the classification of vehicle types at a level that could be judged from the exterior. The

Table 2. Equations for estimating the reduction effect of various parts

Parts	Equation for estimating reduction effect	Determination coefficient R^2
(a) Front door	$= 0.0348 \times M + 35.1$	0.72
(b) Rear door	$= 13.3 \times S_S - 11.6 \times \varepsilon - 20.8$	0.80
(c) Bonnet	$= 11.5 \times D - 6.33 \times \beta + 13.5 \times \gamma + 9.36$	0.90
(d) Back door	$= 0.066 \times M - 8.59$	0.75
(e) Transmission	$= 0.185 \times M + 5.79$	0.55
(f) Engine	$= 168 \times D + 67.4$	0.85

multiple regression variables are set on the basis of this information, and we derive an estimation equation. In this study, the objective variable is assumed to be [A], and the explanatory variables are: the following: vehicle length (L [m]), vehicle width (W [m]), vehicle height (H [m]), vehicle mass (M [kg]), engine displacement (D [L]), and a dummy variable referring to the vehicle type. In addition to these, length × width (T_S [m^2]), length × height (S_S [m^2]), and height × width (F_S [m^2]) are used. Six vehicle types are considered. Their value is set to one if the vehicle type applied; otherwise it is zero: light automobile (α); three-row seat (minivan) (β); automobile in which the engine room, crew space, and trunk are independent (sedan) (γ); automobile in which the crew space is combined with the trunk room (hatchback) (δ); sport utility vehicle (SUV) (ε); and light truck (ζ). Considering the relationships between the objective variable and each explanatory variable, the explanatory variable is selected with careful attention paid to the sign of the standard partial regression coefficient.

Table 2 shows the results of the multiple regression analysis. The value of [A] varies from M to D for the front door, back door, transmission, and engine. Consequently, as the vehicle's mass and engine's displacement increase, the automobile and its parts generally become larger. The value of [A] for the rear door can be estimated from S_S and ε. S_S corresponds to the area of the side view of the automobile. For the SUV, ε is included in the estimation equation because the wheel arch is larger than in other models, and the rear door is smaller. Although [A] for the bonnet could be calculated mainly from D, variables β and γ are included in the estimation equation because the bonnet of the minivan is short, whereas that of the sedan is long. From Table 2, all parts reached a significance level of 1% in the scatter analysis, and the determination coefficient indicated a comparatively high value. Thus, a reduction effect could be assumed for the uninvestigated automobile models.

4. Conclusion and Future Works

This study quantitatively assesses the reduction of CO_2 emissions through the use of reused automobile parts. The focus is on the production of large parts, which significantly contributes to CO_2 emissions. However, some reused parts have a high cost and environmental load. Therefore, using reused parts may not always be advisable with regard to the environmental impact. In any case, the relationship between CO_2 emissions and automobile parameters is clarified, and the reduction effect for automobile models not investigated here may be derived. By raising public awareness of the environmental load reduction effect of various reused automobile parts, customers will perceive them as "environmentally friendly" and become more interested in them.

Increasing pressures from various directions have caused automobile supply chain managers to consider and initiate the implementation of green practices to improve both the economic and environmental performance of the supply chain [13, 14]. Future works will focus on investigating as well as conducting a comprehensive analysis of the costs, environmental impact, and value of the parts.

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