# A Literature Review Concerning Microcars' Safety Issue

Rui Mu[1], Toshiyuki YAMAMOTO[2]

[1]PD, Institute of Innovation for Future Society, Nagoya University
(C 1-3 (651), Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan)
E-mail: murui@trans.civil.nagoya-u.ac.jp
[2]Member of JSCE, Professor, Institute of Materials and Systems for Sustainability, Nagoya University
(C 1-3 (651), Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan)_
E-mail: yamamoto@civil.nagoya-u.ac.jp

**Abstract:** Following new mobility era, more and more microcars are manufactured and used. Its safety issue is much concerned. This paper reviews safety analysis relating to microcar or small car in three point of view, history statistic data analysis, physical calculation, policy analysis and others. History statistic data analysis from different countries is reviewed, and in USA introduction of smaller car decrease the accidents rates while it increase the injury rate. In Japan smaller car like Kei car have lower accident and fatal rate in earlier year such as 1981 and 1982 which is due to lower speed limitation and drivers' more caution compared with conventional vehicle, however, they have higher accident and fatal rate nowadays. In physical calculation review, smaller size and weight vehicle have high relative injury risk. In policy analysis and other aspects, academics suggest that people do not only peer on smaller cars' safety disadvantage straightly caused by the smaller size, but the other aspects and how to avoid the safety issue by using smaller cars' specification.

***Keywords:*** *microcar, safety issue, review*

## 1 INTRODUCTION

As a new vehicle classification in Japan, microcar is defined at May of 2012 by the Ministry of Land, Infrastructure, Transport and Tourism, and it is a classification between Kei car and motorcycle. Table 1 shows definition of Kei car and micro-car by six main specifications in Japan. The upper limit of engine displacement of microcar is much lower than that of Kei car. For instance, the COMS produced by Toyota, it has a highest rated output of 5kW, which is much lower than that of a common Kei car or a conventional vehicle (usually tens of kW). And the lower engine displacement bring about lower maximum speed. The COMS has a maximum speed of only 60km/h (http://coms.toyotabody.jp/specs/index.html). Microcar also has smaller footprint to match its name. Especially to mention is that microcar can take at most two people, although it is half of Kei car, it is enough for citizen's daily trip (the personal trip passenger occupancy rate is 1.3 person/vehicle (Table 2-3 in http://www.mlit.go.jp/road/ir/ir-data/data_shu.html)). In brief, microcar has a smaller size and less dynamic performance than Kei car, and the significant difference is that Kei car can drive on expressway, while microcar cannot. It is possibly due to safety consideration.

Micro-cars were generated in Europe immediately after World War I, which were often motorcycle-based and were called cycle-cars, and usually three-wheeled. Many micro-car designs flourished in post-

World War II Europe, evolved out of demand for cheap personal motorized transport emerged and fuel prices being high. In 1959, Automobile and motorcycle manufacturer BMW introduced Austin Mini, and the Mini provided four adult seats and more practical long distance transport often at a lower cost, which often credited with bringing about the demise of the bubble car. After that, four-wheeled micro-cars dominated the consumer market gradually. There was another tide of micro-car in 1980s, because of its advantages in fuel saving, maneuverability, and local trip-making primarily, and consequently there came a series of discussion about micro-cars' safety issue in the following several years. After that, micro-cars exist as a portion of personal automobile consumption market for twenty to thirty years, but not so popular. Then there comes transformational change to the automobile recent years[1]. Micro-car concept is put forward again to cater to the new challenge from private automobile.

**Table 1** Specifications of Kei car and microcar in Japan

| | Kei car | Microcar |
|---|---|---|
| Engine displacement | 660cc or less | 125cc or less Rated output 8kW or less |
| Length | 3.4m or less | 2.5m or less |
| Width | 1.48m or less | 1.3m or less |
| Seating capacity | 4 | 2 |
| Loading capacity | 350kg | 350kg |
| Expressway use | Yes | No |

The definition of microcar is different from different countries. The upper limit for microcar in other countries is usually higher than that in Japan, mainly on engine displacement and size. For instance, the Register of Unusual Micro-cars in the UK says: "economy vehicles with either three or four wheels, powered by petrol engines of no more than 700cc or battery electric propulsion, and manufactured since 1945".

Microcars' safety issue is a significant concern for their existence on road since their birth. They have many advantages such as less energy consumption and emission, easy for parking, less tax, no need for driving license in some country. Meanwhile they get many misgivings about their safety for their smaller size and weight than conventional vehicles. There are literatures discuss microcars' or Kei car's safety issue, and they can be classified into three aspects, history statistic data analysis, physical calculation, and policy analysis. These literatures are reviewed here and maybe we can find some solution to get microcars' risk lower.

This paper is structured as follows, Section 2 conclude literatures analyzing statistic data of smaller vehicles such as microcar and Kei car. Section 3 reviews researches which calculate vehicles' relative safety risk based on mechanics and physical theory. Section 4 introduce researches related to policy analysis. Section 5 do a conclusion of the previous three sections and put forward some solutions of the safety issue.

## 2 HISTORICAL STATISTICAL ANALYSIS

Vehicle mass and size is a significant aspect for traffic safety consideration. Literatures that focus on analyzing historical statistic accident data to compare the difference between smaller vehicles (Kei car and microcar) and conventional vehicles are reviewed in this section.

In order to find whether car size influence accidents involvement rate, Evans[2] examined a function between car mass and accidents per unit travel distance using police reported crashes data from North Carolina, New York, and Michigan. Nine subsets in which three states multiply three age groups in 1979 are investigated. It was found that accident involvement rate increase with car mass when vehicles were driven by drivers with similar age, and the reason can be inferred to be drivers behave in different way to protect themselves vary with car size in the same age group. Exponential curve fitting (Equation 1) is applied for the relationships of accident involvement rate and car mass for each age group. Table 2 shows the curve fitting result as well as the percentage of distance travelled and crashes for each age group and for data of all groups of North Carolina in 1979. A truth is found that younger people drive less distance while have more accidents, and at the same time younger people prefer smaller cars. That is the reason why the trend shows an opposite direction if the driver age groups are aggregated, which supports the headline "Large Cars Have Lower Crash Rates"[3], in which the similar North Carolina data is used[4] for all ages. And all data from the selected three states have the similar trend as the description above.

$$Y = a * \exp(bm) \quad (1)$$

where Y is number of crashes for drivers of different age group divided by the total distance travelled for the corresponding age group, m is the car mass, a is the intercept and b is the slope.

**Table 2** Values of parameter b in equation 1 for the North Carolina crashes data in 1979.

| Age | Percent of Distance Travelled | Percent of Crashes | b in units of $10^{-5}$ $kg^{-1}$ |
|---|---|---|---|
| 16-24 | 12.0 | 41.6 | 21±7 |
| 25-34 | 25.1 | 24.3 | 17±3 |
| 35 and older | 62.9 | 34.1 | 38±5 |
| All | 100 | 100 | -1.3±0.4 |

As the curve fitting function used in equation 1 could not reflect the truth, Equation 2 is applied. In that case, it is assumed that the relative relationship between car mass and crashes per unit travel distance is the same for all age groups. So b is a slope that assumed to be the same for all age groups, and a(G) is an intercept which depends on age category. Finally a b for all the data from the three states is estimated, and it indicates a relationship between car mass and relative accident involvement rate as in equation 3

$$\ln\big(Y(G, m)\big) = a(G) + bm \quad (2)$$

where, m is vehicle mass in kg.

$$R \propto \exp(0.00036m) \quad (3)$$

where, m is vehicle mass in kg.

**Table 3** Accidents rate for multi-vehicle accidents by vehicle type from 2010 to 2013 in Japan (the number of accidents is get from traffic accidents annual report of Institute for Traffic Accident Research and Data Analysis, the number of vehicles is get from statistic table of Automobile Inspection and Registration Information Association, and the number of Kei-car is get from statistic data of Lighter Motor Vehicle Inspection Organization)

| **Multi-vehicle accidents** | **2010** | **2011** | **2012** | **2013** |
|---|---|---|---|---|
| **Conventional vehicle accidents rate** | 0.79% | 0.75% | 0.72% | 0.68% |
| **Kei car accidents rate** | 0.78% | 0.74% | 0.72% | 0.67% |
| **Conventional vehicle fatal accidents rate** | 0.0015% | 0.0014% | 0.0014% | 0.0013% |
| **Kei car fatal accidents rate** | 0.0019% | 0.0018% | 0.0017% | 0.0015% |

Although relative accidents involvement rate decrease as car mass decrease, the national traffic fatalities increase radically as car mass decrease. Evans[5] also presented a new approach to yield relationships between car mass and driver fatality likelihood, and driver behavior's effect on fatality is limited. The results illustrated that a driver of a 900 kg car is 2.6 times as likely to be killed as is a driver from a 1800 kg car. However, the value would decrease to 1.68 if the driver behavior were considered to be associated with driver fatality. The literature supply evidence suggesting that drivers of small cars would exhibit greater caution, possibly with a perception of greater danger and in order to reflect quickly. In further changes of driver behavior might negate, or even bottom up, any safety disadvantages of small vehicles. Krishnan and Carnahan[6] concludes from the automobile insurance data in United States that small cars increase injury risk to their occupants. Researches above demonstrate that smaller cars' decrease the accident rate while cause more injury in United States. However, it is concluded by the United States General Accounting Office[7)] that heavier cars are not immutably safer than lighter cars in its testimony “Automobile Weight and Safety”. Cars in the middle of the weight distribution have the highest fatality rates. And they estimated that if the proportion of small cars on road were to grow adequately, the total fatality rate in two-car accidents would decline slightly due to the decreased likelihood of comparatively deadly collisions between large and small cars.

**Table 4** Accidents rate for Single-vehicle accidents by vehicle type from 2010 to 2013 in Japan (the data source is the same with Table 2)

| Single-vehicle accidents | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|
| Conventional vehicle accidents rate | 0.022% | 0.020% | 0.018% | 0.016% |
| Kei car accidents rate | 0.031% | 0.028% | 0.025% | 0.022% |
| Conventional vehicle fatal accidents rate | 0.00073% | 0.00069% | 0.00060% | 0.00072% |
| Kei car fatal accidents rate | 0.00089% | 0.00082% | 0.00075% | 0.00098% |

Whereas Sparrow[8)] concluded from the statistic data of 1980, 1981, and 1982 that Kei cars in Japan have less accidents and fatalities except they have more fatalities in 1980 than conventional vehicles, this phenomenon is possibly attributed to special speed limitation for Kei car in Japan (80km/h for Kei car while 100 km/h for conventional car). However, the situation is not true nowadays in Japan (see Table 3, 4, 5). The accident rate as well as the fatal accidents rates of Kei car is higher than that of conventional vehicle, both in multi-vehicle accidents and single-vehicle accidents. The accidents’ fatal rate of Kei car is higher than that of conventional vehicle in multi-vehicle accidents, meanwhile, it is in opposite way for single-vehicle accidents. It means that if accidents happens, Kei car will suffer less fatality in single-vehicle crash, and it is still due to the lower speed limitation. The higher accidents and fatal rate of Kei car recent years remind people that they are not as cautious as before when driving a Kei car, and this is a more dangerous way.

In brief, for historic statistical analysis, small cars will suffer more safety issue if only considering their weight or size. However, precisely because of this, the drivers in such vehicles will try to reduce the risk by increasing their perception of danger, and will be more cautious for driving. And this kind of behavior may provide opportunity for smaller car to be driven in a similar safety level with conventional vehicle.

**Table 5** Accidents rate for Single-vehicle accidents by vehicle type from 2010 to 2013 in Japan (traffic accidents annual report from Institute for Traffic Accident Research and Data Analysis)

| Accidents’ fatal rate | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|
| Conventional vehicle in multi-vehicle accidents | 0.19% | 0.18% | 0.19% | 0.19% |
| Kei car in multi-vehicle accidents | 0.24% | 0.25% | 0.23% | 0.22% |
| Conventional vehicle in single-vehicle accidents | 3.36% | 3.50% | 3.41% | 4.51% |
| Kei car in single-vehicle accidents | 2.89% | 2.93% | 3.00% | 4.47% |

## 3 RELATIVE RISK IN PHYSICAL WAY

The relationship between car size and accidents was discussed in the following literatures by building equations or experimenting actual collisions between two vehicles, both based on mechanics and physical theory.

Niederer et al.[9)] investigated the low mass vehicles’ safety characteristics in terms of structural compatibility. They performed two crash experiments along with a theoretical model analysis to evaluate the compatibility properties of low mass vehicles (LMV) with rigid-belt body (RBB). The results indicated that due to its low mass a LMV cannot represent an excessive compatibility problem for other car occupants in spite of the stiff RBB characteristics. So the possible changes in driver protection with car mass may generate decreases in driver risk, and partially offset the expected increase in fatalities. These studies suggest that small cars will suffer more safety issue. However, these studies just experimented on the collisions between two vehicles which were regarded as physical substance. They ignored the driver behaviors, which is an important factor affecting traffic safety.

Evans and Frick[10)] assumes relative risk to be a function of ratio of the mass of the heavier to that of the lighter in two-vehicle crashes, and the function fit well with the Fatal Accident Reporting System data. Driver's fatality risk in lighter cars increases exponentially than in heavier ones.

Wood[11)] examined the influence of car size and mass on the relative safety of cars using Newtonian mechanics to derive a generalized equation for the relative safety of cars of different sizes when involved in frontal collisions. They are combined with overall injury criteria to give a series of predicted Relative Injury Risk (RIR) relationships. RIR of all collisions is proportional to Mass ratio of partner car/case car to the power of some number. So vehicles with smaller size and mass must get a higher RIR than normal ones. The theory showed that the size (length of the car) determined RIR in collisions between cars of similar size and in single vehicle accidents, whereas mass and the structural energy absorption properties of the cars is the determinant for risk in collisions between dissimilar sized cars. Occupants of small cars have a greater risk of injury than those in larger cars. The safety disadvantage of small cars relative to large cars can be reduced by changing the design of the front structures of small cars in a number of ways. The theory has a high level of correlation with the field evaluations of RIR to car occupants carried out in United States and Europe.

Tolouei et al.[12)] confirmed again that vehicle mass has a protective effect on its own driver injury risk and an aggressive effect on the driver injury risk of the colliding vehicle in two-vehicle crash. They also confirmed that there is a protective effect of vehicle size above and beyond that of vehicle mass for frontal and front to side collisions.

## 4 POLICY ANALYSIS AND OTHERS

Sparrow and Whitford[13)] gave a short history of small vehicles regulations in the U.S., the worldwide markets for such vehicles, and closed with a discussion of mini/micro-cars' safety issues in urban traffic and on expressway. It was summarized that mini/micros should not be dismissed as posing too great a safety risk just because of size. The effects of introducing micro-cars into traffic flow for congestion perspective have been studied in previous research[14)]; it was proved that micro-cars will relieve traffic congestion to some extent, and that the volume will be greater in higher density traffic due to the smaller size of micro-car. Mu and Yamamoto[15)] also calculated the frequency of lane changing and deceleration as well as coefficient of speed variation of traffic with different rate of micro-cars driven on a hypothesized expressway segment and an arterial road segment with traffic signal by a cellular automata model. The results suggested that micro-cars have a positive effect on safety when the number of decelerations and speed variations are considered for both kinds of road when traffic density is over 75 veh/km/two lane, in other words, micro-cars bring affirmative effect on safety in high density traffic.

## 5 CONCLUSION AND DISCUSSION

This is mainly a review of discussion about smaller cars' safety issue. And the perceptual intuition is their smaller size and weight. Actually academics mostly focus on this, and the researches can be sorted in three aspects, historic statistical analysis, physical calculation, as well as policy analysis and others.

Historic statistical analysis is the point focused by many academics. And there are reviews for different countries. Reviews which analyze USA data demonstrate that smaller car reduce accident rate, and the highest accident rate is caused by vehicles which have medium weight. However, smaller cars increase the fatal rate or injury risk due to their smaller size or lighter weight if crash happens. Researches which focus on Kei car in Japan conclude that Kei car have less accident rate and fatal rate in earlier year such as 1981 and 1982. However, our investigation on the accidents data in recent years shows that Kei car is more dangerous than conventional vehicle as they have both higher accidents rate and fatal accident rate, which force people to catch more cation on driving Kei car or other smaller cars, especially the new defined microcar in Japan.

Relative injury risk of crashes is calculated by Newtonian mechanics in more and more reasonable ways. Driver's relative injury or fatality risk is higher in smaller or lighter cars than in bigger or heavier ones.

In the policy analysis review, microcar not only have disadvantages but have advantages, and they advise people to recognize microcars' more specifications other than only smaller size. The in the other safety consider aspects, it is found that microcar is safer in high density traffic if consider number of deceleration and speed variation as the safety indicator.

Microcars' safety issue follows its convenience. One way to solve the problem is to produce microcar with heavier weight, even heavier than conventional vehicle, such as the Tango (http://www.commutercars.com/). However, if microcar have a similar weight with conventional vehicle, it will consume approximate amount of energy, and it may betray the original intention of microcars' existence. Another way is to drive smaller cars in a safer way, and it is a challenge. If in this way, the investigation on behavioral difference between microcar drivers, Kei car drivers and conventional car drivers including driving speed, acceleration, deceleration, etc. is necessary, because after we know the specifications of driver behavior in different vehicles, we can find some solution to drive smaller car safer technically or politically. For instance, it may be dangerous for smaller vehicle to accelerate or decelerate sharply due to its smaller size or lighter weight, then the manufacture can set lower limit for acceleration and deceleration.

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