RESEARCH INTO NEW SIDE IMPACT TEST BASED ON ACCIDENTS IN EUROPE AND JAPAN

Taisuke Fujiwara
Hiroyuki Murayama
Toyota Motor Corporation
Japan
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ABSTRACT

The current test procedures described in European and Japanese side impact regulations and ratings are conducted so that a non-crabbed Mobile Deformable Barrier (MDB) strikes a stationary test vehicle. However, in real-world accidents, many struck vehicles are not stationary but moving when the collision occurs. In consequence, it is advantageous to consider the velocity of the struck vehicles as well as that of the striking vehicles.
Accordingly, data of accidents occurring in Europe and Japan was analyzed. This accident data analysis showed that in both regions, more accidents occurred when struck vehicles were moving than when stationary. Consequently, car-to-car side impact tests were conducted using a moving target vehicle to comprehend the real-world deformation characteristics of the struck vehicle. Two side impact tests were then conducted using the Advanced European - Mobile Deformable Barrier (AE-MDB) Ver. 3.3, which represents the front-end stiffness of vehicles in Europe and Japan. The tests were conducted so that the AE-MDB struck both stationary and moving vehicles to compare the differences between the two scenarios. The test results indicated that larger and more severe peak intrusion level can be seen on stationary vehicles, but different types of deformation mode were seen between the stationary and moving vehicles. Based on these results, a new side impact test procedure using AE-MDB Ver. 3.3 was devised. The AE-MDB trolley was moved at a crabbed angle to reflect the moving condition of the target vehicle. This procedure represents a more common accident scenario that occurs in the real-world, and it allows for the direction of load applied to the struck vehicle to be taken into consideration. Such a test procedure that represents a more common real-world accident scenario is useful to further advance vehicle safety in side impacts.

INTRODUCTION

Since the fatalities in side impact accidents have not decreased in comparison with that of frontal impact accidents, many research institutes and vehicle manufacturers are examining various aspects of vehicle safety in side impacts. As one of these aspects, it can be stated that the existing ECE regulatory side impact test procedure (R95) is becoming less representative of the impact severity observed in recent accident data [1]. It has also been stated that side impact tests should be made more severe than the R95 procedure in order to represent a more severe side impact crash as found in real-world side impact accidents. Yonezawa [2] et al. investigated vehicle front-end characteristics and clarified the differences between them and the existing R95 barrier. Based on this data, the Japan Automobile Manufacturers Association, Inc. (JAMA) and the Japan Automobile Standards Internationalization Center (JASIC) developed AE-MDB Ver. 3.3 to represent the front-end stiffness of recent vehicle [3]. In addition, after researching accident data in the Co-Operative Crash Injury Study (CCIS) and considering the repeatability and reproducibility of tests, the European Enhanced Vehicle-safety Committee Working Group 13 (EEVC WG13) developed a new side impact test requirement using AE-MDB [1].
However, the CCIS accident data researched at that time was out of date and did not reflect recent accidents, additionally the accident data were not collected from other regions.
For these reasons, this paper presents a new test procedure using AE-MDB Ver. 3.3. The procedure represents a more common side impact accident scenario based on real-world accidents and research into vehicle characteristics conducted in Europe and Japan.

ANALYSIS OF ACCIDENTS AND VEHICLE CHARACTERISTICS

The European and Japanese accident databases used in this research are from CCIS (2002/1-2005/12), the German In-Depth Accident Study (GIDAS: 2003/1-2005/12), and the Institute for Traffic Accident Research and Data Analysis (ITARDA: 1994/1-2003/12).
Research requirements:

1. Accident cases involving car-to-car side impacts, and resulting in fatality or injury (MAIS 2+) were extracted.
2. Regardless of fastening seatbelt or not.
3. Curb weight of striking and struck vehicles is 2500 kg or less.
4. Non-multiple accidents.
5. Cases resulting in fatality or injury due to side slipping were omitted.

Supplementary explanations:
In CCIS database, cases resulting in fatality or injury occurred in roundabout were omitted.

In CCIS and GIDAS data that correspond to the requirements listed above, based on investigations into the sketch, account, and photo of each accident, cases in which cabins of struck vehicles were not deformed, and collision configurations which were not considered as side impacts were omitted.
In addition, accident data that did not contain the sketch nor account of each accident were also omitted.

Impact Direction
The impact direction in side impact accidents was analyzed. The angle at which the struck and striking vehicles are configured on impact is defined as the impact direction. In real-world accidents, vehicles are most likely to be struck from the directions around 3 or 9 o'clock (90 degrees) (Figure 1).

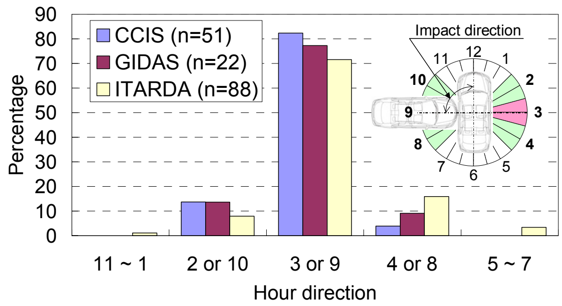


Figure 1. Frequency of Impact Direction in Side Impact Accidents.

Impact Velocity of Striking Vehicle
Next, the impact velocity of striking vehicles was analyzed. This data is available from GIDAS and ITARDA, since these databases have impact velocity data. The values from GIDAS are estimated or calculated, and those from ITARDA are based on evidence given by drivers or are estimated from brake marks. ITARDA, which contains a larger amount of data than GIDAS, shows that the highest percentage of fatality or injury can be seen when the impact velocity is approximately 55 km/h (Figure 2).

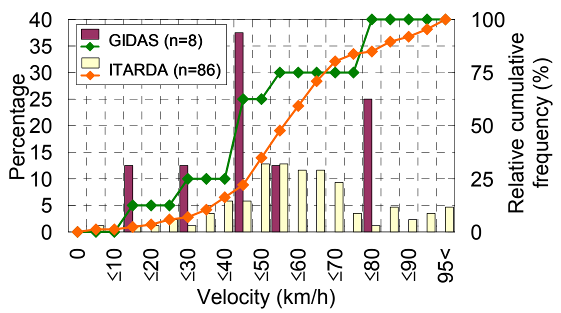


Figure 2. Velocity Distribution in Side Impact Accidents.

Accident Situation
Accident situations were also analyzed. The CCIS data shows that the highest percentage of side impact accidents occurred while the struck vehicle was turning right or left. On the other hand, the GIDAS and ITARDA data show that the highest percentage of side impact accidents occurred while the struck vehicle was traveling in a straight line. The percentage of side impact accidents that occurred while the struck vehicle was stationary is low in all 3 databases (Figure 3).

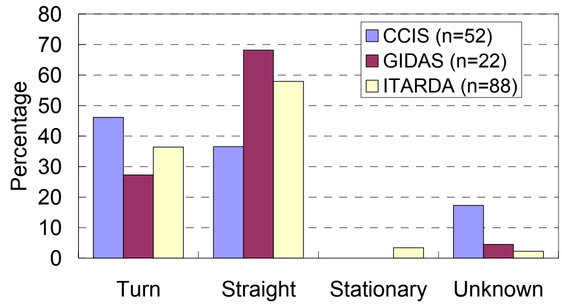


Figure 3. Frequency of Struck Vehicle Condition in Side Impact Accidents.

Velocity Ratio
As Figure 3 indicates, few accidents occurred when the struck vehicle was stationary. For this reason, the velocity ratio of the striking vehicles to the struck vehicles was analyzed. This was calculated based on the data from GIDAS and ITARDA, since these databases have impact velocity data. Consequently, a high percentage of velocity ratios between 1 and 3.73 were found in these databases (Figure 4). Converting the ratios to the direction of load applied to the struck vehicle obtained an angle of about 30 degrees. This direction is seen most often in real-world accidents.

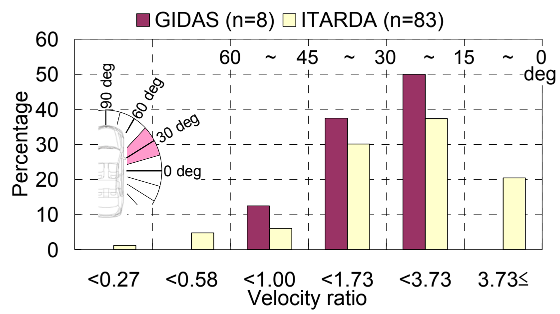


Figure 4. Frequency of Velocity Ratio of Striking Vehicle to Struck Vehicle.

Vehicle Weight
In order to obtain recent vehicle weights, weight data was researched based on vehicle sales data collected in each region. This research did not use accident data. (Research requirements - Europe: 2005 sales data from 19 countries, vehicle models ranked in the top 10 of sales volume of each segment; Japan: 2003 sales data, vehicle models that sold more than 20,000). The result shows that in both Europe and Japan, around 90 % of vehicles sold weighed 1500 kg or less (Figure 5). Accordingly, it can be said that most of the striking vehicles in real-world accidents

would also weigh 1500 kg or less.

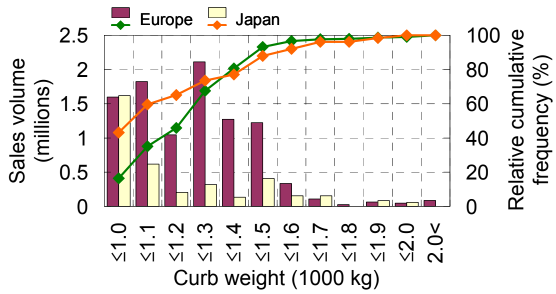


Figure 5. Relative Cumulative Frequency of Curb Weight.

REPRESENTING REAL-WORLD ACCIDENTS

Test Conditions

Car-to-car tests were conducted in order to reproduce real-world accidents.
The test conditions were defined as follows based on previous research (Figure 6).

1. Impact Direction - The longitudinal centerline of the bullet vehicle perpendicular to the longitudinal centerline of the target vehicle when the bullet vehicle strikes the target vehicle.
2. Impact Velocity of Striking Vehicle - The velocity of the bullet vehicle was 55 km/h, which is the same velocity specified in J-NCAP. In addition, half of side impact accident fatalities and injuries in Japan occur when the striking vehicles were traveling at 55 km/h or less, as shown in Figure 2.
3. Velocity Ratio - In the real-world, many struck vehicles are side impacted at an angle of 30 degrees in the direction of applied load. Therefore, the velocity ratio between the target and bullet vehicles was specified to be 1 to 2.
4. Vehicle Weight - The bullet vehicle weight was specified to be 1500 kg.
5. Impact Point - The impact point was specified at a position where the bumper beam of the bullet vehicle does not contact the front pillar and rear wheelhouse of the target vehicle during the impact development, in order to apply the most severe deformation to the target vehicle.

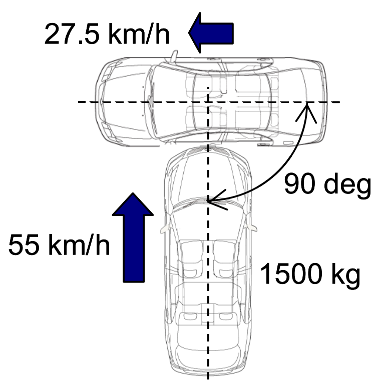


Figure 6. Test Conditions.

Conducting Representation Test

Bullet Vehicle Models - The 1500 kg Passenger Car (PC) was used as the baseline bullet vehicle. In addition, more severe tests using the 2000 kg PC and 2000 kg Sport Utility Vehicle (SUV) as the bullet vehicles were also conducted to obtain reference data. When the front-end stiffness of these three bullet vehicle models was examined, it was found to be close to the AE-MDB Ver. 3.3 corridor (Figure 7).

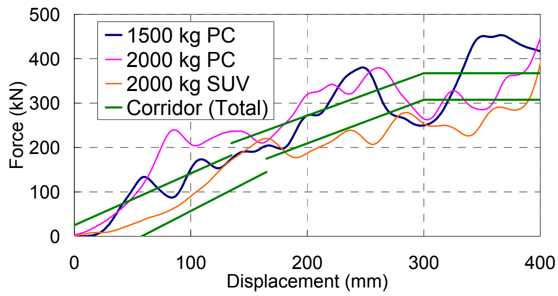


Figure 7. Vehicle Front-End Stiffness.

Target Vehicle Model - Another 1500 kg PC was used as the struck vehicle. The PC equipped with side airbags and curtain shield airbags.

Anthropometric Test Devices - Since the ES-2 dummy, which is seen as being an improvement over the EuroSID-1, is used in Euro-NCAP, it was also used in this research.

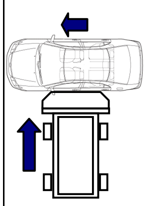
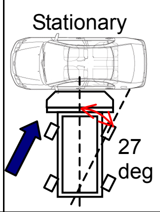
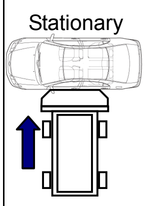
Test Observations - The deformation in the struck side of the target vehicle after the baseline test is shown in Figure 8. There was no indication that the bumper beam of the bullet vehicle intruded far enough to contact the front pillar and rear wheelhouse. This indicates that the test met test condition 5, "Impact Point".

Figure 8. Struck Side of the Target Vehicle.

Representation with AE-MDB Ver. 3.3

Subsequently, three types of test procedures were considered to define their potential to help represent a severe real-world side impact accident using AE-MDB Ver. 3.3 (Table 1).

Table 1
AE-MDB Test Matrix

Name	MtM	CtS	MtS
Config-uration			
Impact point (mm)	SRP-66.5	SRP-66.5	SRP+250
Velocity (km/h)	27.5 x 55	62	55

MtM = Moving trolley to moving vehicle
CtS = Crabbed moving trolley to stationary vehicle
MtS = Moving trolley to stationary vehicle
SRP = Seating reference point

The trolley weight for the three tests was 1500 kg. A 1500 kg PC was used as the target vehicle. This was the same target vehicle as that used in the car-to-car test.
The ES-2 dummy was used.

MtM Test - The MtM test was conducted in accordance with the car-to-car test conditions previously explained. The impact point was arranged as the position where the beam element of the AE-MDB was deemed not to contact with the front pillar and rear wheelhouse of the target vehicle during the impact development.

CtS Test - In the CtS test, the crab angle was specified to be 27 degrees, reflecting the velocity ratio of 1 to 2. The impact velocity was calculated from the relative velocity of the MtM test condition. The impact point was the same as that of the MtM test.

MtS Test - In the MtS test, the impact velocity was specified to be 55 km/h. This is the same as that of the bullet vehicle specified in the MtM test. The impact point was specified to be SRP+250 mm, based on the research paper of Ellway [1] et al.

Vehicle Intrusion Profiles
In all of the tests conducted, the geometrical characteristics of each target vehicle were mapped before and after each impact. The measurement lines for these tests are shown in Figure 9. Regarding the front and rear door panels, the inner panels were measured.
The post-test deformation profiles for each line were shown in Figure 10. The data set contains the results of the six tests explained previously.

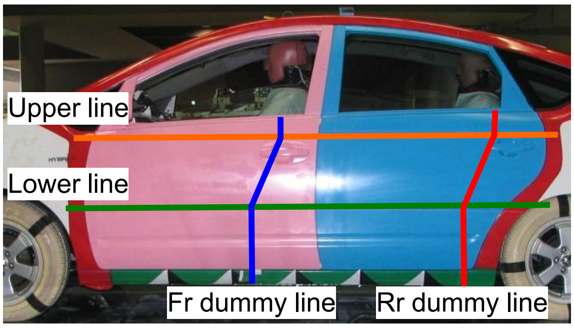


Figure 9. Measurement Lines of the Target Vehicle.

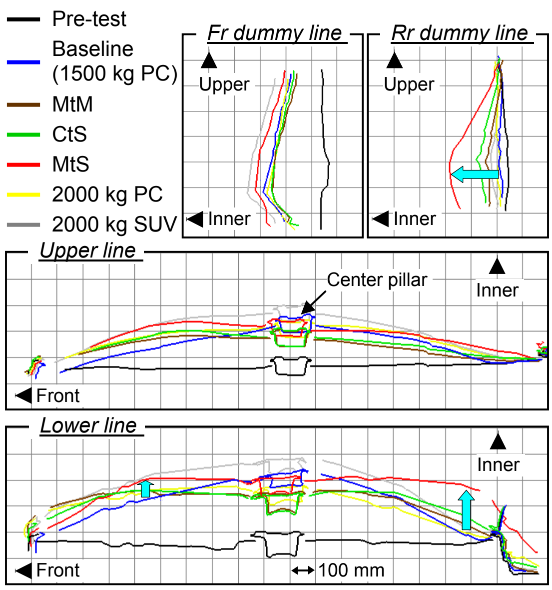


Figure 10. Intrusion Profiles of the Target Vehicle.

In the MtM test, although the peak intrusion level of the Fr dummy line was 36 mm smaller than that in the baseline test, the deformation mode was very similar.
In the CtS test, the intrusion level of the Fr dummy line was almost the same as that in the MtM test. This indicates the MtM test and the CtS test are essentially equivalent.
On the other hand, in the MtS test, the intrusion level of any point in the Fr dummy line was larger than that in the baseline test, and the peak intrusion level of the Rr dummy line was 192 mm larger than that in the baseline test. Especially, for the deformation at the lower lines, the center pillar intrusion level was almost the same as that in the baseline test, but the deformation mode at the front part of the front door inner and the rear part of the rear door inner was much different.

Front and Rear Dummy Responses
The percentages of measured injury values to injury criteria are shown in Figure 11. The injury criteria are defined in R95. The data set contains the results of the six tests explained previously.
In the MtM test, the values for pelvis injury in the

rear dummy were higher than those in the baseline tests, whereas the values for other body part injuries were at similar.
In the CtS test, the results were similar to those in the MtM test. There was no major difference between the results in the baseline test, except the value for pelvis injury in the rear dummy.
However, in the MtS test, the values for pelvis injury in both the front and rear dummies were higher than those in the baseline test, and the maximum deflection at the thorax in the rear dummy was lower than that in the baseline test.

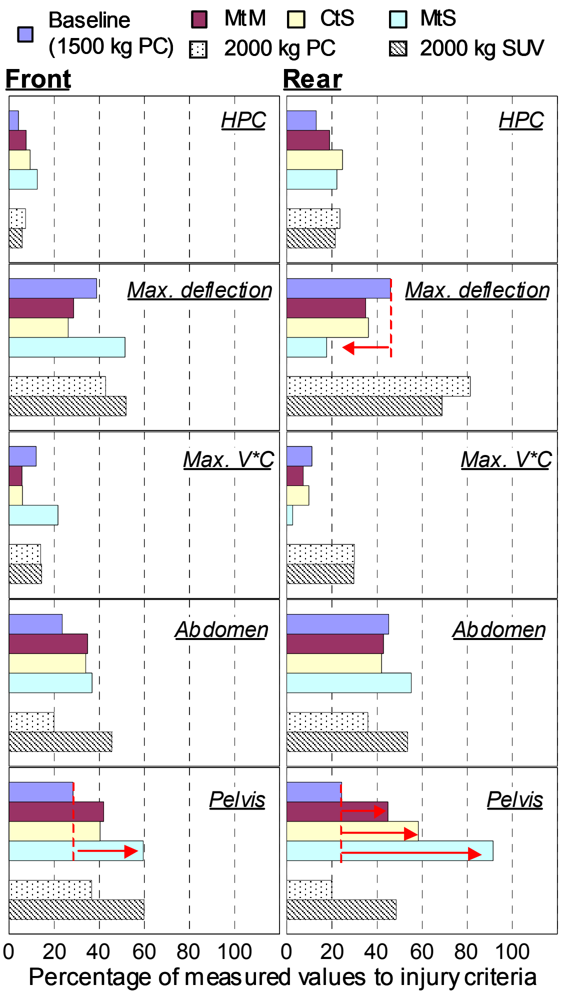


Figure 11. ES-2 Dummy Responses.

DISCUSSION

This paper integrates the results of research on real-world accidents and vehicles into test conditions to define their potential to develop a more representative test condition using AE-MDB Ver. 3.3.

In the case of the baseline test, the deformation mode at the door inner and center pillar on the target vehicle showed an arc. Similar results were seen after impact from different bullet vehicles. This result implies that the bullet vehicle does not perpendicularly intrude into the target vehicle, but instead slides to the rear of the target vehicle and intrudes into the target vehicle in accordance with the velocity component of the target vehicle.
In contrast, in the case of the three tests using AE-MDB Ver. 3.3 as the bullet vehicle, the door inner and the center pillar appeared to be intruded parallel to the pre-test configuration. Especially in the MtS test, larger deformation was seen at the rear part of the rear door. This result is totally different from the one in the car-to-car test. However, in the MtM and CtS tests, the velocity component of the target vehicle was considered, and the deformation mode was more similar to that in the car-to-car test.

In the MtM test, the dummy responses were more similar to those in the baseline test than those in the MtS test. In the CtS test, the dummy responses were similar to those in the MtM test.
In the MtS test, the value for pelvis injury was higher than that in the baseline test. This is assumed to be because a higher intrusion level at the door inner was seen in the MtS test than that in the baseline test.
According to analysis of Japanese accident data as researched by Yonezawa [2] et al., chest injuries occur more than pelvis injuries in side impact accidents. However, in the MtS test, the value for maximum deflection at thorax for the rear dummy was lower than that in the baseline test. This result is different from the trend of injured body part that occurred in real-world side impact accidents.
For these reasons, it is believed that the test conditions of the MtM or CtS tests, which represent the values for injury tendency seen in real-world accidents, are more effective than the those of the MtS test for occupant protection.

Since the CtS test considers the direction of load applied to the target vehicle of the MtM test, the vehicle intrusion level, deformation mode, and dummy responses are very similar in the two test conditions. This result indicates that the CtS test conditions can be used as a substitute for the MtM test conditions.

Tests were also conducted using AE-MDB Ver. 3.3. After the tests, it was found that the beam element of AE-MDB Ver. 3.3 was bent. This result caused a lower intrusion level at the center pillar than that in the baseline test. Consequently, JAMA and JASIC have developed a new generation barrier by applying a frontal plate to the beam element of AE-MDB Ver. 3.3 to increase the strength of the element. With the new generation barrier, it is thought that the intrusion level at the center pillar will be more similar to that found in the baseline test.

FUTURE RESEARCHES

In this research, only one vehicle model was used as a target vehicle. In the future, various types of vehicles should be investigated to verify the same tendency.

In addition, when the MtM and CtS tests were conducted, lateral bending and shear were found on the AE-MDB. In the car-to-car test, lateral bending was found at the front side rail on the bullet vehicle. Therefore, it is necessary to study to make the lateral mechanical properties of the AE-MDB correspond to those of the bullet vehicles.

CONCLUSIONS

1. Based on real-world accident analysis research in Europe and Japan, a side impact test procedure using AE-MDB Ver. 3.3 was devised.

2. In an MtM test using AE-MDB, the trends of deformation mode for the target vehicle and the injury values provide a more representative test condition than the MtS test condition, when compared to recent real-world accident data.

3. Based on the research completed, the CtS test can be conducted as a substitute for the MtM test.

REFERENCES

[1] Ellway, J. D. (on behalf of EEVC WG13). 2005. “The Development of an Advanced European Mobile Deformable Barrier (AE-MDB).” The 19th International Technical Conference on the Enhanced Safety of Vehicles (ESV) (Washington D.C., Paper No. 05-0239).

[2] Yonezawa, H. 2001. “Japanese Research Activity on Future Side Impact Test Procedures.” The 17th International Technical Conference on the Enhanced Safety of Vehicles (ESV) (Amsterdam, The Netherlands, Paper No. 267).

[3] Japan Automobile Standards Internationalization Center (JASIC). 2004. “Full-scale Side Impact Test Results in Japan.” The 37th EEVC WG13.

[4] Lowne, R. (on behalf of EEVC WG13). 2001. “Research Progress on Improved Side Impact Protection: EEVC WG13 Progress Report.” The 17th International Technical Conference on the Enhanced Safety of Vehicles (ESV) (Amsterdam, The Netherlands, Paper No. 47).

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Currently CCIS is managed by TRL Limited, on behalf of the United Kingdom Department for Transport (DfT) (Transport Technology and Standards Division) who fund the project along with Autoliv, Ford Motor Company, Nissan Motor Company and Toyota Motor Europe. Previous sponsors of CCIS have included, Daimler Chrysler, LAB, Rover Group Ltd, Visteon, Volvo Car Corporation, Daewoo Motor Company Ltd and Honda R&D Europe (UK) Ltd.

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Further information on CCIS can be found at http://www.ukccis.org

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