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TECHNOLOGICAL DEVELOPMENT AND VALIDATION OF *SPEED KIDNEY,* A NEW TRAFFIC CALMING DEVICE

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ABSTRACT

Traffic calming has been widely applied to urban areas the last decades to moderate both speed and traffic volume. Most used measures are physical which obligate the vehicle to modify its path and speed.
Among the benefits of traffic calming highlights the safety improvement due to the speed reduction and traffic volume reduction. However, traffic calming has disadvantages such as emergency response delays, traffic diversion, noise, vibrations, damage to vehicles and discomfort. In fact, common traffic calming devices do not consider discomfort on drivers who achieve an appropriate calmed and safe speed.

Consequently, it was necessary to develop a new traffic calming device to moderate speed and to minimize the disadvantages of the previous devices. The Highway Engineering Research Group (HERG) of the Universidad Politecnica de Valencia has invented, designed and developed a new traffic calming device named *Speed Kidney.*

The present paper provides the objectives of the *Speed Kidney*, the description of the new traffic calming device and its geometric design. Moreover, the technological development of the device is described, as well as the main results from: preliminary tests; a real implementation in a campus street; and a controlled test track. Implementation criteria are also given.

The *Speed Kidney* is another functional, feasible, sustainable and safety solution for traffic calming.

INTRODUCTION

Traffic calming measures (TCMs) have been widely used by some local jurisdictions in Europe and the United States. The aim of traffic calming is to reduce both frequency and severity of crashes on local streets and low volume roads.

There are two techniques to moderate the traffic (1). The first one is a partial restriction in order to limit excessive speeds on urban areas. This technique does not reach to the traffic problem on the whole traffic system. The second one takes into account not only the speed reduction but also the traffic volume decrease.

Traffic calming plans and programs are used to change the road users' perception of the area and force them to drive according to the main activities on the area. Among the elements used in traffic calming highlight physical measures involving vertical and/or lateral deflections to discourage speeding. Also, cross section or pavement variations are used. Nowadays, the most common traffic techniques are related to vertical changes on the profile, such as speed tables, speed humps and speed bumps, and horizontal changes on the alignment like roundabouts and chicanes.

Several research have been conducted to evaluate the effect of TCMs on traffic operation. Mostly all the studies reported speed reductions about 18% (2, 3). It was concluded that speed reduction depends mainly on the spacing between traffic calming devices (4, 5). The traffic calming organization had analyzed the impact on traffic operation of different traffic calming measures (6). The results indicated that the speed reduction was higher on speed humps than the other devices. Moreover, Barbosa et al (7) analyzed the speed profile obtained with 16 pneumatic sensors of cushions, chicanes, speed humps and speed tables. It was found that the speed tables were the TCMs with a higher impact on traffic operation. Cumulative effect due to close spacing was also studied (3, 8, 9). The optimal spacing has been found at 90 m (9). Therefore, it can be stated that the traffic calming measures, correctly implemented, can increase safety, comfort and mobility (10).

On the other hand, traffic calming may have negative effects that sometimes overshadow the benefits. TCMs influence on driving performance and may cause discomfort on passengers. Moreover, traffic calming devices can divert traffic to other streets in order to avoid discomfort. Furthermore, the impact of the wheels on a traffic calming device can damage the vehicles and increase both noise and vibration levels. Other studies also reported higher emissions and fuel consumptions due to sharp acceleration while approaching and leaving the device (11). The influence on emergency vehicles has been also stated (12, 13, 14). The amount of delay that was incurred depended on the type of emergency vehicle tested and the desired operating speed. The delay per speed hump varied from 2.3 to 9.6 seconds. Traffic calming measures may also affect to public transport. In fact, it has been developed guidelines of traffic calming measures for bus routes to qualify both bus operation and measures acceptance (15). The best TCMs for buses are: changes on pavement texture and color; control speed signs; cushions; and speed tables. Speed cushions were tested to minimize emergency vehicles delay (16). The response was generally positive. However, finding a speed cushion wide enough to slow most private vehicles and yet narrow enough to permit fire trucks and transit vehicles to pass easily, without overloading those heavier vehicles' rear axles proved difficult (17).

It is important to highlight that some users have been the most vocal opponents of speed humps since the negative effects of traffic calming affects to all users, even the drivers who achieve an appropriate calmed and safe speed.

OBJECTIVES

The aim of the study was to develop a new traffic calming device that moderates speeds and minimizes the disadvantages of existing traffic calming devices.

The objectives of the new traffic calming device are: to moderate the speed of passenger cars; to minimize the discomfort on passengers whose car circulates at an appropriate speed; to reduce the damage on vehicles as the vehicles do not have to overpass the device; to minimize the emergency response delays; to facilitate the driving to emergency vehicles, public transport and trucks; and to improve road safety by moderating speeds.

Objectives for a new traffic calming device are complied by the new device named *Speed Kidney*. Geometric design, technological development, main results of field tests and implementation criteria are provided in the present paper.

DESCRIPTION

The Highway Engineering Research Group (HERG) of the Universidad Politecnica de Valencia has invented, designed and developed a new traffic calming device named Speed Kidney.

The new traffic calming device is composed of a main speed kidney, as a speed hump, and a complementary speed hump. The device is named after the main speed hump shape, which is curved like a kidney (FIGURE 1). The device offers the drivers a chance to modify their path to avoid vertical discomfort. The optimal path is curved following the main speed kidney curvature. The vehicle straddles the device as the vehicle describes a slight and smooth chicane. Therefore, the speed is moderated.

The *Speed Kidney* also works as a speed cushion. Vehicles can follow straight ahead and surpass the device with one or two wheels over the main speed hump. Consequently, speeding is discouraged due to vertical forces and the consistent vertical discomfort.

The occupation (*O*) is a key parameter. The parameter controls the minimum axle that straddle the device without changing the path and going up the wheels. Vehicles with axle wider than the occupation will not be totally affected by the *Speed Kidney*. However, their speed will be moderated to centrally straddle the main speed kidney. Consequently, the affection to emergency vehicles, such as fire trucks or ambulances, and to public transport vehicles, will be minimized, as speed cushions.

In order to avoid the vehicles to pass between two main speed kidney, a complementary speed hump located between lanes is required. The width of the device also guarantees that a vehicle passes in the middle since the free space between the main speed kidney and the complementary speed hump is narrower than a vehicle width.

Cross section is raised with a trapezoidal profile. The main speed kidney has a flat top and side slopes not lower than 1:6. The width of the device (*A*) is equal or lower than the axle of the lowest vehicle to control. So, the passenger car does not go up on the speed hump if the curved path is adopted. On the other hand, side slopes facilitate the car to follow the curvature of the main speed kidney due to the gravity effect.

Motorbikes and bicycles can pass between the main speed kidney and the complementary speed hump. In order to center the wheels, their speed will be also decreased. Moreover, the narrowing effect caused by the device can encourage a speed reduction.

Consequently, the *Speed Kidney* is a traffic calming measure that involves a change on both horizontal and vertical alignment, as well as on cross section. The *Speed Kidney* allows drivers to choose between a straight and a curved path. The drivers who adopt a straight path will suffer the inconvenience of going up the device and the disadvantages of another vertical traffic calming measures. On the other hand, drivers that follow a curved path moderate their speed as well as minimize the discomfort and damage to their vehicle.

The *Speed Kidney* can be installed using prefabricated rubber pieces or constructed in site with asphalt concrete.

GEOMETRIC DESIGN

The parameters to determinate the geometry (FIGURE 2) of the *Speed Kidney* are: width (*A*); occupation (*O*); radius (*R*); corner radius (*r*); and length (*L*). The recommended values are shown in TABLE 1.

As stated before, width (*A*) is equal to the minimum axle passenger car which speed is controlled; and occupation (*O*) is equal to the axle of the minimum heavy vehicle that straddles the device. The adopted width is 1.7 m following the recommendations for speed cushions (1, 16). Consequently, emergency vehicles would not be affected by the device and could straddle the main speed hump without any disturbance.

According to the recommended values, the minimum two lane carriage width (A_T) to implement a pair of main speed kidney and the complementary speed hump is calculated with Equation 1.

$$A_T = 2 \cdot (S_b + A + S_i) + A_c \tag{1}$$

Where: A_T is the minimum carriage width; S_b is the offset between the main speed kidney and the kerb; A is the main speed kidney width; S_i is the offset between the main speed kidney and the complementary speed hump; and A_c is the complementary speed hump width. All the parameters are in meters.

The minimum width of the complementary speed hump is conditioned by the transversal margin of safety (M_t) required to adopt the curved path. The margin in rural roads is 0.50 m considering 3.5 m lane width and a centered heavy vehicle 2.5 m width. In urban areas the value is 0.38 m. So, the transversal margin of safety is stated as 0.40 m. The transversal margin of safety can be calculated considering the geometric parameters of the *Speed Kidney* and the vehicle width including the mirrors (Eq. 2).

$$M_t = \frac{A_c}{2} + S_i + \frac{A}{2} - \frac{H}{2} - \left(R_{me} + R + \frac{A}{2}\right) \cdot (1 - \cos(\alpha)) \tag{2}$$

Where: M_t is the transversal margin of safety; A_c is the complementary speed hump width, S_i is the offset between the main speed kidney and the complementary speed hump; A is the main speed kidney width; R is the radius; and H; R_{me}; and α are defined on FIGURE 2b.

The most common vehicle width including the mirrors is 2.10 m (19). Applying Equation 2 and considering the same radius as the main speed kidney ($R_{me} = R + A/2$); the main speed kidney location can be deduced. The main speed kidney is located 2.23 m from the axis of the road or street. Therefore, Equation 3 has to be satisfied in order to accomplish the required transversal margin of safety (0.40 m).

$$\frac{A_c}{2} + S_i + \frac{A}{2} \geq 2.23 \ m \tag{3}$$

Where: A_c is the complementary speed hump width, S_i is the offset between the main speed kidney and the complementary speed hump; A is the main speed kidney width.

Many streets are not wide enough to implement a *Speed Kidney*. In this case, the sidewalk kerb can accompany the *Speed Kidney* curvature to maintain the offset between the main speed kidney and the kerb, as shown in FIGURE 2c, 2d. To calculate the minimum required length of the kerb to accompany the *Speed Kidney*, Equations 4 to 9 can be applied.

If the deflection (f) is lower than 0.20 m, the accompaniment to facilitate the transition to heavy vehicles can be performed as a simple curve (FIGURE 2c). If the value is higher than 0.20 m, a reverse curve on the kerb is needed.

$$R_b = R + A + S_b \tag{4}$$
$$f = \left(\frac{A_c}{2} + S_i + A + S_b\right) - C \tag{5}$$
$$\theta = \arccos\left(1 - \frac{f}{R_b}\right) \tag{6}$$
$$L = 2 \cdot R_b \cdot \sin(\theta) \tag{7}$$
$$\omega = \arccos\left(1 - \frac{f}{R_b + R_e}\right) \tag{8}$$
$$L_b = 2 \cdot (R_b + R_e) \cdot \sin(\omega) \tag{9}$$

The parameters are defined in FIGURE 2c and 2d.

EXPERIMENTATION

To evaluate the operation of the *Speed Kidney* and the acceptance of the users, three tests were designed: a preliminary test (FIGURE 3a); a real implementation in a campus street (FIGURE 3b); and a controlled test track (FIGURE 3c). Furthermore, seven *Speed Kidney* will be constructed on a urban ring-road. Moreover, the implementation will be extended to cross-town roads and urban streets.

Preliminary Test
The preliminary test was carried out on September 2009. The influence of the radius was quantified by marking the contour of the *Speed Kidney* on the floor. Three radii were taken into account: 10; 15; and 20 m. Two vehicles, a BMW X3 and a Mini Cooper, were used by different drivers. The objective of the test was to circulate over the *Speed Kidney* at a prefixed speed, the objective speed. Then, the path was obtained using the Mobile Traffic Laboratory of the HERG.

The Mobile Traffic Laboratory is composed of a movable platform equipped with 6 video cameras. The cameras are controlled in real time with a laptop and they are connected by wireless to the recording machine. The platform can raise the cameras up to 12 m. The focus and orientation of the cameras in real time allows to record videos of wide areas with proper quality. To obtain the path from the video frames, software developed for another study was used (20). Furthermore, the speed and acceleration profiles can be deduced by numerical derivatives (21).

Subjective perception of both driver and co-driver were also collected at each trajectory. Horizontal comfort (*HCP*), vertical comfort (*VCP*) and risk perception (*RP*) were rated between 1 and 5 using a Likert scale.

The first results showed that the vehicle type did not influence driver performance and subjective perception. According to the subjective perception, the estimate operating speed in km/h is the double of the radius in m. However, the guidance effect of the raised speed hump is not taken into account.

Real Implementation on a Campus Street
The first *Speed Kidney* was executed on January 2010. The *Speed Kidney* was made of concrete asphalt and it was constructed in a street campus (FIGURE 3b). No advance warning signs were placed before the *Speed Kidney*. The signal of the device was the usual sign for speed humps. The radius of the main speed kidney was 15 m according to an estimate operating speed of 30 km/h. A before-after study was conducted to evaluate the effectiveness of the traffic calming device. The paths, speeds and acceleration profiles were calculated using the previously described methodology. The data were collected on working days with good weather conditions between February and March 2010.

The operating speed at the *Speed Kidney* location before the installation of the *Speed Kidney* was 49 km/h from a sample of 67 vehicles. After the construction of the *Speed Kidney*, the operating speed decreased to 31 km/h. Moreover, the operating speed for curved and straight paths was calculated and it result the same although the speed distributions were slightly different.

No statistical difference on deceleration rate was found for the paths. The 15th percentile of the deceleration rate was -0.65 m/s^2 and the acceleration rate was 1.1 m/s^2. Both were comfortable values.

Vehicle's path was also analyzed. From a sample of 247 vehicles, one third of the drivers intuitively followed a curved path. Two thirds of vehicles went straight ahead going up the right wheel. It was observed a learning effect as the proportion of vehicles that adopt a curved path had slightly increased.

92 drivers were surveyed to obtain the perception of: comfort; risk; and speed reduction. The drivers were stopped 200 m after surpassing the device. It was found different rating depending on the driver's path (TABLE 2). Comfort rates were higher on drivers with curved path, as well as they perceived lower risk. Subjective speed reduction does not match with objective speed reduction. While 67% of drivers with curved path perceived a high speed reduction, 52% of drivers with straight path felt a high speed reduction. However, the objective speed reduction was the same. This subjective perception can explain why drivers adopt a straight path even the discomfort and damage to their vehicles. It is important to highlight that the discomfort is lower compared to a conventional speed hump.

Eventual marking and signing was also assessed. Drivers preferred the used marking with red flat top. The entrance and exit ramp were also red. A white triangle indicated the direction on the entrance ramp. Vertical signs were evaluated too. The preferred sign was the plan view of the *Speed Kidney* and the path followed by the wheels (22).

Test Track

The third stage consists of the construction of 18 geometries of *Speed Kidney* in a test track. The controlled conditions allowed evaluating the operation of the *Speed Kidney* and the influence of the geometry on vertical comfort, horizontal comfort and risk perception. . For both vertical and horizontal comfort, 1 was the less comfortable and 5 was the most comfortable; while the riskiest perception received 1 and the safest perception had 5.

The Speed Kidneys were divided into two sets. 12 *Speed Kidney* were constructed on the first set on February 2010. The parameters that varied were: radius; entrance and exit ramp slope; and side slope. The first results highlighted that the vehicles could follow a straight path without going up the wheels. Therefore, a higher occupation and width was needed. 6 additional *Speed Kidney* were installed on June 2010. The geometry of the devices is shown in TABLE 3. It is important to highlight that the height remained constant. The hypothesis accorded to a previous research where it was observed that traffic operation was not influenced by the speed hump height (5).

Four vehicles were used to perform the tests: Nissan Terrano; Ford Mondeo; Peugeot 307; and Daewoo Lanos. The vehicles were driven by four different drivers. Each driver had a designated co-driver who guided on the test. Therefore, sixteen different pairs of driver and vehicle could perform the test.

Each test consists of passing a *Speed Kidney* at an objective speed with a prefixed path. Consequently, the driver was told the *Speed Kidney* number, the speed and the path. The drivers were not aware of the geometric characteristics of the devices.

Six objective speeds were initially programmed. However, the number of objective speed was limited to 4 the second test day. The objective speeds varied from 20 to 60 km/h and depended on the path and *Speed Kidney* geometry. Three paths were considered: straight path with the right wheel over the main speed kidney (path A); straight path straddling the main speed kidney (path B); and curved path following the main speed kidney curvature (path C). More than 3,600 test were carried out between March and July 2010.

At each test, both driver and co-driver rated the horizontal comfort perceived (*HCP*), vertical comfort perceived (*VCP*) and risk perception (*RP*). Moreover, the tests were recorded with the Mobile Traffic Laboratory. Therefore, paths, speeds and acceleration profile were obtained.

The average ratings were analyzed to find correlations between the subjective perception, the geometrical characteristics, the path and objective speed. The parameters taken into account were: radius; occupation; entrance ramp slope; side slope; and flat top width. The driver and co-driver perception was distinguished.

The analysis of the ratings showed that the key parameter on subjective perception depended on the followed path. In case of path A, the most important parameter was the entrance ramp slope (*I*). For path B, the key factor was the occupation (*O*), and finally, the radius (*R*) was the main parameter on path C. The subjective perception is represented depending on speed and the key parameter.

FIGURE 4 shows the subjective perception of the both driver and co-driver with path A depending on speed and entrance ramp slope (*I*). The figure shows that the higher the entrance ramp slope, the worse perception. In all the cases, the lower entrance ramp slope had better results. It can be observed that the optimal speed that minimizes the discomfort was between 30 and 40 km/h at the *Speed Kidney* with the lower entrance ramp slope. Furthermore, the risk perception was correlated with the comfort perception since the graphs had the same shape. On the other hand, the co-driver rated the vertical comfort lower than the driver because the vertical displacement was higher on the co-driver as the right wheel went up the device. However, the speed is usually chosen by the driver. Therefore, the speed selection may differ if the car has passengers. The results match with the observations that confirm that the preferred path to pass a speed cushion is straight ahead going up the right wheels (18). Besides, the

risk perception on drivers is lower than on co-drivers. The co-drivers tend to rate lower the safety since they are not secured to the wheel.

The occupation (*O*) was the key parameter on path B. It can be observed in FIGURE 5 that the rates were higher compared to path A. The lowest occupation (*O*=1.5 m) was not enough to moderate the speed since the rates were independent of the speed. After the first results, 6 new *Speed Kidney* were constructed with higher occupation. It was confirmed that a higher occupation resulted on a lower comfort. Other parameters like radius may influence the subjective perception since the highest occupation was not the lowest rated. However, the differences on rates were slight.

FIGURE 6 shows the subjective perception with path C. The average score given by the co-driver was also lower than the score of the driver, for both vertical and horizontal comfort. Risk perception was also conditioned by the horizontal acceleration since the trend was similar to the horizontal comfort. It can be observed that the score was not influenced by the radius for speeds higher than 30 km/h. Consequently, the initial hypothesis of speed control based on radius was not confirmed by the results. Drivers accommodated a curved path with different radius than the main speed kidney: the radius of the path was independent of the main speed kidney radius and it was the same in all the cases. So, the vehicle had an equal lateral acceleration and the subjective perception was the same.

A comparison between path A, B and C was carried out to determine the optimal path depending on speed. For each path, the most restrictive parameter on subjective perception was taken into account: vertical comfort on path A; vertical comfort on path B; and horizontal comfort on path C. The results are represented on FIGURE 7.

The results differed depending on driver and co-driver perception. The discomfort reported by co-drivers suggests that the preferred path is B or C if the speed is lower than 40 km/h in case of radius equal to 10 or 15 m. The optimal path perceived at speeds higher than 40 km/h is B for these radii. The threshold is higher if the radius is 20 m, and it is stated about 50 km/h.

On the other hand, the results from drivers may indicate that the preferred path is C if the speed is lower than 40 km/h. Consequently, the *Speed Kidney* gives comfort until 40 km/h. Speeds higher than approximately 40 km/h will probably encourage drivers to going straight ahead, with paths A or B, depending on the entrance ramp slope.

The observations on the real implementation (campus street) correspond to a *Speed Kidney* with 15 m radius and 9.3 % entrance ramp slope. Two thirds of drivers used to take a straight ahead path (A) and just one third of them followed a curved path. The observed speeds were around 20-30 km/h, where the path A is not as discomfort as regular speed humps. Therefore, the majority of drivers adopted a straight ahead path A, but drivers rarely drove a straight path B. Path C was adopted by drivers with the highest speeds, as test conclusions have confirmed.

IMPLEMENTATION CRITERIA

In order to give guidelines of the implementation of the *Speed Kidney,* the following criteria are established:

- The *Speed Kidney* can be used not only in local streets but also on local distributor roads and cross-town roads.
- The *Speed Kidney* admits a wide range of traffic volume.
- The installation on sharp horizontal and vertical curves should be avoided.
- Enough stopping sight distance is required at the location of the *Speed Kidney.*
- The grade should be lower than 5%.
- Maximum posted speed limit is 50 km/h; since the *Speed Kidney* aims to achieve an appropriate safe speed along an entire road rather than spot speed reduction.
- The *Speed Kidney* should not be used as a crosswalk.
- The *Speed Kidney* should be located at a minimum distance to decision points of 20 m.
- The rain off must be guarantee.

- Traffic composition does not influence the installation since any negative effects on trucks, motorbikes and bicycles are found.
- The *Speed Kidney* can be installed on designated public transport routes and access routes to hospitals.
- Prefabricated *Speed Kidney* is preferred on streets with snow removal during winter.
- The *Speed Kidney* should be located where parking is forbidden to avoid drivers to straddle the center speed hump.

CONCLUSIONS

Several countries have introduced an extensive use of traffic calming measures during the past years; specially speed tables, speed humps, speed bumps and roundabouts. However, these measures are centered on speed reduction and ignore some of their disadvantages such as the increase on the emergency response delays, the discomfort on passengers and the damage to the vehicles.

The Highway Engineering Research Group (HERG) of the Universidad Politecnica de Valencia has invented, designed and developed a new traffic calming device named *Speed Kidney*. The design of the new traffic calming device moderates the speed and minimizes the inconvenience caused to the passengers, the noise and vibrations, the damages to the vehicles, the emergency response delays and the maintenance.

The description and geometric design of the *Speed Kidney* has been defined. The experimentation of the new traffic calming device has been carried out in three stages: (1) preliminary test with only the contour; (2) real implementation in a campus street with actual drivers; and (3) controlled test in a specific test track with 18 different geometries. The results of the different test are given. It was found on the first stage that the operating speed was approximately the double of the radius. On the second stage, it was observed that one third of the drivers take with a slight curve the main speed kidney intuitively. The operating speed was reduced from 49 km/h to 31 km/h, and the same operating speed is obtained for all the paths. The controlled test gave many conclusions. One of the most important is that the key parameter on speed selection depends on the path. It was observed that the curved path gave comfort and the consistent safety until a threshold of 35 km/h. From 35 km/h, the preferred path was straight ahead. Furthermore, the implementation and evaluation of *Speed Kidney* will be extended to cross-town roads and urban streets.

The *Speed Kidney* is, consequently, a functional, feasible, sustainable and safety solution where users are integrated.

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LIST OF TABLES AND FIGURES

TABLE 1. Recommended Values

Main Speed Kidney			
Dimension		**Recommended Value**	**Interval**
Width	A	135 cm	130-140 cm
Occupation	O	170 cm	150-175 cm
Radius	R	Depends on speed	10-20 m
Length	L		500-900 cm
Corner Radius	r	30 cm	0-A/3 cm
Height	H	7.5 cm	6-8 cm
Entrance Ramp Slope	P	12.0%	10-15%
Side Ramp Slope	pl	16.5%	15-20%
Complementary Speed Hump			
Width	A_c	170 cm	150-200 cm
Offset			
Main Speed Kidney – Complementary Speed Hump	S_i	Depends on available line width	90-120 cm
Main Speed Kidney - Kerb	S_b	Depends on available line width	70-120 cm

TABLE 2 Subjective Perception

Comfort			Risk Perception			Speed Reduction		
	Path			Path			Path	
	Straight	Curved		Straight	Curved		Straight	Curved
Very comfortable	7	22	Very safe	10	11	Very high	14	17
Comfortable	31	44	Safe	31	61	High	38	50
Medium	21	28	Medium	14	17	Medium	17	28
Uncomfortable	17	0	Unsafe	24	6	Low	24	6
Very uncomfortable	24	6	Very unsafe	21	6	Very low	7	0
TOTAL	**100**	**100**	**TOTAL**	**100**	**100**	**TOTAL**	**100**	**100**

TABLE 3 Geometry of the *Speed Kidney* installed on the Test Track

ID	Radius (m)	Entrance ramp		Side ramp		Flat top width (m)	Occupation (m)	Width (m)
		Length (m)	Slope (%)	Length (m)	Slope (%)			
1	10	0.500	14.0	0.375	18.7	0.45	1.50	1.20
2	10	0.500	14.0	0.450	15.5	0.30	1.50	1.20
3	10	0.625	11.2	0.375	18.7	0.45	1.50	1.20
4	10	0.625	11.2	0.450	15.5	0.30	1.50	1.20
5	15	0.500	14.0	0.375	18.7	0.45	1.50	1.20
6	15	0.500	14.0	0.450	15.5	0.30	1.50	1.20
7	15	0.625	11.2	0.375	18.7	0.45	1.50	1.20
8	15	0.625	11.2	0.450	15.5	0.30	1.50	1.20
9	15	0.750	9.3	0.375	18.7	0.45	1.50	1.20
10	15	0.750	9.3	0.450	15.5	0.30	1.50	1.20
11	20	0.625	11.2	0.375	18.7	0.45	1.50	1.20
12	20	0.750	9.3	0.450	15.5	0.30	1.50	1.20
13	10	0.625	11.2	0.375	18.7	0.45	1.65	1.35
14	10	0.625	11.2	0.375	18.7	0.45	1.75	1.35
15	15	0.625	11.2	0.375	18.7	0.45	1.65	1.35
16	15	0.625	11.2	0.375	18.7	0.45	1.70	1.35
17	15	0.625	11.2	0.375	18.7	0.45	1.75	1.35
18	20	0.625	11.2	0.375	18.7	0.45	1.75	1.35

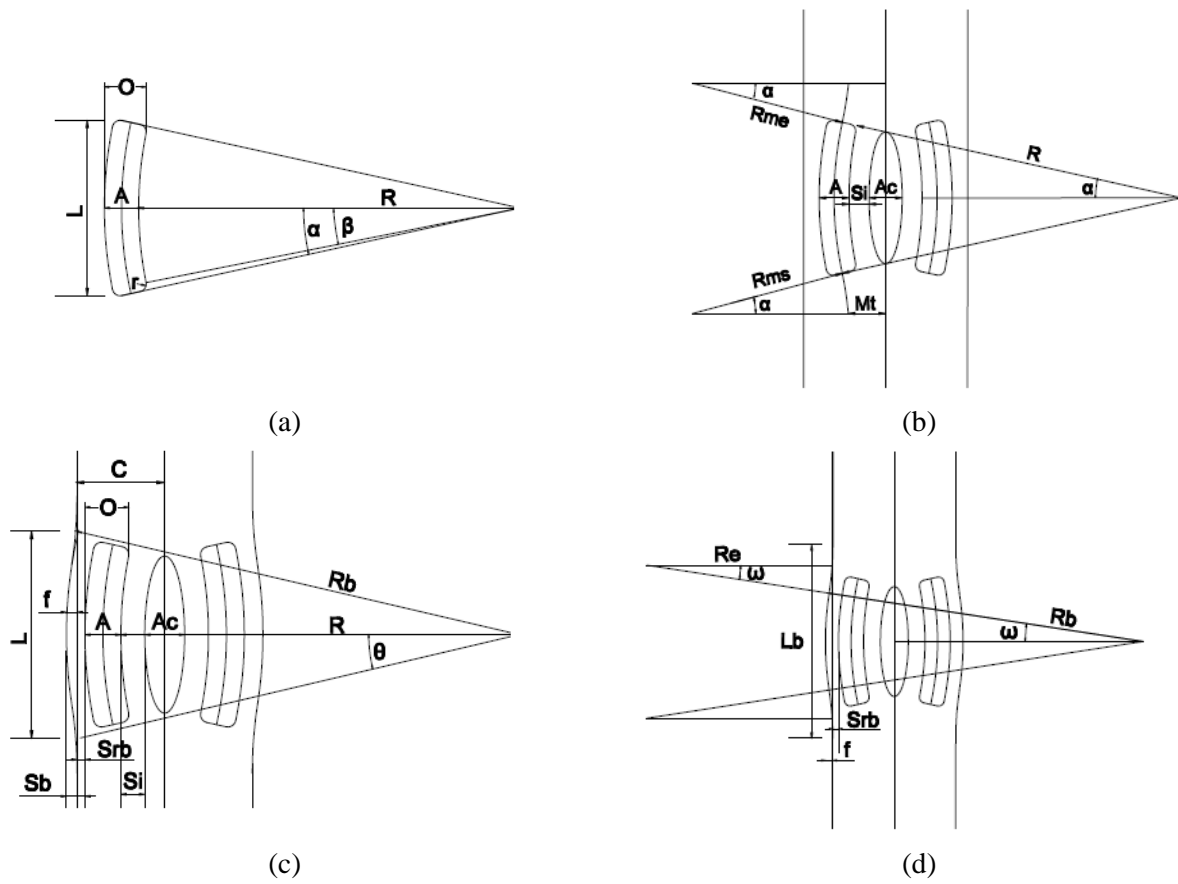(a)   (b)
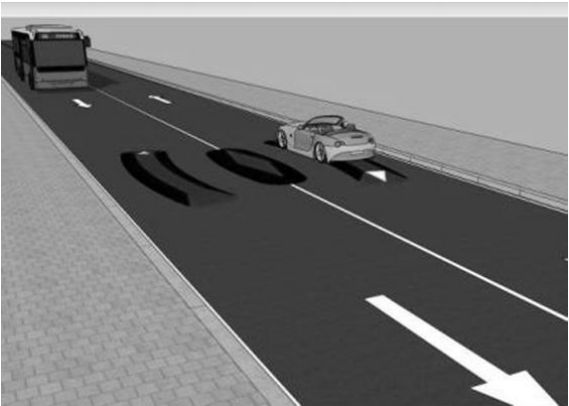
FIGURE 1 *Speed Kidney*.

(a)

(b)

(c)

(d)
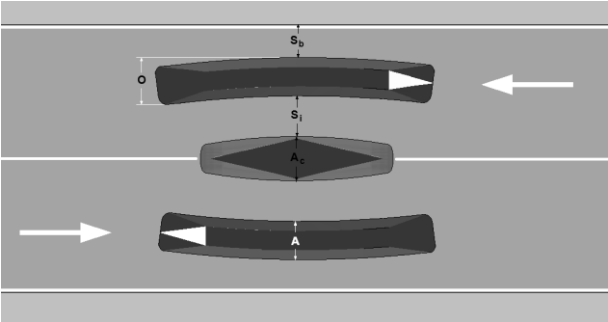
FIGURE 2 *Speed Kidney* **Geometry.**

(a)   (b)

(c)

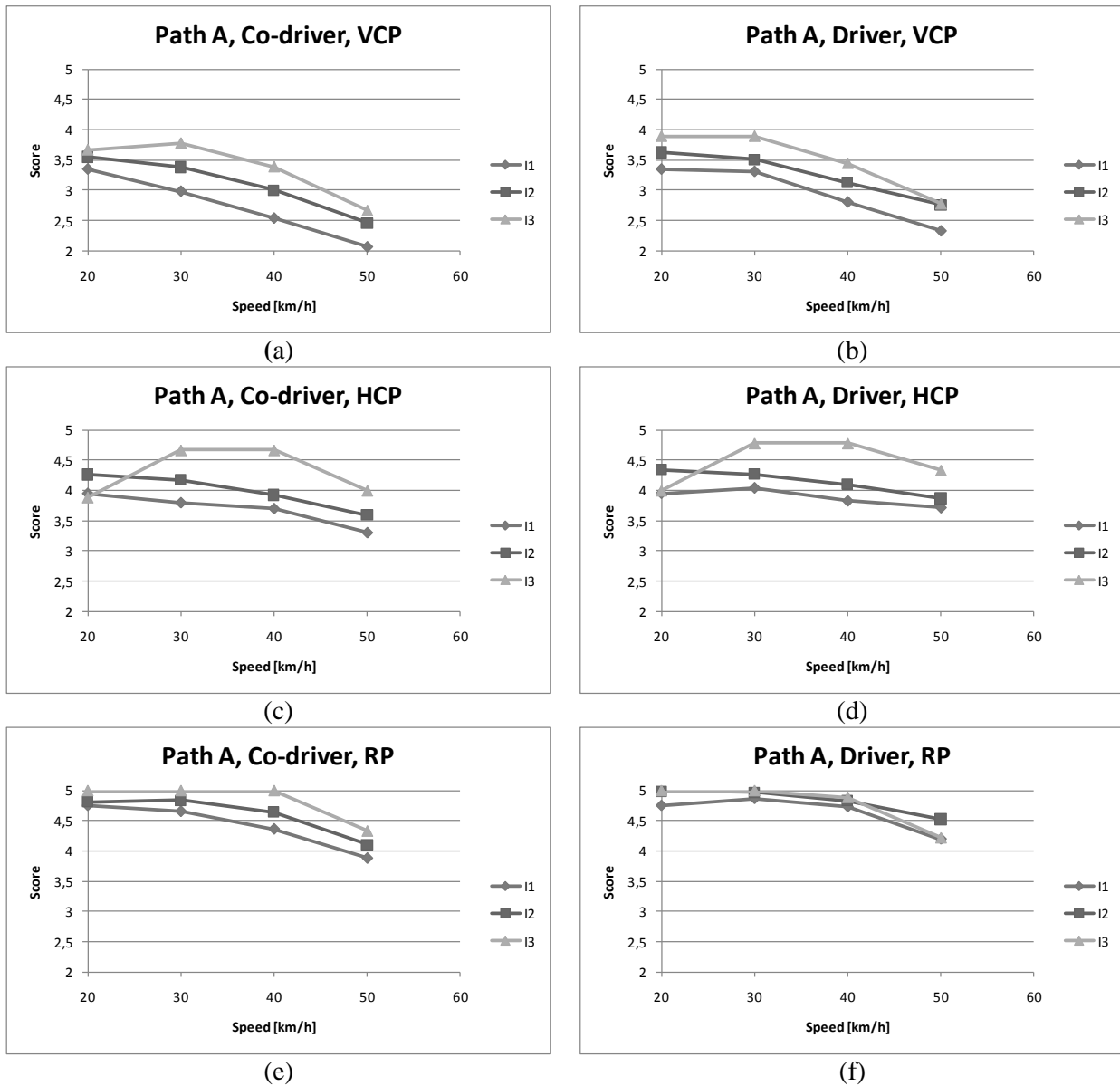**FIGURE 3** *Speed Kidney Experimentation: (a) Preliminary Test; (b) Real Implementation; (c) Test Track.*

FIGURE 4 Subjective Perception with Path A of: (a) Co-Driver Vertical Comfort; (b) Driver Vertical Comfort; (c) Co-Driver Horizontal Comfort; (d) Driver Horizontal Comfort; (e) Co-Driver Risk Perception; (f) Driver Risk Perception.
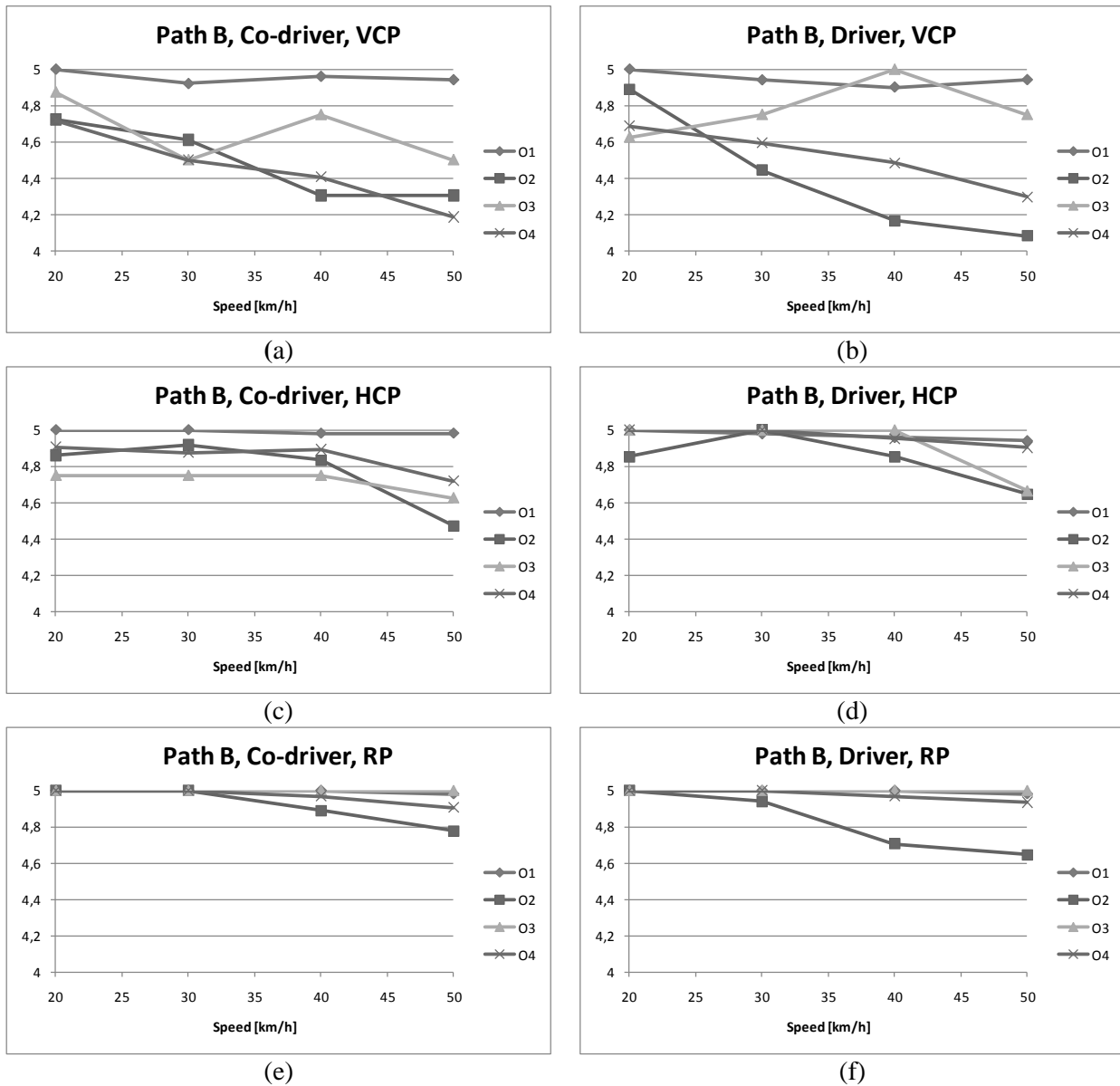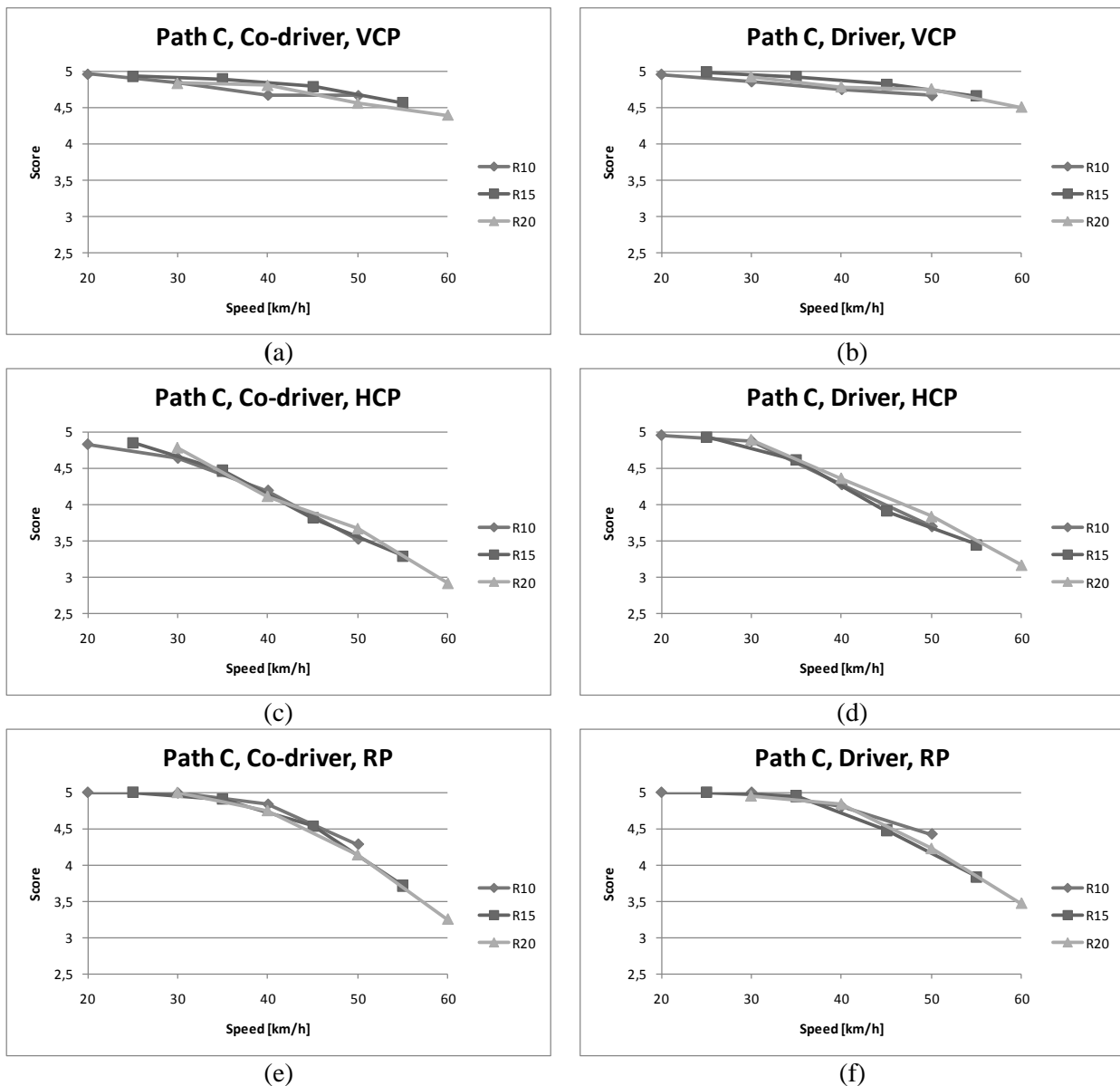
FIGURE 5 Subjective Perception with Path B of: (a) Co-Driver Vertical Comfort; (b) Driver Vertical Comfort; (c) Co-Driver Horizontal Comfort; (d) Driver Horizontal Comfort; (e) Co-Driver Risk Perception; (f) Driver Risk Perception.
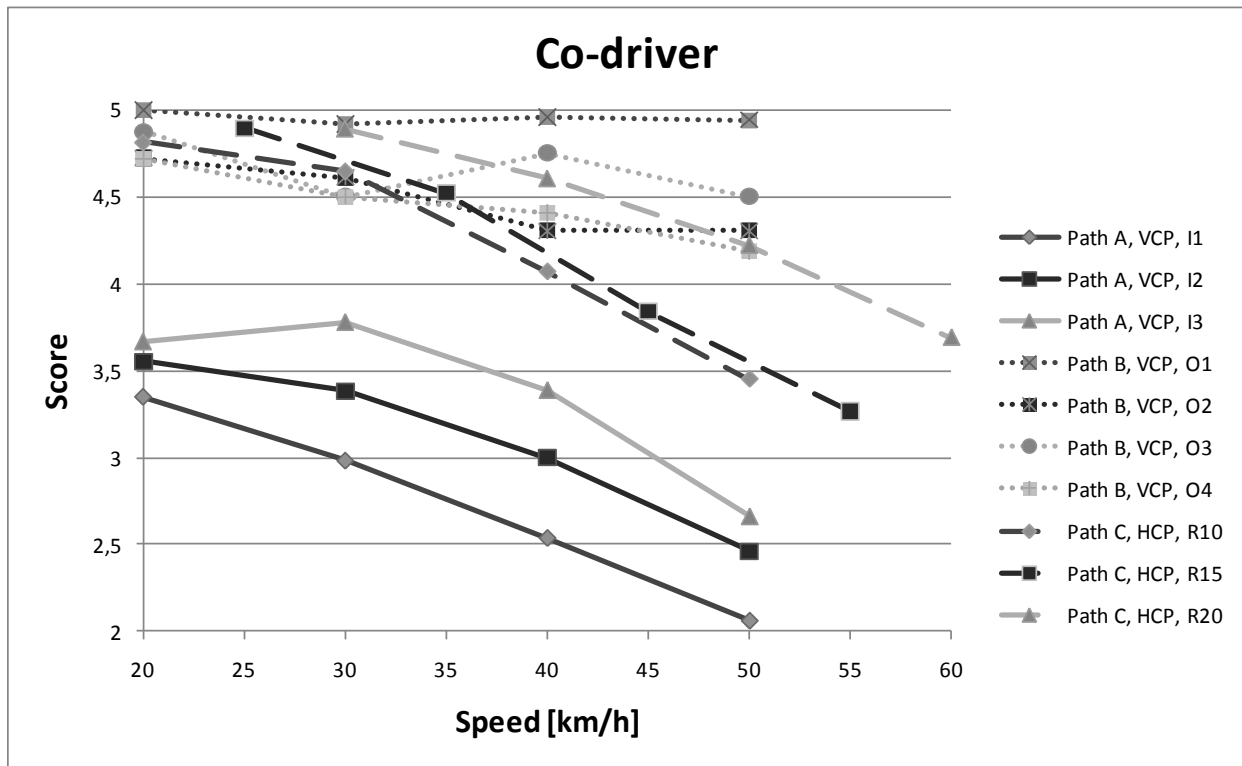
(a)

(b)

(c)

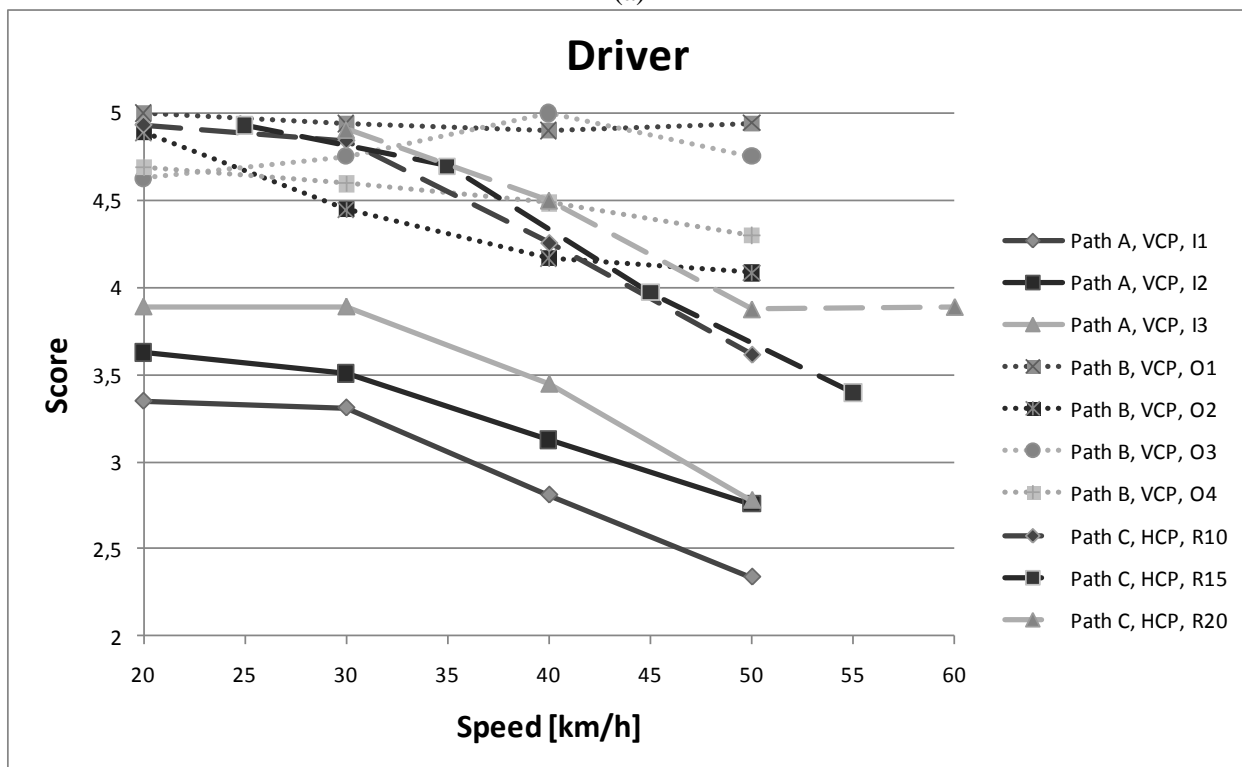**(d)**

(e)

(f)

FIGURE 6 Subjective Perception with Path C of: (a) Co-Driver Vertical Comfort; (b) Driver Vertical Comfort; (c) Co-Driver Horizontal Comfort; (d) Driver Horizontal Comfort; (e) Co-Driver Risk Perception; (f) Driver Risk Perception.

(a)

(b)

FIGURE 7 Subjective Perception Comparative Path : (a) Co-Driver; (b) Driver.