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Active Safety Bicyclist Test Targets Recommendation

RATIONALE

Improving bicyclist safety is one of the major goals for active safety systems. As more active safety systems, especially the automatic emergency braking (AEB) systems, are introduced to the market, a standard surrogate bicyclist target is needed for automotive industries to test and evaluate AEB systems. SAE International created an Active Safety Bicyclist Test Target Task Force under the Active Safety Systems Standards Committee to study this topic and to recommend a surrogate bicyclist standard. The goal of the Bicyclist Test Target Task Force is to develop standard specifications/requirements for bicyclist target (including bicycle target and bicycle rider mannequin). This target should be representative of real bicycles and bicyclists to the sensors used in Forward Looking Bicyclist Detection systems and can be used for performance assessment of such in-vehicle systems (including warning and/or braking) in real world test scenarios/conditions. This document is the result of committee study and recommendation.

INTRODUCTION

Improving bicyclist safety is one of the major goals for active safety systems. As more active safety systems, especially the automatic emergency braking systems, are introduced to the market, a standard surrogate bicyclist target is needed for automotive industries to test and evaluate the AEB (Automatic Emergency Braking). SAE International created an Active Safety Bicyclist Test Mannequin Task Force under the Active Safety Systems Standards Committee to study this topic and to recommend a mannequin standard for frontal bicyclist detection systems. All members of the task force are from industry, government, and academia. Many members had experience in using, testing, and/or developing bicycles and bicyclist mannequins. The task force gathered information of all surrogate bicyclist targets known to the committee members and analyzed the state of the art features of these mannequins [1, 2]. This document is the result of committee study and recommendation.

The task force reviewed a similar standard created by ISO [3] as a group including feedback from members who are familiar with ISO activity. The task force understood that this ISO test mannequin standard was created based on European data and bicyclist target specification is mainly for side view tests. The SAE workgroup is for developing a target based on U.S.-specific data and U.S. population. This SAE bicycle and bicyclist target specifications are representative for 360 degree approach angles.

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1. SCOPE

The goal of the Bicyclist Test Mannequin Task Force is to develop standard specifications/requirements for bicyclist test mannequins (one adult and one child) that are representative of real bicyclists to the sensors used in Bicyclist Detection systems and can be used for performance assessment of such in-vehicle systems (including warning and/or braking) in real world test scenarios/conditions. This version of the document only includes the recommended bicyclist mannequin characteristics for vision, Lidar, and/or 76 to 78 GHz radar-based Bicyclist Pre-Collision systems.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

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3. DEFINITIONS

ACTIVE SAFETY SYSTEM: Vehicle safety systems that sense and monitor conditions inside and outside the vehicle; identify perceived present and potential dangers to the vehicle, occupants, and other roadway users; and then automatically react to help avoid or mitigate crashes via various methods including alerts, vehicle system adjustments, and active control of the vehicle motion subsystems (brakes, throttle, suspension, etc.).

ANECHOIC: Free from echo (like an anechoic chamber).

ARTICULATION: Arm and leg rotation on a mannequin, similar to a real walking human.

AUTOMATIC EMERGENCY BRAKING (AEB): (Advanced emergency braking system, autonomous emergency braking, automatic emergency braking, collision imminent braking, automated emergency braking.) Combines advanced driver assistance systems and subject vehicle braking to slow the vehicle to avoid or mitigate a collision.

BICYCLIST TARGET: A surrogate object that includes the bicycle and bicyclist.

INFRARED: Have a wavelength just greater than that of the red end of the visible light spectrum but less than that of microwaves. In this document, infrared refers to near-infrared radiation that has a wavelength from about 800 nm to 1 mm.

LIDAR: An active sensing technology that can measure the distance to, or other properties of, targets by illuminating the target with light and analyzing the backscattered light.

MICRO DOPPLER: Mechanical vibrations/rotations/movements of a target or structures on the target may induce additional frequency modulations on the returned radar signal that generate sidebands about the target's body return Doppler frequency. These frequency modulations are called the micro-Doppler effect.

NATURALISTIC DRIVING STUDY (NDS): A study to provide insight into driver behavior during everyday trips by recording details of the driver, the vehicle, and the surroundings through unobtrusive data gathering equipment and without experimental control (<http://www.udrive.eu/index.php/about-udrive/what-is-naturalistic-driving>).

4. SYMBOLS AND ABBREVIATIONS

AEB	Automatic Emergency Braking
AsPeCSS	Assessment Methodologies for Forward-Looking Integrated Pedestrian and a Further Extension to Cyclist Safety Systems
IIHS	Insurance Institute for Highway Safety
LIDAR	Light Detection and Ranging
NHTSA	National Highway Traffic Safety Administration
Radar	Radio Detection and Ranging
RCS	Radar Cross Section
TASI	Transportation Active Safety Institute
OSU	Ohio State University
CSRC	Collaborative Safety Research Center

5. BICYCLIST TARGET SPECIFICATIONS

The bicyclist target should provide sufficient details of the bicycle and bicyclist characteristics to satisfy the need of all state-of-the-art detection sensors and anticipated potential new detection sensing technologies. Table 1 shows the bicyclist characteristics that have the potential effect to the sensing outcome. They should be considered in the bicyclist target specifications (Table 1).

Table 1 - Bicyclist characteristics versus detection sensors

Sensor Type	Bicyclist Target Characteristics					
	Size	Pedaling	Wheel Rotation	Rcs	Viewing Angle	Clothing Color
Camera	X	X	X		X	X
76-78 Ghz Radar (Including Micro Doppler)	X	X	X	X	X	
Lidar/Active Infrared	X	X	X		X	X

5.1 Viewing Angles

The detection sensors are frequently exposed to bicyclists from different angles during naturalistic driving. Figure 1 shows that detection sensors can detect the bicyclist surrogate from different angles such as crossing the road and moving along the road. The shape differences of the bicycle and bicycle rider may affect the target perception by sensing systems. The shape change leads to surface area change that affects the RCS (Figure 2). Therefore, it is essential that a standard bicycle and bicyclist target represent a real bicycle and bicycle rider from all 360 degree horizontal viewing angles. Figure 2 is an example of varying radar response of a bicycle and a bicyclist from 360-degree angles.

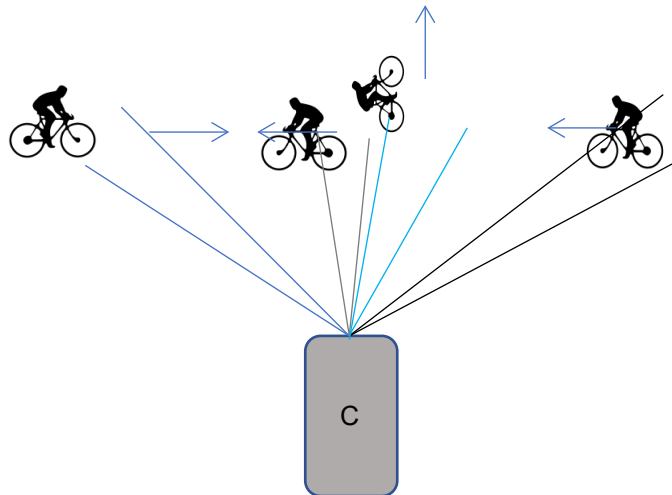


Figure 1 - Vehicle senses the bicycle and bicyclist from different angles when the bicycle is crossing the road and traveling along the road

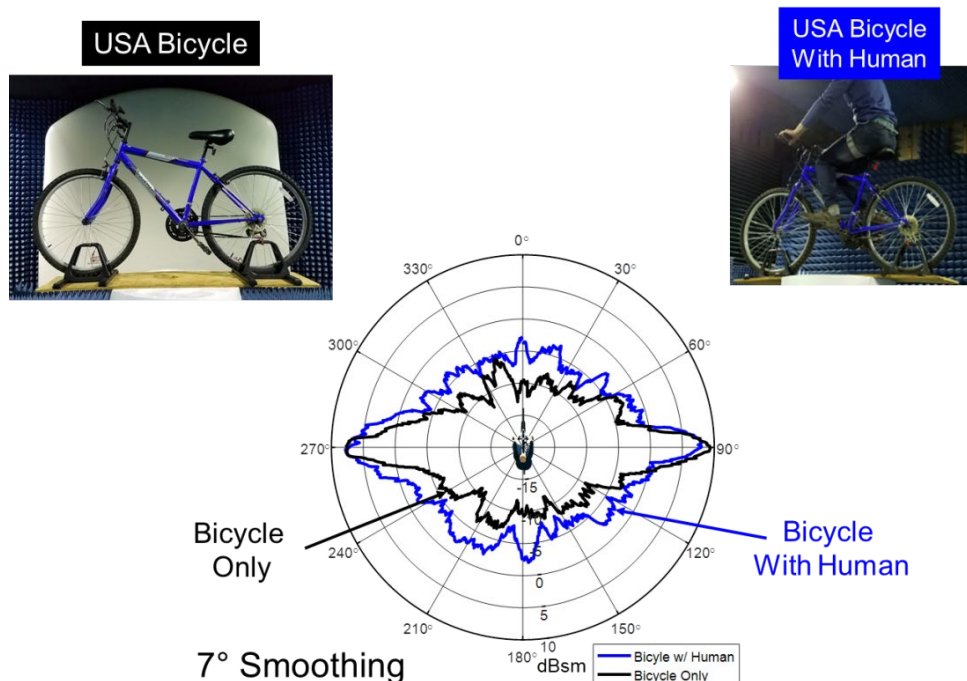


Figure 2 - Measured RCS data of a US 26-inch bicycle and a bicycle with a rider from 360-degree angles [20]

5.2 Surrogate Bicycle and Bicycle Rider Sizes

According to NHTSA's Traffic Safety Facts 2015 Data [4], cyclists of age 15 and above represent 94.6% and 78% of all bicyclist fatalities and injuries, respectively. Cyclists of age between 10 and 14 represent 3.43% and 17.78% of the bicyclist fatalities and injuries, respectively. Cyclists of age between 5 and 9 represent 1.22% and 4.44% of the bicyclist fatalities and injuries, respectively. Since 85% of bicyclists killed and 80% of bicyclists injured were males [4], the gender-weighted adult sized bicyclist surrogate is recommended.

5.2.1 Surrogate Bicyclist Sizes

Historically, bicyclist size characteristics have been drawn from similar studies of vehicle occupants. The 50th percentile male adult size and the 6-year-old child size were used for safety tests of vehicle occupants. Similarly, NHTSA (National Highway Traffic Safety Administration), IIHS (Insurance Institute for Highway Safety), and AsPeCSS used the 50th percentile male adult size and the 6-year-old child size as the sizes for pedestrian AEB test mannequins. The same sized mannequins are used as the bicyclist riders in Europe and ISO surrogate bicyclist target standards.

Here the representative adult bicyclist height is calculated as the sum of the weighted average of 50th percentile adult male height and 50th percentile adult female height. According to the CDC (Centers for Disease Control and Prevention) data, the 50th percentile height of U.S. male adults is 175.6 cm and 50th percentile height of U.S. female adults is 161.9 cm [5]. Therefore, with 85% male and 15% female in bicyclist fatalities, the representative bicyclist height is $85\% * 175.6 + 15\% * 161.9 = 173.5$ cm.

The average height of children aged from 10 to 14 years is 150 cm [5], which is the small adult size. Therefore, it is not meaningful to consider the 10 to 14 year old's size as the size of the surrogate child bicyclist for AEB testing. Here, the recommended surrogate child bicyclist size is 120 cm [5] tall that represents the 50th percentile of 7-year-old children for bicyclist group of age 5 to 9 years.

The names and measurements of the body parts of the surrogate bicycle riders are shown in Figure 3 and Table 2, respectively.

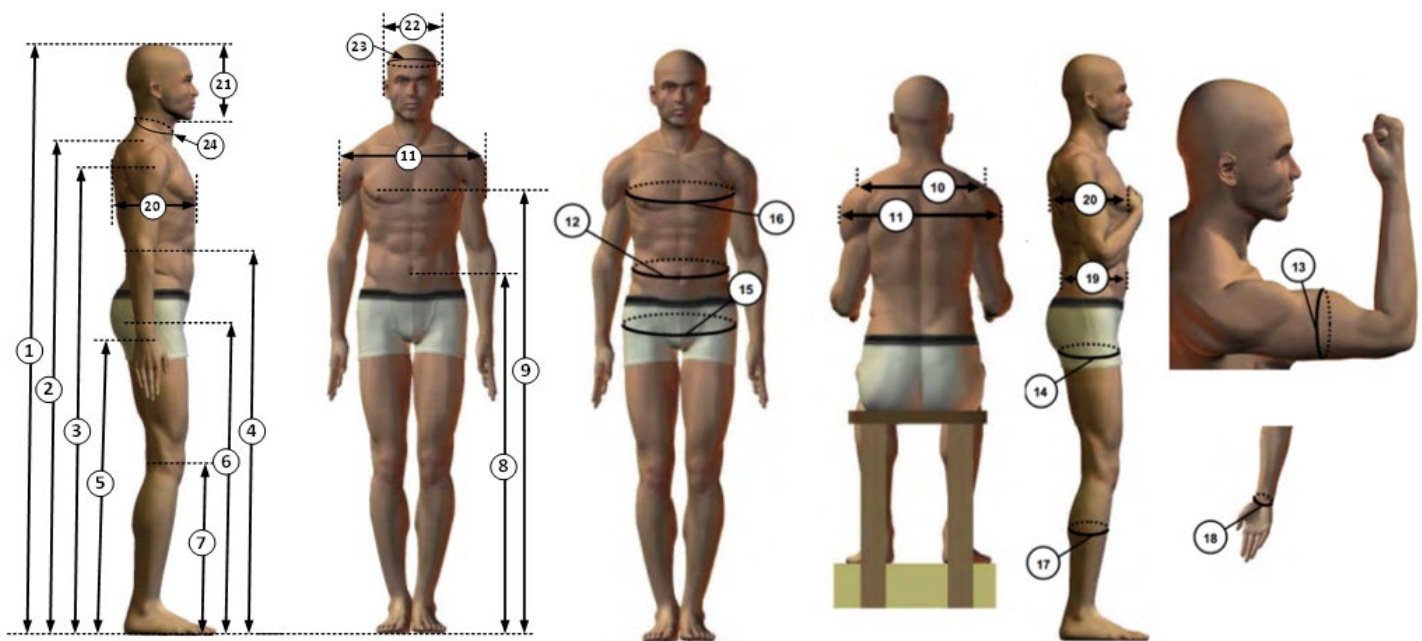


Figure 3 - Bicycle rider body parts model [5]

Table 2 - Detailed bicycle rider surrogate dimensions

Item in Figure 3	Measurement	Description	Suggested Bicycle Rider (mm) Without Shoes		Tolerance (%)
			Adult	Child	
1	Stature	Head to toe height	1735	1194	±2%
2	Acromion height	Shoulder cap to toe height	1408	944	±2%
3	Shoulder pivot height	Mid-shoulder cap to toe	1343	924	±2%
	Arm length	Shoulder pivot to wrist	525	390	±2%
6	Hip pivot/buttocks height	Hip pivot to toe	924	571	±2%
7	Knee pivot height	Knee pivot to toe	511	301	±2%
8	Waist height	From wrist to toe	1129	679	±2%
9	Chest height	From chest to toe	1254	873	±2%
11	Shoulder width	Distance between shoulders from back	511	281	±2%
12	Waist circumference	Measured around belly button	890	573	±2%
13	Arm circumference	Arm circumference is measured over bicep	305	172	±2%
14	Thigh circumference	Thigh circumference is measured mid- thigh	535	325	±2%
15	Buttock circumference	Measured around hips	1010	583	±2%
16	Chest circumference	Around chest underneath armpits, chest circumference at axilla	1020	573	±2%
17	Calf circumference	Measure at widest part of calf (Maximum horizontal circumference of the calf)	420	230	±2%
20	Torso depth		234	143	±2%
21	Head height		200	184	±2%
22	Head width		140	139	±2%
23	Head circumference		550	515	±2%
24	Neck circumference	Measured around middle of neck	375		±2%
	Bicycle rider weight		<4 kg	<4 kg	

5.2.2 Bicycle Size

Most bicycles sold in the U.S. are imported. U.S. bicycle imports started to increase in 1996, and domestic production started to dramatically decrease that same year, with imports capturing 87% of the U.S. market in 1998, increasing to 98% in 2000 and 2001 [6]. According to the statistic report of 2012 from National Bicycle Dealers Association (NBDA) [6], the frame types of majority of the adult bicycles are mountain bicycles and road bicycles and the wheel sizes of majority of bicycles imported to U.S. market were 26-inch wheels for adult bicycles. Based on Statistica [19], 26-inch bicycle import is 2.5 times of other imported adult sized bicycles. The type of adult surrogate bicycle is defined as a mixed shape of mountain and road bike.

Since the recommended surrogate child bicyclist represents child bicyclist group of age 5 to 9 with height 120 cm, the bicycle size should match this age group. According to bikedirect.com, the 16-inch wheel diameter bicycle fits the child of height 120 cm.

The measurements of the suggested surrogate bicycles are shown in Figure 4 and Table 3.

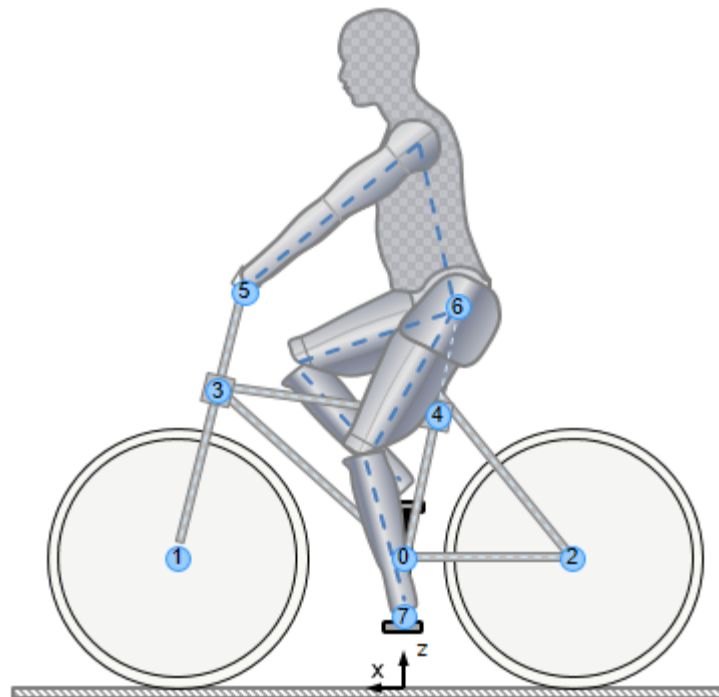


Figure 4 - Bicyclist reference points

Table 3 - Detailed bicycle surrogate dimensions

		Adult			Child	
Reference Points (Figure 4)		X (mm)	Z (mm)		X (mm)	Z (mm)
0	Pedal crankshaft	0	300		0	194
1	Centre axis front wheel	590	330		420	203
2	Centre axis rear wheel	-410	330		-302	203
3	Front top frame	440	790		292	524
4	Rear top frame	(1)	(1)		(1)	(1)
5	Handlebars	380	1030		196	767
6	Saddle	-120	890		-120	573
7	Left pedal spindle (with cranks vertical)	0	135		0	69
		Adult			Child	
Tire width		37 mm			45 mm	
Handlebar width		511 mm			281 mm	
Mudguard (front and rear wheels)		Optional				
Chain guard		Optional				
Rear luggage rack		Optional				
Bicycle weight		<8.5 kg			<8.5 kg	
Notes:						
1.	Point 4 is not specified but should lie along the line connecting points 0 and 6.					

5.3 Wheel Rotation and the Articulation of Bicycle Rider (Pedaling Motion)

The detectability of bicyclists by AEB systems may be affected by micro-Doppler effects caused by wheel rotation and pedaling motion. These effects may change the appearance and shape of bicyclists to AEB systems. For radar-based systems that utilize micro-Doppler as detection features, the pedaling motion and the tire rotation can generate very strong and clear micro-Doppler response that may be used to improve system identification of bicyclists. Figure 5 shows the H-shaped micro-Doppler signature of a bicyclist. It should be noted that this H-shaped bicycle signature cannot be observed when the bicycle motion and vehicle motion are in the same direction. The micro-Doppler signature of pedaling motion, with stationary wheels, is shown in Figure 6. Similar signatures can be observed from the rear side of the bicyclist.

A naturalistic driving study [7] concluded that 83% of bicyclists had pedaling motion when crossing the road and 100% of bicyclists had pedaling motion when moving along the road. In addition, an AEB test of a commercially available vehicle interacting with a bicyclist [20] showed consistently that AEB performance was affected by the leg motion of the rider.

For these reasons, it is important that bicyclist surrogates can generate the appropriate micro-Doppler effects associated with wheel rotation and pedaling. These effects may be achieved by incorporating into the design, rotating wheels, induced pedaling motions, or by other any means that generate the desired effect. Ideally, the method for producing the effect associated with pedaling motion should be allowed to either “pedal” or “freewheel” to simulate coasting.