The 6th Joint International Conference on Multibody System Dynamics and
The 10th Asian Conference on Multibody System Dynamics
November 1-5, 2020, New Delhi, India

Simulation based Risk Analysis of Autonomous Emergency Braking System Test Scenario Using Analytic Hierarchy Process Method

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Abstract

Multibody vehicle dynamic simulations are essential tools for the virtual testing of autonomous vehicle function, and various scenario-based testing methods are developed to evaluate the safety and performance of autonomous vehicle functions in complex and real-world traffic situations. One of the most important aspects of scenario-based testing is how to guarantee the criticality of the scenario so that it can effectively and validly evaluate autonomous functions. As an evaluation method to analyze the criticality of test scenarios, the analytic hierarchy process (AHP) method, which solves multiple criteria decision-making (MCDM) problems, is commonly used. This paper proposes a new scheme to evaluate the risk of the autonomous emergency braking system (AEBS) for pedestrians using a novel AHP method in multibody vehicle dynamic simulation environments.

In order to evaluate the performance of AEBS-pedestrian, European New Car Assessment Programme (Euro NCAP) [1], including car-to-pedestrian farside adult (CPFA), car-to-pedestrian nearside adult (CPNA), car-to-pedestrian nearside child (CPNC), etc.. provides a procedure to test the possible collision avoidance scenarios. The velocity of the test vehicle, impact point, and pedestrian velocity are considered in the test. However, the challenge of the testing procedure comes from the difficulty in assessing the criticality of the test. In this regard, the AHP method, which calculates the priority importance of a set of factors in the MCDM problem, is widely used to calculate the criticality of test scenarios [2]. However, in the AHP method, the elements of pairwise comparison values should be assigned by the individual expertise or experience of the person involved, thus making the AHP method subjective and less reproducible.

This paper proposes a novel AHP approach to automatically generate pairwise comparison values by adjusting the correlation between the risk and the performance metric obtained by simulation. The risk of the test scenario is determined from the pairwise comparison values of AHP. In order to validate the proposed method, the AEBS-pedestrian test scenario is evaluated based on Euro NCAP. The test vehicle's braking distance (d) is defined as the performance metric.

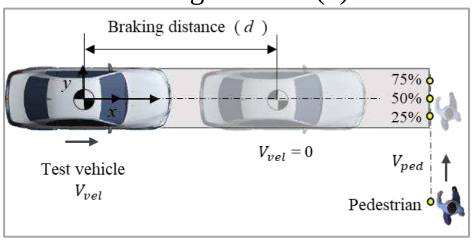

Figure 1: AEBS-pedestrian test scenario.

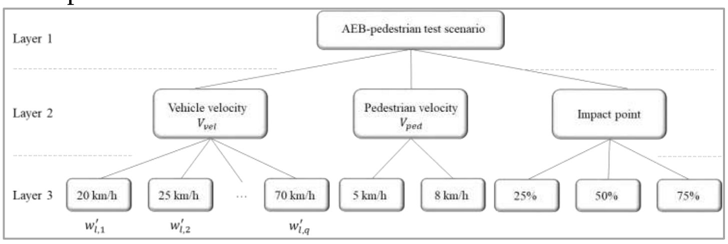

Figure 2: Hierarchy model of AEBS-pedestrian test scenario.

Figure 1 shows that the autonomous vehicle detects the crossing pedestrian and performs the braking maneuver. The initial position of the test vehicle is determined by the time the pedestrian reaches impact points (25%, 50%, 75%) with a walking speed. In Figure 2, the AEBS-pedestrian test scenario is defined as an objective at layer 1, and layer 2 presents the vehicle velocity, pedestrian velocity, and impact point, and layer 3 is the assigned value for variables of layer 2. The decomposition process from layer 1 to layer 3 is called global decomposition, and the decomposition process from one layer to the next layer is called local decomposition. In each local decomposition, decomposed factors are compared in pairs with each other, which is called the pairwise comparison value and defined as a_{q_i,q_j}, and arranged in rows and columns of comparison matrix $\boldsymbol{A}_{l,q}$ as shown in Eq. (1).

$$\boldsymbol{A}_{l,q}=\begin{bmatrix} 1 & a_{1,2} & \cdots & a_{1,q_j} \\ 1/a_{1,2} & 1 & \cdots & \cdots \\ \cdots & \cdots & 1 & a_{q_i,q_j} \\ 1/a_{1,q_j} & \cdots & 1/a_{q_i,q_j} & 1 \end{bmatrix} \quad q_i \in [1, \ ...\ ,(q-1)],\ q_j \in [1, \ ...\ ,q] \tag{1}$$

where q is the number of decomposed factors, l is the number of layer, $\boldsymbol{A}_{l,q}$ is the comparison matrix representing the decomposed factors q in layer l, a_{q_i,q_j} is the pairwise comparison value in the q_i-th row and the q_j-th column of comparison matrix. Comparison matrix should satisfy the paired reciprocal comparison (e.g., shown as a_{q_i,q_j} and $1/a_{q_i,q_j}$ in matrix $\boldsymbol{A}_{l,q}$ in Eq.(1)).

In each local decomposition, in order to compute the priority importance of decomposed factors, the priority importance value $\boldsymbol{w}_{l,q}$ is defined and obtained by an approximation method, which is compute by normalized comparison matrix $\boldsymbol{A}_{l,q}$. Thus, the priority importance value $\boldsymbol{w}_{l,q}$ of decomposed factors can be expressed as Eq.(2);

$$\boldsymbol{w}_{l,q} = [\, w_1\ w_2\ \dots\ w_{q_i}]^T \quad q_i \in [1, \ ...\ ,q] \tag{2}$$

Because the risk of test scenario should be calculated by the priority importance of assigned values of variables in global decomposition, the calculated priority importance values in every local decomposition are combined into the same reference frame. The priority importance values of layer 3 in the global decomposition is called as priority importance index and represented as $\boldsymbol{w}'_{l,q}$ in Eq. (3).

$$\boldsymbol{w}'_{l,q} = [\, w'_{l,1}\ w'_{l,2}\ w'_{l,3}\ \dots\ w'_{l,q}]^T \tag{3}$$

There is only one path from $w'_{l,q}$ to layer 1, and the transfer path is recorded as $R_{l,q}$. Each priority importance value from layer 2 to layer 3 is defined as $w_{2\sim3}^{R_{l,q}}$. Therefore, the priority importance index can be obtained as Eq. (4).

$$\boldsymbol{w}'_{l,q} = \prod_2^3 w_{2\sim3}^{R_{l,q}} \tag{4}$$

When a test scenario is generated, the risk index (*RI*) of the test scenario can be calculated based on the calculated priority importance index as shown in Eq. (5),

$$RI = \sum_1^m (w'_{l,q})_m \tag{5}$$

where m is number of variables in layer 2, $w'_{l,q}$ is priority importance index of q-th factor in layer 3.

In order to automatically generate the pairwise comparison values, the correlation between the risk index and corresponding simulated performance metrics of test cases is considered and expressed numerically by the correlation coefficient ($r_{(d,RI)}$). To simulate the AEBS-pedestrian test scenarios, a vehicle dynamic model, including mass and inertia of vehicle, chassis, suspensions, brakes, steering and braking systems, tire model, etc., is used. The test vehicle has a radar sensor with a horizontal angle of 16 deg and a detection distance of 200 m, and a camera sensor with a horizontal angle of 45 deg and a detection distance of 100 m. The AEBS, which is used to automatically decrease the vehicle velocity based on the time to collision (TTC) function, is modeled. In order to generate the AEBS-pedestrian test scenarios, the assigned values in layer 3 of Figure 2 are combined (44 cases) based on the CPFA, CPNA, and CPNC. Figure 3. shows the correlation between the risk index and braking distances. The results demonstrate that the risk index increases with increasing braking distances. This coincides with the long braking distance caused by the high vehicle velocity or large impact point, increasing the risk of the test scenario. The result also shows that the pairwise comparison values generated by the novel AHP have a great correlation ($r_{(d,RI)}$= 0.801) between the risk index and the braking distance. Thus, the proposed risk analysis method can effectively evaluate risk in AEBS-pedestrian or other test scenarios.

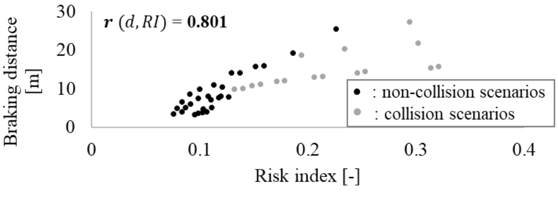

Figure 3: Correlation between risk index of test scenarios and braking distances.

References

[1] EuroNCAP, "European New Car Assessment Programme (Euro NCAP) Test Protocol – AEB VRU systems V 3.0.4," 2021.

[2] J. Duan, F. Gao, and Y. He, "Test Scenario Generation and Optimization Technology for Intelligent Driving Systems," *IEEE Intelligent Transportation Systems Magazine,* pp. 1-1, 2020.