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EXAMPLE APPLICATIONS OF IEEE STD 2846-2022 TO FORMAL SAFETY-RELATED MODELS

Authored by

IEEE VT/ITS/AV Decision Making Working Group

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TABLE OF CONTENTS

ABSTRACT 5

1. INTRODUCTION 6

2. ASSUMPTIONS IN SAFETY-RELATED MODELS FOR ADS 6

2.1. ASSUMPTIONS ON KINEMATIC PROPERTIES OF ROAD USERS 7

3. RESPONSIBILITY-SENSITIVE SAFETY 8

3.1.INTERPRETATION OF RSS RULES 8
3.2. RSS PROPER RESPONSE 9
3.3. APPLICATION OF REASONABLY FORESEEABLE ASSUMPTIONS IN RSS 10

4. RULEBOOKS 13

4.1. APPLICATION 1: OFF-LINE ASSESSMENT OF ADS-OPERATED VEHICLE BEHAVIOR 14
4.2. APPLICATION 2: MINIMUM VIOLATION PLANNING UNDER REASONABLY FORESEEABLE BEHAVIOR OF OTHER ROAD USERS 16

5. SAFETY FORCE FIELD 19

6. ANALYSIS OF SAFETY-RELATED MODELS 20

7. REFERENCES 25

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EXAMPLE APPLICATIONS OF IEEE STD 2846-2022 TO FORMAL SAFETY-RELATED MODELS

ABSTRACT

While automated driving system (ADS)-operated vehicles hold the potential for safety improvement compared to human drivers, the recognition that transportation will continue to entail some level of risk has to be considered. Human drivers rely on extensive daily experience in their interactions with other agents on the road, which helps them craft assumptions about reasonably foreseeable behavior of other road users. Similarly, ADS-operated vehicles will also need to make assumptions. Such assumptions play a role within ADS safety-related models, which provide a representation of safety-relevant aspects of driving behavior pertaining to both ADS-operated vehicles and other road users. Furthermore, formal safety-related models provide transparency and certainty in ADS decision-making contexts as they can be formally verified. Therefore, this paper introduces how several safety-related models are making use of reasonably foreseeable assumptions to help with the decision making of an ADS-operated vehicle.

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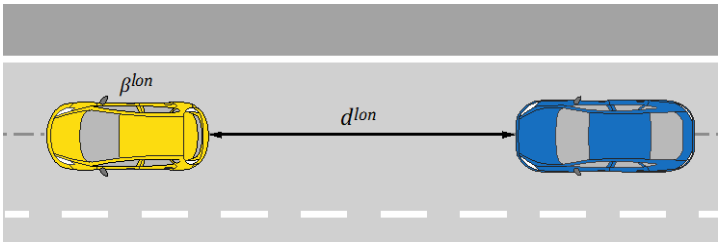
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1. INTRODUCTION

The safety assurance of decision making of an ADS-operated vehicle (i.e., ego vehicle) is of paramount concern to government and society. Formal models provide transparency and certainty in ADS decision-making contexts as they can be formally verified and expressed in formal notation. Formal models such as Responsibility Sensitive Safety (RSS) from Mobileye, Rulebooks from Motional, and Safety Force Field (SFF) from NVIDIA all rely on reasonably foreseeable assumptions to inform the boundaries of operation that can be assured by the formal model. This paper uses the high-level scenario depicted in FIGURE 1 to demonstrate how the reasonably foreseeable assumptions defined in IEEE Std 2846™-2022 [1] are used within these commercially deployed safety-related models.

FIGURE 1 Ego vehicle driving longitudinally behind another road user



The level of safety ultimately delivered by the ADS-equipped vehicle may, additionally, be dependent on what values are used for the reasonably foreseeable assumptions considered in safety-related models. The whitepaper “Literature Review On Kinematic Properties of Road Users for Use on Safety-Related Models for Automated Driving Systems” [2] presents a summary of peer-reviewed scientific publications, related standard documents, and active industry documents that studied road users’ behavior, identifying values (and/or distributions) for the kinematic properties of road users using data-driven analyses.

2. ASSUMPTIONS IN SAFETY-RELATED MODELS FOR ADS

This section provides a high-level introduction of the assumptions about reasonably foreseeable behavior of road users that are defined in IEEE Std 2846-2022.

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2.1. ASSUMPTIONS ON KINEMATIC PROPERTIES OF ROAD USERS

The reasonably foreseeable assumptions defined in IEEE Std 2846-2022 are primarily based on kinematic properties of other road users that include, among others, longitudinal and lateral velocities, accelerations, and decelerations,[1] and response time. The response time of a road user, while not a kinematic property, is relevant in the context of a safety-related model and should be understood as the time it takes a road user to perceive a specific stimulus and start executing a response (e.g., braking, steering, etc.). TABLE 1 presents a summary list of the kinematic properties considered in the standard. See ITS IEEE VT [2] for the related literature on values for kinematic properties.

Within the scope of IEEE Std 2846-2022, the assumptions about kinematic properties are based on the classification of different road user types, namely, pedestrians, bicyclists, vehicles, and other vulnerable road users (VRUs), such as a person riding an electric scooter, or a person using a wheelchair. Assumptions about these kinematic properties can take the form of bounding limits, such as reasonably foreseeable minimum and maximum boundaries (e.g., $v^{lon} \leq v^{lon}_{max}$), and their applicability depends on the driving scenario and the safety-relevant road users to be considered.

TABLE 1 List of road user properties considered in IEEE Std 2846-2022

Notation	Description
v^{lat}, v^{lon}	Lateral and longitudinal velocity of a road user
$\alpha^{lat}, \alpha^{lon}$	Lateral and longitudinal acceleration of a road user in its direction of travel
β^{lat}, β^{lon}	Lateral and longitudinal deceleration of a road user in its direction of travel
h	Heading angle (yaw) of a road user
h'	Heading angle rate of change (yaw rate) of a road user
λ	Lateral margin for small lateral fluctuation performed by road user moving in forward motion
ρ	Response Time of a road user

[1] The lateral deceleration of a road user, β^{lat}, can be understood as the decrease in the absolute value of the lateral speed of a road user, whereas a lateral acceleration, α^{lat}, can be understood as the increase of the absolute value of the lateral speed of a road user.

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3. RESPONSIBILITY-SENSITIVE SAFETY

Mobileye first published the Responsibility-Sensitive Safety (RSS) model in 2017 [3]. RSS is an open and transparent technology-neutral formal model for safety that provides complete coverage for any driving scenario that an ADS-operated vehicle may encounter within the bounds of assumptions about reasonably foreseeable behaviors of other road users.

RSS is based on common-sense human notions of what it means to drive safely. RSS formalizes common-sense human driving rules as the following:

1) Do not hit someone from behind
2) Do not cut in recklessly
3) Right-of-way is given, not taken
4) Be careful in areas of limited visibility
5) If you can avoid an accident without causing another, you must do it

3.1. INTERPRETATION OF RSS RULES

The first two rules formally define a longitudinal and lateral safety envelope that is the foundation of determining what constitutes safe distances with respect to other road users in all driving situations. These safe distances are physics-based calculations that account for the capabilities of the ADS-operated vehicle while also incorporating reasonably foreseeable assumptions about the behavior of other road users.

Rule 1 states that the minimum longitudinal distance for a trailing road user is to have an adequate stopping distance to prevent a collision due to the sudden hard braking of a lead road user (e.g., see FIGURE 1).

$$d_{min}^{lon} = \left[v_r \rho + \frac{1}{2} \alpha_{max}^{lon} \rho^2 + \frac{\left(v_r + \rho \alpha_{max}^{lon}\right)^2}{2\beta_{min}^{lon}} - \frac{v_f^2}{2\beta_{max}^{lon}} \right]_+$$

where

v_r is the following vehicle's longitudinal speed [m/s]

ρ is the following vehicle's response time [s]

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