Towards Human-Centric Middleware for Future Automotive CPS: A White Paper

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A key challenge in the design of future automotive cyber-physical systems (CPS) is the provisioning of the appropriate safety to its inhabitants. Road accidents lead to about 42000 fatalities and 1.5 million injuries in US every year. There are primarily three contextual aspects for improving safety of an automobile's inhabitant:

1. *Perimeter Awareness*, which requires monitoring and communication with the adjacent cars to gauge the adjacent traffic pattern, status of the adjacent cars and any imminent danger;
2. *Status Awareness*, which requires monitoring the mechanical, structural and electrical state of the automotive and its equipments; and last but not the least
3. ***Human Awareness***, which require interaction of the automotive CPS with the inhabitants (passengers and the driver) to offer appropriate safety mechanisms based on their behavior, alertness level, and physical capabilities.

To facilitate development of an automotive CPS with the above safety features, there is a need to build a **context-sensitive** (situation-aware) middleware [5], which – i) can generate the aforementioned awareness using deployed sensors and Electronic Control Units (ECUs); and ii) based on the generated awareness, can provide appropriate human-centric automation and facilities to manage crises - situations leading to catastrophes such as injuries and loss of lives.

Typically, such management encompasses four phases of operation [6]: 1) immediate *response* to the crisis for protecting lives, 2) *recovery* efforts in the aftermath of the crisis, 3) *mitigation* to lessen the impact of the crises, and 4) *preparedness* to learn from the outcome of crises response and mitigation to prepare for the future crises. Such management involves adaptive and real-time feedback control mechanisms, which need to perform and/or enable response within a *window-of-opportunity* to avoid any injuries. Research and development in modern day automobile technologies can play an important role in developing the Perimeter and Status awareness levels and the required automated control mechanisms. For example, the design of the Volvo XC 90 car includes the option of forward collision warning, blind spot detection, telephone/telemetric and more [2]. Computer networking research has been geared towards the development of Vehicular Ad hoc NETworks (VANETs) to form inter-car networks and the required innovations in dynamic information exchange [7]. The automated control agent technologies in CPS can provide an organized and systematic response, recovery, mitigation and preparedness for handling crisis. Recent technological advancements such as ABS technology, adaptive cruise control, traction control etc. have enlivened such possibilities.

However, the automation can lead to decrease in human alertness and the possibility of negligent technology usage, resulting in increased accidents [8]. The design, testing and evaluation of the future automotive CPS therefore need to focus on human interaction – both in terms of ensuring distraction minimization and *Human Awareness* – in the envisioned context-sensitive middleware to increase the dependability of the automotive CPS. For example, a forward collision warning in the Volvo XC 90

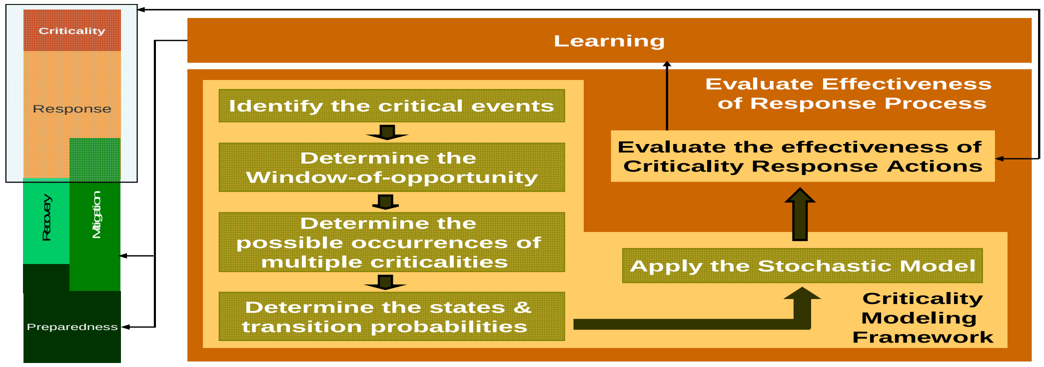

Figure 1: Criticality Modeling Framework for Crises Management [1].

may require appropriate steering control or brakes to avoid the collision depending on the situation. However, the quality of such responses may depend on the agility and the alertness level of the driver. Young people may respond differently (with more agility but less alertness) than the elderly people. The system design has to further account for the panic-stricken behavior which may hinder the automated response (e.g. drivers tend to turn the steering wheel by instinct in case of imminent collision). In this regard, the context-sensitive middleware may used additional sensors installed in the car and may even interact with the body sensor network deployed on the driver's (and passengers') body to collect health information [4]. Further, the occurrences of one crisis may lead to further cascading crises – such as passenger having a heart-attack due to the forward collision warning. A novel modeling framework taking into account – the human behavior, alertness, and medical condition – is needed to manage crises in the context-sensitive middleware for future automotive CPS. Such modeling framework is also useful to – characterize different evaluation criteria, develop proper testing methodologies and benchmarks. This would not only facilitate the determination of the effectiveness of crises management for future automobiles, but also enable dynamic learning in the automated agent technologies employed.

The concept of *Criticality* is used to characterize crises in smart-spaces [2][3]. The changes in the system's environment which lead the system into a crisis/disaster are called *critical events*. The *resulting effects* of the critical events on the smart-spaces are defined as criticalities. Two verifiable properties of criticality management – *Responsiveness* to criticalities, and *Correctness* of criticality response – are identified and analyzed. A *controllability condition* is established based on the real-time requirements of the criticalities. This condition encompasses the level of responsiveness to give an upper bound on the time taken for detecting and responding to the critical events. *Manageability* metric characterizes how *effectively* the crisis management can respond maximizing inhabitants' safety. This is measured in terms of the *Q-value* or the *Qualifiedness* of the response actions. The Q-value depends on the controllability condition and the uncertainties involved in performing the response actions due to possible human involvement. A *state-based stochastic model* is established in this regard where critical states are considered when the system is under one or more criticalities. Using the stochastic model a generic modeling framework is developed i) to evaluate the effectiveness of the crises management in smart-spaces; and ii) to select appropriate crises response actions accordingly [1]. Figure 1 depicts the modeling framework and its applicability to various phases of crises management.

Such framework is a promising solution to incorporate human-centric behavior in the context-sensitive middleware envisioned for future automotive CPS. For example, in case of a forward collision warning in the Volvo XC 90, the identified criticalities may include – the warning itself, the health hazards (e.g. heart-attack due to the warning), and so on. The window-of-opportunity to avoid accident depends on the distance of the possible forward collision and the speed of the vehicle, whereas for heart-attack the window-of-opportunity is the golden hour after the attack. Both the criticalities can occur simultaneously. The framework can evaluate the effectiveness of different response actions and their order of actuation based on the maximum Q-value achieved, and thereby enable proper facilities and context-sensitive services to maximize the passenger safety.

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