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# Engineering Models and Public Policy: The Case of Crash Test Dummies and the Role of Engineering Education

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## Abstract

Engineering models are critical in public policy; they provide frameworks, data and an ability to predict system behavior. At the same time, engineering education plays a critical role in situating models and analyses in the larger context of engineering and its impact on society. We explore the political, economic, cultural and moral foundations of the research and engineering of crash test dummy models in the automotive industry. The research question underlying this work in-progress is: how do representative models in engineering influence public affairs in the context of safety in the automotive industry? Automotive safety for years has been known to rely on crash test dummy models created in the 1950s that are modeled after the average male. This resulted in a significant gap in a balanced representation in vehicle safety data acquired over the years. We focus on this technology's governance and regulation within the United States. Our research focuses primarily on the development and implementation of a female crash test dummy, which currently has the dimensions of 4'11'' and weighs 108 pounds, while the average American female is 5'4'' and 170 pounds. This project explores the meaningful representation in crash testing to improve safety outcomes for all occupants, and has policy implications on pregnant women, people of different ages, people with disabilities, children and infants. We investigate, from a variety of perspectives, the various ways that transforming forces influenced decisions in this area. We explore how both the engineering and the political communities make priorities, develop organization and institutionalize standardization of technological innovation in this field. We discuss the historical development of the technology with a focus on the scientific, socio-economic, institutional and cultural factors, and the interactions between these factors, that have influenced the technology's evolution, with special attention to the role of engineering education up to the present. We share our on-going work to analyze common injuries and the vehicle response to a female anatomy in comparison to a male, which, ultimately, will allow us to pinpoint critical changes required to better make the automotive industry safer, with results transcending to other modes of transportation. We pay special attention to the impact that situating modeling in engineering education within public policy brings to the discourse on the topic. Our findings will advocate for a future that is safer for the public.

## 1. Introduction

The primary reason for test dummies in crash testing is to *measure* human injury under different conditions. Test dummies play a crucial role as part of testing programs that provide valuable data to both automative manufacturers and customers. Automotive manufacturers gain insight into the simulated behavior of the human body in their designs during crash under regulated conditions. They are, therefore, required to meet certain standards as regulated by the National Highway Traffic Safety Administration (NHTSA), a federal agency that regulates the safety of motor vehicles [1]. As for customers, the five-star safety ratings produced by NHTSA as the measured outcome of the testing programs provide a key source of information about safety when purchasing a vehicle [2]. The regulations are thoroughly detailed, prescribing and documenting fine specifications on things ranging from bumper standards to fuel economy to odometers and theft protection. For example, as for the Anthropomorphic Test Devices (49 CFR Part 572), its purpose is described as follows:

> "The design and performance criteria specified in this part are intended to describe measuring tools with sufficient precision to give repetitive and correlative results under similar test conditions and to reflect adequately the protective performance of a vehicle or item of motor vehicle equipment with respect to human occupants." [3]

Although cars are getting safer with the infusion of new technology, like air bags, various sensors and driver automated assistance systems, the use of dummies in well-established testing programs continues to be the standard for regulation, communication with the public and future improvements. Testing using dummies informs the design of the vehicle through data collected primarily by three types of sensors: accelerometers (measuring acceleration in a specific direction); load sensors (that measure the force of impact on a specific body part); and motion sensors (that measure deflection of a body part during a crash). Variations in responses based on body types and shapes are, therefore, expected. The results are translated to a five-star rating system about every manufactured vehicle, which is communicated with the public.

## 2. Synopsis of testing with dummies

The first recorded automobile fatal accident took place in 1869 in Parsonstown, Ireland, when Mary Ward was thrown out of the vehicle and killed [4]. The vehicle was steam-powered, and that incident took place well before Karl Benz invented the gasoline powered automobile in 1886. In the U.S., the first reported fatal accident took place about thirty years later when, in 1899, Henry Bliss was hit while stepping off a New York City trolley [5]. As automotive technology continues to change, especially with the emergence of automated vehicles, so do testing programs and procedures. Furthermore, communication with the public needs to be clearly available to articulate the conditions of testing which predicate the awarding of safety stars.

In our ongoing work, we explore how both the technical and the political communities make priorities, develop organization and institutionalize standardization of technological innovation in this field. We attempt to explore the relationship between technology, education and public affairs in the context of this problem.

Currently, a dummy known as Hybrid III is the standard crash test dummy used by automotive manufacturers in standardized testing programs. This dummy is a modified version of Hybrid I and Hybrid II. Tracing of this development is insightful in showing the relationship between public and private organizations in standardizing crash testing programs. Hybrid I was introduced in 1971 by GM and was called the "$50^{th}$ percentile male" dummy, residing in its dimensions and proportions in the middle of the male population in the U.S. in the 1970s. GM shared its design with competitors and with coordination with the Society of Automotive Engineers (SAE), resulting in continuous development of a more sophisticated dummy, Hybrid II. With rigorous documentation, Hybrid II was adopted by the American Federal Motor Vehicle Safety Standard (FMVSS) for the testing of lap and shoulder belts.

The development of the dummies represents a common problem in engineering; that is, answering questions about models' accuracy in replicating phenomena, and the usefulness of simulations in making public policy decisions.

A mismatch between technology that is far advanced in brand new cars that are being produced today with older testing programs makes answers to these questions even more pressing. Although standardized for consistency, the interpretation of such testing programs may not convey the safety results they claim with the certainty provided. From a marketing standpoint, communicating that certainty with a level of affirmation is questionable. Consider, for example, the following statement describing the Hybrid III $5^{th}$ Female dummy model. The statement is found on the website for *Humanetics*, one of the early companies to pioneer anthropomorphic testing: "Humanetics harmonized Hybrid III 5th Female ATD represents the smallest segment of the adult population for the evaluation of automotive safety restraints in frontal crash testing and was created using scaled data taken from our Hybrid III 50th dummy […] The Hybrid III 5th Female dummy is dynamically tested and proven to the latest test conditions and includes the ability to measure the thorax Viscous Criterion." [6]

The ability to "measure" to "proven" conditions characterizes certainty. While the idea of the dummy itself has advanced to record and reduce injury to the occupants, dummies are still made using scaled versions of the dimensions of $50^{th}$ percentile male crash test dummy representing the middle point of all adult male in the 1970s. The female-based counterpart of the dummy was made as a scaled down version, 149 cm tall (4' 11'') and weighing 48 kg (108lb), representing the smallest 5% of women by the standards of the mid-1970s. The average size of the American woman in 2018 is 5' 3'' with 170 lb [7]. Furthermore, not only does this dummy fail to properly represent women in size, but the various sensors and instrumentations do not properly measure the impact of injury, being unable to take into account factors such as the female's neck being weaker or shoulders being less broad. Yet the spring used to simulate a male in a crash is the same one used on the female model. Pinpointing the question as to why women sustain a higher amount of head and neck injuries that result in crashes being fatal [8], the current Hybrid III model does not seem to provide proper representation of size nor the effects of the impact a crash would have on the female body as opposed to the male body.

### 3. Physiological Differences

Simply scaling down the male version of the testing dummy, by the standards of the mid 1970s, ignores the variations in body structure among other parts of the population, including infants, children, and women [9]. Women generally have lower bone density, different fat distribution, and distinct hip, chest, and pelvic structures [10]. The 5$^{th}$ percentile dummy does not represent the average female body geometry, such as the shape and form of the torso, female muscle and ligament strength, female spinal alignment, female dynamic responses to trauma, or mass distribution of different body parts. All these factors can influence posture while in a vehicle. Studies have shown that the probability for a female occupant to be injured in a frontal crash is 73% greater than that for a male occupant [10]. According to NHTSA, "young-adult women up to the age of approximately 35 have 25 to 30-percent higher fatality risk, given similar physical insults, than men of the same age. Men's advantage, however, diminishes after age 35; by age 70, female and male drivers are about equally at risk" [11]. See Table 1.

Table 1. Female increased risk of injury. NHTSA estimated increase of risk for moderate injuries in a car crash compared to a male driver or right front passenger of the same age [9].

| **Body part** | Female increased risk of injury |
|---|---|
| Head | 22.1% |
| Neck | 44.7% |
| Abdomen | 38.5% |
| Chest | 26.4% |
| Arm | 58.2% |
| Leg | 79.7% |

These statistics are largely based on mathematical models: double-pair-comparison and logistic regression analyses of data ranging from 1975 to 2010, in an attempt to *quantify* the effects of aging and gender on fatality and injury risk. Statistical models are pervasive in the field of safety. Models become problematic when they are used to promote safety ratings in marketing, overlooking the actual meaning they convey and overlooking parameters they represent. For example, aside from testing using dummies, women's normal seated position is different from the standard seating position: "Occupants of small stature or large girth sitting close to the steering wheel are at greater risk of internal injuries particularly during frontal collisions with airbag deployment" [12, p. 11]. Although testing programs, using simulations and dummies, have advanced our understanding of crash and enhanced the design for safety, uncertainty in statistical analysis, testing protocols and testing parameters should be both communicated to the public and continued to be present in the discourse in public policy. Engineering education, therefore, plays a major role that we seek to explore.

## 4. Why hasn't this changed

The development of a new crash test dummy has been long hindered by policy and economic barriers. Furthermore, the interpretation of testing results and communicating that to the public seems to heavily rely on statistical modeling that often get challenged when faced with real crashes that involve people's lives. Two illustrative cases are the following.

The first case shows the negotiation of the testing parameters between a company (Denton ATD, Inc.) and the government (NHTSA representing the Department of Transportation). In 2006, NHTSA denied a petition submitted by Denton regarding the Hybrid III $50^{th}$ Percentile Adult Male Test Dummy "to provide additional specifications for the head assembly" [13, p. 34868].The claim by Denton requested that NHTSA provides " additional specifications for the head and cap skin […] the skull and skull cap" among other things for manufacturers of test dummies. Denton wanted to know "component weight specifications for the individual flesh components of the head assembly (head skin and cap skin), (2) providing head skin thickness dimensions and tolerances, and (3) availability of patterns for the head skin, cap skin and skull cap" (p. 34868). However, NHTSA response was denial stating the following:

> "The agency believes it is unnecessary to further specify the head assembly weight by requiring inclusion of individual head skin and cap skin weights. NHTSA believes that the currently specified weight tolerance and Center of Gravity (CG) location for the head assembly provide sufficient manufacturing flexibility to produce the HIII–50th head assembly to specified requirements." (p. 34868).

The Agency's response seems to underscore the need to provide specifications with enough details but without over specifying requirements, on the following basis:

> "The agency reviewed Denton's petition and found no data establishing how the additional requested specifications would result in improvements in dummy response in tests leading to better assessment of occupant safety. Furthermore, the agency has found no evidence that a lack of alleged detail in the head and cap skin, and the skull and skull cap specifications, results in dummies not meeting the agency's performance specifications. The agency concludes that the recommended changes are neither needed nor would serve to improve occupant protection." (p. 34868).

While the previous example with Denton involved discussion about data establishing more safety for "better assessment of occupant safety," our second illustrative case shows what motivated NHTSA to act based on the "number of lower limb injuries in full and offset-frontal vehicle crashes and the pain and suffering, disability, long-term impairment, and high rehabilitation costs frequently associated with such injuries" [14, p. 22381]. An example of real data reported included the following: "An analysis of data from the Wisconsin Crash Outcome Data Evaluation System (CODES) project, for example, found that one in six occupants hospitalized after a crash had serious lower limb injuries." (p. 22382) In this case, the harm due to real crashes warranted concern, resulting in the motivation to incorporate more instruments during testing:

> "The agency believes that there is considerable merit in utilizing crash test dummies with instrumented lower legs in vehicle crash tests to either assess the risk of occupant injury or mitigate either the number or severity of these injuries. This document requests comments on two potential devices for assessing the injury potential to lower limbs in full- and offset-frontal vehicle collisions. Under consideration are two types of instrumented lower legs that can be retrofitted to the Hybrid III 50$^{th}$ percentile male and 5th percentile female dummies." (p. 22381)

In other words, the impact of real injuries on testing programs clearly supersedes any arguments about statistical modeling. We are not claiming that altering the testing programs, by adding different models that are representative of the population, or other means such as more enhanced simulations, could be the solution; in fact, it could be another way of overlooking the real problem of models, modeling, simulations and testing to the safety of the public.

Recently, however, many within the U.S. government have taken a stance in support of the dummy development. For example, U.S. Senator Ron Wyden (D-Oreg.) shared in 2024 that "the fact that women are much more likely to be seriously injured in a car crash is not just alarming–but flat out unacceptable, safety testing that only uses male test dummies is negligent, and women are paying the price. We need to rectify the status quo so that the safety of everyone is a priority." [15]

On 9 May 2024, U.S. Senators Deb Fischer (R-Neb.), Patty Murray (D-Wash.), Marsha Blackburn (R-Tenn.), and Tammy Duckworth (D-Ill.) introduced legislation to "improve passenger vehicle safety by requiring the use of the most advanced testing devices available — including a female crash test dummy. The She Develops Regulations In Vehicle Equality and Safety (She DRIVES) Act would enhance passenger vehicle safety by updating U.S. crashworthiness testing procedures" [16].

The process of upgrading testing programs and standards to include dummies that represent different segments of the populations would be lengthy and costly—a dummy cost can range from $100,000 to a $1 million dollars [17]. The process is always challenged with consistency and standardization during research and development and across models of vehicles. The question that will always persist is what these statistical measures mean and how those are being communicated to the public.

## 5. Social awareness and future work

The inclusion of more representative crash test dummies is vital. Making such major changes to safety standards is needed; yet, this has not been a priority despite research showing that women, elderly and infants are more likely to suffer severe injuries in car crashes. The inclusion of diverse, more representative test dummies will add to the fidelity of models, modeling, simulations and testing programs; however, models, testing and statistical analysis do not necessarily eliminate the uncertainty of injury during real crashes. Models can always be contested; real-life injuries cannot. The problem becomes more serious when star-rating and their standardization are advanced and marketed without sharing the real parameters of tests in advertisements. In future work, we are working on exploring the role of engineering education in this discourse. One of the authors had the opportunity of interviewing multiple experts, friends, family members, as well as professionals that formerly worked in the design and engineering of vehicles for Ford. Not a single person prior to their conversation was aware of the discrepancy in crash test dummies, nor was aware that this could put stakes on the safety of women, elderly and infants using cars. Social awareness of this issue should be studied in the relationship between engineering and public policy as it could prompt a greater demand for automotive manufactures to undergo more testing with more representative dummies, and, most importantly, while sharing the contexts of testing with drivers and passengers.

Engineering models are never conclusive; therefore, they should not be used as a marketing tool, especially in ways that may cause harm to the public. At the same time, models and modeling have dominated engineering education since the rise of the role of quantitative analysis in engineering in the mid 1950s. As we continue to move to live around engineered systems, engineering education should embrace the need to integrate public policy in the curriculum. Situating engineering design and analysis within the public context where systems operate is much needed in engineering education. The case we present in the role of modeling in crash testing is a representative case for the need for responsible designing.

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