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Can Hick's Law be applied to In-Vehicle Systems?

Introduction

Hick's Law, or the Hick-Hyman Law, was established in 1952 by William Edmund Hick and Ray Hyman [1]. The law was defined at that time as a formula [2], but in its simplest form, the law states that "the more choices a human is presented with, the longer the person will take to reach a decision [3]".

According to the Interaction Design Foundation, Hick's Law has been applied to everything from the layout of options on your microwave to the layout of the menu at your favorite restaurant. It can be presumed, then, that Hick's Law and other UX principles have historically been applied to the controls in automobiles. Unlike microwaves and restaurant menus, whose features have remained fairly stable over the years, the automobile has gone through multiple generations of technological advancements, adding new functionality and methods to control them over its history.

In fact, by taking a look at the 1952 edition of the best-selling vehicle in the US, we can see that the application of design principles as it relates to the ergonomics of the driving experience was well underway. The 1952 F-100, the first model year for Ford F-Series trucks to adopt the three-digit naming system, benefited from designing the cab of the truck around a mannequin known as the "Measuring Man [4] ". Due to the use of the Measuring Man, Ford was able to make improvements to the gauge cluster, the position of vehicle controls, and even the size of the seats [65]. The truck's features have also been described as being "on par" with its contemporary passenger vehicle counterparts at the time, suggesting a fit and finish suitable for daily use as opposed to one primarily for utility.

Standard and optional features of vehicles have changed significantly since 1952. When compared to today's features, that 1952 F-100 would look as antiquated to us as the first Ford Model T that rolled off the line in 1908 would have looked to the F-100. The controls vehicle operators needed to operate the Model T consisted of a hand crank to start the engine, a steering wheel to control the axle, a steering column stalk to control the timing of the spark plugs, a separate stalk for the throttle, a pedal to select the gear, a pedal to brake the vehicle, and a pedal to reverse the car [5]. All of these were necessary to operate the vehicle, but only the brake pedal remains in its current form today.

The impacts of utilizing additional functionality above and beyond those initial controls needed to move a vehicle forward can potentially be significant. According to the National Highway Traffic Safety Administration (NHTSA), 8.5% of traffic fatalities in 2017 were "distraction-affected crashes [6]". The NHTSA defines distracted driving as "any activity that diverts attention from driving, including talking or texting on your phone, eating and drinking, talking to people in your vehicle, fiddling with the stereo, entertainment, or navigation system—anything that takes your attention away from the task of safe driving [7]."

It should be evident that every second the driver's attention isn't dedicated to the road is a second that could lead to an accident or death. On its surface, Hick's Law seems like an appropriate way to measure the effectiveness of these secondary functions. For each new system added to the car, and the more complex each new system becomes, the more time is potentially needed to make a decision, which in turn takes decision time away from the primary task of operating the driving controls for a vehicle.

The Evolution and Impacts of Vehicle Controls

Since the time of the Model T, there have been a number of significant technological advancements, each adding new controls for the operator to manage. While sources often support different definitions of "firsts" regarding the addition of vehicle features, with discrepancies based on how each technology was implemented (e.g., hydraulic power windows vs. electrical power windows), and "first" availability often predating "standard" or "commonplace" availability by decades, we can piece together a rough timeline of features as they became available to the general public. All of these added driver controls that were not necessary for the primary operation of the vehicle:

- **Creature Comforts** including the car radio introduced by Motorola in 1930 [8], the in-dash heater introduced by Ford in 1933 [9], the powered retractable hardtop introduced by Lancia in 1934 [10], air conditioning introduced by Packard in 1939 [11], power windows introduced by Buick in 1950 [12], power seats introduced by Ford in 1955 [13], and heated seats introduced by Cadillac in 1966 [14].

- **Changeable Media** including the FM radio introduced by Blaupunkt in 1953 [15], the attempted record player by Chrysler in 1955 [16], the 8-track player by Ford & Motorola in 1965 [17], and cassette tapes in the 1970s [18].
- **Digital Media** including the compact disc player by Mercedes in 1985 [19], support for MP3 by Volkswagen in 2004 [20], DVDs with passenger video displays in vehicles like Chrysler minivans in the 2000s, Blu-ray in 2013 [21], and Apple CarPlay integration between the phone and the vehicle in 2014 [22].
- **Driving Assistants** supported by the introduction of touch screens by Buick in 1986 [23], steering wheel controls by Pontiac in 1987 [24], the first in-car GPS by Oldsmobile in 1994 [25], and OnStar, the first in-vehicle roadside assistance service for GM vehicles, in 1996 [26].
- **In Vehicle Telephony** was attempted by Bell System as early as 1946 [66]. System in Europe evolved starting in the late 1950's through the early 1980's, eventually being phased out in the late 2000's due to the introduction of modern mobile phones in the 1990's.
- **Full Convergence of Car Systems** and the decline of physical buttons with the Tesla Model S in 2012.

Research on technology in vehicles and its impact on drivers can be traced back to the 1930s and the introduction of the car radio. While this research predates Hick's Law and focuses more on general attention shifts away from the road rather than the time needed for the driver to operate various radio features, it shows that even early on, there were those keenly aware of the focus needed to operate a vehicle and how response times could be impacted if those cognitive resources were allocated elsewhere, even momentarily.

In 1934, the New York Automobile Club circulated a survey to the public to measure their views on the car radio. During this time, bans on the devices were being proposed in multiple states, including New York, New Jersey, Ohio, and Illinois [27]. As reported by The New York Times, 56% of those who responded to the survey felt the radio was a "dangerous distraction [28]." This study was quickly followed by one from the Radio Manufacturers Association, whose own study touted the radio as a safety feature [29]. The association's position focused on the radio's ability to inform drivers of traffic and weather conditions that might affect their drive, along with its ability to keep drowsy drivers mentally stimulated. Ultimately, proposals to ban radios were dropped, and the radio would become a standard feature of most vehicles on the road.

The radio wouldn't be the last technology debated by legislatures regarding its impacts on vehicle operators. More recently, in 1999, the city of Brooklyn, Ohio became the first jurisdiction to ban the use of cell phones while operating a vehicle [30]. Subsequent bans at the state level started with New York in 2001 [31]. While the integration of phones with car radios at this time was limited to either purpose-built OEM integrations or aux/line-in adaptations for without those, it was clear to legislators and the NHTSA that increased use of cell phones in vehicles was becoming an issue. Starting in 2000 (results published in 2001), the NHTSA began tracking crash statistics involving cell phone use and found that at any given time, 3% of drivers on the road were using cell phones, and another 0.9% were using hands-free cell phones [32]. As cell phones and technology continued to evolve, NHTSA’s studies evolved to include all electronic devices in use in vehicles beginning in 2007.

A convergence of in-vehicle systems began to take place as jurisdictions around the world continued to ban cell phone use while the cell phone industry began to shift away from flip phones to touchscreen-based smartphones with the 2004 release of the iPhone. Now, in-vehicle systems support for hands-free operation of third-party cell phones began to emerge via native and USB support for external MP3 players such as the iPod, which was quickly extended to the iPhone [33] due to their shared connectors. Once these in-vehicle systems incorporated navigation functionality, they began to take on physical similarities to the touchscreen phones they were supporting.

While touchscreens were initially introduced in the 1980s with Buick, the Lexus RX in the early 2000s has been referred to as containing the first modern infotainment system [34] by bringing together trip information, outside temperature, time, climate and radio controls together in a single interface. This system, and those to come after it, such as Ford’s “Sync” system introduced in 2007 and powered by Microsoft [35], included graphical user interfaces with touch-based controls providing access to multiple subsystems including audio, navigation, and climate controls. As vehicles began to move towards electrification, those interfaces began to provide access to deeper vehicle systems including vehicle health, charge levels, energy usage, and regeneration. Further, the addition of third-party software applications and the ability to connect the vehicle to the internet culminated in the Tesla Model S in 2012 [36].

In the Model S, all systems could now be controlled through a single, touchscreen interface. This same interface could be used to play music over terrestrial or internet radio, a CD, or an external media player. It could allow the user to make hands-free calls, dictate text messages, and request turn-by-turn directions to their destination using their voice. Drivers could see any obstacles behind them when the vehicle was reversing, monitor powertrain energy usage, fine-tune braking or acceleration speed, and change the vehicle's climate. They could even run apps and browse the internet on a fully-featured web browser while the car was in operation.

Just 13 years after the initial cell phone ban in Brooklyn, Ohio, and 8 years after the introduction of the iPhone, the system Tesla built into the Model S resembled an oversized version of the very device that was seen as distracting to drivers. The dedicated physical buttons drivers relied on for decades to operate the features of their vehicle were suddenly seen as antiquated, and a consolidated experience on a large touch-enabled video display was being described as “innovative,” “intelligent,” and “inspiring [37].”

It’s at this point of convergence that we can start to evaluate whether Hick’s Law can be applied to in-vehicle systems. What is the impact of having all driver systems available on a single touch display, many of which may not always be accessible to a driver without accessing a menu? We can begin to assess this by looking at evaluations conducted on prior generations of vehicles.

Assessing the Consolidation of Controls on the Driver

In 2006, the National Highway Traffic Safety Administration (NHTSA) released the results of their “Driver Workload Metrics Project.” The goal of the project was to “develop performance metrics and test procedures to assess the visual, manual, and cognitive aspects of driver workload [38].” The test evaluated drivers in laboratory, highway, and track settings and aimed to identify the “workload associated with the use of in-vehicle systems while driving [39].”

The theoretical basis for the research was that as scenarios where the driver is expected to attend to tasks not related to the operation of the vehicle increase, the availability of cognitive resources for the primary task of vehicle operation decreases. This superficially seems to have similarities to the logic based in Hick’s Law. In the study, participants were put through scenarios that utilized auditory and manual inputs/outputs, along with a range of tasks rated as having low to high workload difficulty. The exam also attempted to be forward-looking by using systems available on the market during the time frame the research was conducted, along with approximations of future systems based on assumptions of where the technology was headed [40].

The findings showed that “visual-manual” tasks, those that require the driver to look and physically manipulate controls, decreased the amount of time the driver glanced at the road and their mirrors and increased the amount of time driving events were missed compared to tasks that were auditory-based. This resulted in a 40% drop in attention paid to the road [41]. Additionally, the results specifically stated, “Relative to visual distraction, cognitive distraction accounts for much less of the overall variance in driving performance than visual distraction [42],” suggesting that, with respect to Hick’s Law, the potential for a system that adds time to the driver’s decision-making process increases the likelihood they will become visually distracted for longer periods.

The study also notes that potential follow-up research could focus on the learnability of systems to see how driver performance changes as they become more familiar with the technology they use. The learnability of a system and how items are presented to the user is a nuance that Hick’s Law does not take into account.

In 2018, the National Institutes of Health examined new approaches for researchers to use when attempting to measure the issue of cognitive load for drivers using in-vehicle systems. The research in this study utilized a stimulus/response approach to gauging cognitive load and provided their findings for researchers and manufacturers to apply to their own cognitive load tests. One interesting note from their research showed, without any particular context, audio response times were faster than visual response times, with tactile/touch-sense based responses falling between the two [43]. In addition, it was shown that the intensity of the stimuli improved response rates (e.g., the louder the auditory cue, the faster the response rate up to around 100 decibels [44]). As more systems move towards touch-based interfaces, tactile feedback may take on more importance moving forward.

In 2017, the American Automobile Association (AAA) Foundation for Traffic Safety published a study examining the impact of performing secondary driving tasks through modern in-vehicle systems on drivers' performance. More specifically, they sought to identify which tasks were the most distracting (and what were the sources of the distraction) and which methods of interaction between systems from manufacturers produced the highest levels of workload. Tasks evaluated included audio entertainment, calling & dialing, text messaging, and navigation tasks [45]. The study also tested various layout configurations of what may be commonly referred to as the “center stack” through the following definitions; a “center console” where a display is physically separated from the remainder of the secondary controls of the vehicle, vs. a “center stack” where the screen visually appears as the first element of secondary controls, with additional controls positioned below the display (such as a navigation dial).

Regardless of form factor, the study found that all of these modes of interaction “produced very overall demand on drivers.” Secondary tasks related to audio entertainment and dialing a phone number had a lower overall demand on the driver than tasks related to texting and navigation, with tasks related to texting and navigation showing significantly longer interaction times [47]. Interestingly, the study showed that auditory tasks were “more demanding” for users to perform [48], which seems to counter previously referenced work published by the NHTSA and NIH. The study suggests that this discrepancy was due to the performance of the underlying technology supporting voice recognition, introducing lag in the systems response.

The study provided overall results by vehicle tested, showing that while the cognitive load for all vehicles was above the established threshold, some vehicles performed better than others, with multiple models testing below the established threshold for overall demand. In relation to Hick's Law, this study could support the notion that specific implementation decisions by individual manufacturers could contribute to longer task times, resulting in higher overall demand. However, the study does not definitively determine whether the higher demand can be directly tied to specific decisions in the organization of these systems' user interfaces.

In response to perhaps the perceived challenges in using in-vehicle systems supplied by auto manufacturers and their approach to the integration of external devices with the car, phone manufacturers began to introduce their own user interfaces that could display on the vehicles display through "projection" to access secondary tasks also present on a phone, such as audio entertainment, text messaging, telephony, and navigation. A separate AAA study in 2018 took a look at how these projection-based system performed when compared to their native in-vehicle counterparts.

The study found that overall, these systems outperformed the native in-vehicle systems across the board, including a lower overall demand on the driver [50]. While these devices can't provide access to the same secondary systems as native in-vehicle systems can (such as climate control), for tasks that are shared and have been shown to have a high demand on a driver, these third-party systems appear to confirm that specific decisions in the organization of a system's user interface can have a negative impact on the driver. This was apparent when comparing these third-party systems against their native counterparts and when comparing native systems against one another.

To start looking more closely at the actual implementation decisions of a fully convergent in-vehicle system, the Nielsen Norman Group evaluated the 2019 Tesla

Model S running version 9.0 of their software. Much of their review focused on Fitts' Law, which states that "the amount of time it takes a user to move a pointer is a function of the distance to the target divided by the size of the target [51][52]." In this case, the pointer is the driver's finger, and the distance is the space between the steering wheel and where various functions are displayed on the screen.

As part of their critique of the Tesla system, the NNGroup focused on a specific interaction pattern, which adds an additional level of complexity when attempting to view in-vehicle systems through Hick's Law. In the Tesla system, a number of secondary tasks of the vehicle were organized together in a drawer, accessed through an icon of an up chevron/arrow [53]. When designing for Hick's Law, two approaches are commonly used: the first is to arrange the functionality into related categories and only show those categories to the user, and the second is to obscure the complexity by only showing the options that are relevant in the current context being shown to the user [54]. Ultimately, both of these goals are achievable when we design for Hick's Law in conjunction with other design principles [55].

As written, Hick's Law can be interpreted as a scenario where all the available options are presented to the user upfront, with user efficiency based on the number of items in that single list. This is not how most vehicles are organized, as basic gestalt principals such as similarity are used to organized features, such as climate controls, are grouped in proximity to one another. Each individual touch-screen implementation would thus need to be tested against a baseline vehicle that has been demonstrated to provide the same functionality, which as Consumer Reports suggests, is probably one with physical controls [67].

Therefore, it may be better to look at the Tesla system through the lens of other UX principles or heuristics, and by doing so, we can quickly see that there are a number of areas where the system can be improved:

- First, it could be argued that the use of a drawer in this context would violate the NNGroup's heuristic on matching the system to the real world, as in a more traditional configuration, the user wouldn't have to open a drawer to reveal the buttons needed for similar functions such as placing a call [56]..
- The Gestalt principle of similarity could also be applied here, as the items located in the drawer seem to have no relationship to one another other than that the designer felt their importance was not sufficient enough to warrant their placement on the main screen [57].
- The drawer itself closes through the same icon that expands the drawer, with the arrow/chevron icon being replaced with an "X". The NNGroup heuristic on flexibility and efficiency of use focuses on accelerators, and in cases such as this, users may be more accustomed to having the close button for a drawer located in the drawer itself, typically in the upper right-hand corner. Moving this may impede the user's efficiency [58].
- Consistency and Standards also seem to be a gap here, as the icons inside the drawer have labels but those on the main screen do not. While a user may be familiar enough with the icons for climate controls, the generic car icon may be

ambiguous enough that they may look there for the "energy" and "charging" functionality located in the drawer [59].

- The behavior of the buttons on the main screen doesn't behave in a consistent way. From left to right, the car, music, drawer icon, and fan all seem to launch a panel or dialog, while the other icons act as a toggle or allow the user to cycle through settings (such as heated seat levels). This could be seen to violate the Weinschenk and Barker model's heuristic on predictability. The determination of how these additional icons behave was based on a prototype of the system found in the Tesla Model 3 [61].

Conclusion

In a separate video, the NNGroup identified two conditions where Hick's Law doesn't apply. The first is situations where items presented are done so in alphabetical order. The second is situations where items are known to the user [62]. In this case, the controls in in-vehicle systems are typically known to the user, even if they are unfamiliar with a specific vehicle's layout or implementation of those controls. As features have been added to vehicles over the decades, drivers have learned to identify and use those features alongside the core functional controls for driving the vehicle.

Further, the formula that underlies Hick's Law only takes into account the number of items presented to calculate reaction time. What Hick's Law doesn't seem to take into account are the inherent performance differences between a 30-year-old and a 60-year-old. What may be considered a reasonable response time for a middle-aged man may overwhelm a senior citizen. This oversight could potentially just be due to a 1950s bias towards the subjects selected for observation, but it stands to note that if updated, Hick's Law could potentially be given new life and used as part of an evaluation of in-vehicle systems.

The traditional vehicle controls that the Tesla system has phased out may have more usability benefits than they appear to have. In the NNGroup review of the Tesla system, they expressly call out the lack of haptic feedback with a flat glass panel, which is unable to take advantage of our sense of touch in the same way a button or knob can. As mentioned before, the National Institutes of Health also indicated that touch feedback had a higher response time than visual indicators did. When we look at extreme users, we can often derive usability gains for a general populace by solving for the usability needs of the extreme user. And in this case, we may be able to look to the older population as justification for a revised Hick's Law and, in the case of in-vehicle systems, the return of physical controls.

The AAA Foundation for Traffic Safety published results in 2019 of tests which measured the ability for drivers to perform tasks across age groups using in-vehicle systems. The study found a huge gap in the amount of time older drivers needed to perform tasks when compared to younger drivers. In these tests, older drivers were shown to have a higher visual distraction time than younger drivers. Older drivers' ability to use audio entertainment functionality took over seven seconds longer, and their ability to use navigation functionality took over eight seconds longer than their younger counterparts [63]. At a speed of 60 mph, that translates to a distance of 88 feet per second [64] or over two football fields for those 8 seconds where the driver's attention is potentially not on the road.

There may be an irony then that perhaps the least touch-friendly in-vehicle systems are the ones that are primarily driven by touch, not because of the amount of subsystems and options that have been consolidated down into a single display, but by the simple fact that the form factor itself removes the physical cues that could accelerate their usage. It shouldn't be taken for granted that auditory functionality can fill this gap either. For drivers with vocal disabilities, the ability to fall back to "auditory commands" may not be helpful. This means that physical buttons that are being viewed today as "clutter" could potentially be an accessibility feature that benefits all drivers, not just older ones or those with disabilities.

We may be able to justify the continued design of in-vehicle systems that allow for physical buttons by looking to existing heuristics such as "User Control and Freedom" in how these systems are interacted with, an understanding of "Human Limitations" by considering physical and age-imposed limitations with interacting with touch screens, and potentially by updating Hick's Law for the 21st century by calculating response time not just by the number of options presented to a user at a time, but also by the number of items it takes to overwhelm us at various points in our lifetimes.

Finally, there is the consideration of the data that can be captured through digital based controls over their traditional analog counterparts. Ignoring the monetization of data collection in a vehicle, from a usage metrics standpoint it’s much easier to measure under what conditions and how frequently features are accessed with a digital input device than it is with a traditional physical, analog control. There is much to be said for the value of driver behaviors that can be captured across hundreds of thousands of vehicles vs. conducting a ride-along or journal study with a handful of participants. Even if there were a broader move back to physical controls, the data collected through digital inputs could go a long way to optimizing that transition.

As vehicles continue to integrate touch screens to consolidate vehicle functionality, and as new technology that doesn't exist today is introduced into the vehicle, we can look to the research to see that gains in overall user efficiency can be achieved by how the interface design is executed. And while Hick's Law may not be expressly influencing their design, it will be implicitly determining which other laws, principles, or heuristics are used, just as it has been in other situations for decades.

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