Better Products Need Better Cultures: The GM Ignition Switch Recall

Ray was convinced the project had come straight from hell.

It was early 2002, he was the Engineer responsible for an ignition switch for GM's new Saturn Ion and it had been a constant struggle. The "design concept" developed by someone else years earlier needed to be completely re-designed, which he had done a year ago, but for the past few months he had been dealing with electrical failures in prototype parts, and he had only a few weeks remaining to solve these problems. If he failed, it would delay the new vehicle launch, a sure setback in his career.

Ray was worried for his job. The US automotive industry had seemed a safe place to build a career when he started 30 years earlier, but in the past several years things had changed. GM, Ford, and Chrysler all faced financial problems, with declining market share, unstable profits, and large losses. The automakers were closing plants, reducing health care, and trimming workforces. The ignition switch was a necessary component to the Saturn Ion and a future Chevy vehicle considered critical to GM's survival.

Unbeknownst to Ray, the switch he was working on was a functional component in the airbag inflation system, which protected vehicle occupants in a crash. A separate team of engineers decided that airbags should only inflate when the ignition key was in the "Run" position, and within the corporate bureaucracy of GM did not have means or inclination to communicate this information to Ray. He did not realize that his decisions affected passenger safety.

In mid-February, Ray learned of a new problem; in addition to the electrical problems the switches were failing to meet torque requirements, meaning that in some circumstances the key might unexpectedly fall out of the "Run" position. Improving torque implied use of a stronger spring, but a change at this late date would either delay the launch or lead to recalls. Faced with delaying the product launch he approved the non-conforming part and hoped for the best.

It did not work out that way.

Idea in Brief

When products result in scandals, an immediate response is to find a bad actor to be blamed, but this fails to recognize how bad actions are the result of cultural dysfunction.

Products are developed based on requirements, the completion of which are decomposed across many groups (for example, the Systems Engineering "Vee-model"). It is this decomposition which creates dysfunction and leads to scandal.

This article details how the decomposition approach failed General Motors, eventually leading to a scandalous ignition switch, over 120 deaths, and a multi-billion-dollar recall. It further discusses how the legal team which investigated the scandal reinforced the "bad-actor" fallacy and provides a counter-narrative to the legal report.

A DECADE OF FATALITIES

In July 2004, an accident occurred which became the first case settled by General Motors regarding airbag non-deployments:

> *"<Redacted> died after her 2004 Saturn Ion left the road at high speed, went over a low curb, braked, then struck a utility pole head-on. The airbag did not deploy, and although she had been wearing her seatbelt, she was found dead at the scene.*
>
> *"(GM Engineers) identified the crash as one in which there should have been an airbag deployment, and that the deployment likely would have saved her life."*[1]

Nine years later, a GM attorney wrote the following as reason to settle yet another case due to airbag non-inflation:

> *"There is little doubt that a jury will find that the ignition switch used on the 2005 Cobalt was defective and unreasonably dangerous…*
>
> *"[P]laintiffs' counsel can compellingly argue that GM has known about this safety defect (since 2005) and has done nothing to correct the problem for the last nine years.*
>
> *"[He] will criticize GM for … its failure to take any action… as proof positive of GM's conscious indifference and willful misconduct when it comes to the safety of its vehicles' occupants."*

Eventually, GM would pay compensation on 124 deaths[2]. But as we further investigate the GM Ignition Switch Recall, it is important to note the following comment on page 2 of the Valukas report;

> *"In this same decade, GM issued hundreds of recalls at great expense (including at times when its financial condition was precarious) because in the great majority it correctly determined that the issues that came to its attention implicated safety and demanded prompt action."*

The purpose of this post is to recognize how confusion and organizational dysfunction leads to systemic failures, a matter made even more important as products become increasingly autonomous, and the responsibility for operational control of the product shifts from the driver to intelligent or automated systems.

CONFUSION KILLS

In autonomous products, human decision-making is supplanted by that of the machine. In his "I, Robot" series, Isaac Asimov developed *"Three Laws of Robotics"*, the first being that:

"a robot may not injure a human being,
nor through inaction, allow a human being to come to harm."

By not deploying when needed, GM airbags violated the second clause; through inaction by the robot the human was allowed to come to harm.

Devices like cruise-control and autopilots have been available for decades and make transportation safer and mentally less taxing. When a driver depresses the petal in a car with an anti-lock braking system on an icy road, software causes the brakes to pulse quickly and randomly to bring the car to a controlled stop in a means not possible for the human driver.

In this case, the vehicle's software takes authority for braking away from the driver for a few critical seconds, not allowing the human to come to harm.

But no machine is *truly* intelligent (yet). Autonomous products have thousands of mechanical, electrical, and software components which *simulate* intelligence, and development of same requires thousands of employees across dozens of companies scattered around the globe. Responsibility is divided among groups, these are divided into sub-groups, and each forms a sub-culture protective of "the way we do things here". Scandals begin at moments when individuals prioritize the status quo over product safety, individuals are often blamed after the fact, but the true culprit is organizational dysfunction.

Confusion then lives within nuanced small details, within dots left unconnected. Individuals may succeed in their goals yet create a product which is imperceptibly but fatally broken. Traditional product development methods of decomposing large concepts into small tasks and individual incentives, implies that no product will ever fully adhere to Asimov's First Law:

> *"A robot may not injure a human being, nor through inaction, allow a human being to come to harm."*

Scandalous Products without Scandalous Intent

This post concerns the recall of GM vehicles in 2014 in which airbags did not inflate at moments in which they would have saved lives. There is no sense that these actions were in any way intentional, and the organization did not recognize the possibility of failure until after lives were lost. I teach a graduate-level engineering management course, and a focus of the course is on scandalous products for which there was no scandalous intent; how scandals are not caused by individuals, but rather by dysfunctional cultures.

Systemic confusion grew at General Motors because individuals lacked the ability or inclination to understand the systemic nature of how their decisions impacted others; a focus on averting individual losses rather than achieving systemic wins, and an unwillingness to challenge the status quo.

Automobiles are assemblies of 20,000 parts and each must conform to dozens of requirements. Tens of thousands of individuals employed by the top-level "Original Equipment Manufacturer" (OEM) and supplier organizations decompose thousands or millions of requirements into individually manageable tasks; yet no single person understands the entire system, and each faces career and social pressure to "check their boxes" to meet deadlines and achieve individualized goals.

A study in the journal Organizational Behavior and Human Decision Processes discusses the dark side of such outcome-based goal setting, and recognizes that a "prevention focus" develops. Individuals become more concerned about failing personally than winning collectively. The study's authors find that:

> *"Prevention focus increases unethical behavior as those with outcome goals work to prevent failure through cheating and other shortcuts to enable goal attainment. This indirect effect is exacerbated as goal difficulty increases."*

As products become more complex, thousands of requirements explode into tens or hundreds of millions, rife with negative interactions which are impossible to recognize. The product development process is such that these millions of requirements are decomposed and assigned to mechanical, electrical, and software specialists who never gain understanding of how individual decisions impact the group. Information silos reinforced by individualized goals create an environment for unethical behaviors which may not become apparent for years. Individuals may not even realize that they are behaving unethically as they balance conflicting goals.

THE PRODUCT DEVELOPMENT PROCESS

The car in your driveway is the summation of nearly a million requirements converted to metal, plastic, rubber, glass, and software. Developing requirements begins with conversations on "What do customers want to buy?", "What do we want to sell?", and "What regulations are applicable?" Top-level product managers develop high-level goals and allocate the goals to specialized groups, at which point the goals become "requirements". The specialists decompose mid-level requirements into successively more granular form and create test criteria at each level to ensure conformance. Prototype components are manufactured at the lowest level, then assembled and tested into larger and larger structures until a prototype vehicle is formed. The result is thousands of manufacturing plants which fabricate and assemble thousands of components, each of which conform to established testing criteria.

The System-Vee Model

We can think of the prototyping process as following the shape of the Vee shown in the figure.[3] High-level specifications begin at the top-left, are expanded into successively finer detail, and define the behavior of each component. Engineers at the Vee's bottom work with suppliers to develop processes which build millions of parts per year.

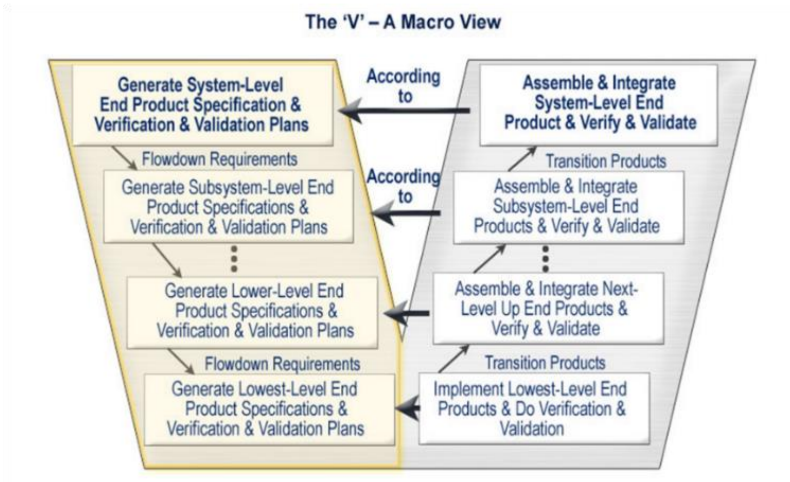

Figure 1: System Vee Model
© International Council of Systems Engineers

In moving up the Vee's right-hand side, there is an inherent assumption that each sub-requirement is valid, that no component is approved unless it passes its tests, and there are no unexpected interactions between components; but this rarely the case and the right side becomes very "heavy". It becomes increasingly difficult to determine if requirements are valid, or if they conflict with other requirements. And as we will see, important information in one small area of the Vee can greatly impact another, and the organization is such that this information may never be communicated.

DECOMPOSITION LEADS TO DYSFUNCTIONAL CULTURES

An automobile industry existed prior to Henry Ford; cars were built by craftsman who would diligently shape each component part to fit neatly with adjacent components. No two vehicles were the same and thus the owner needed a chauffeur who could maintain the vehicle as well as to drive it. The product was *complicated*, in that it was "made up of parts, intricately combined"[4]. The world-wide market for automobiles in the early 1900's was about 2,000 per year.[5]

Ford realized that he could make automobile assembly less complicated through interchangeable parts. Instead of craftsmen shaping each component to fit its mates, his factories built identical components measured against a gauge such that any instance of a component can attach to any instance of a mate. Any axle will fit onto any car, any wheel onto any axle, and any lug nut onto any hub. Interchangeability eventually led to the assembly line and mass production. Ford decomposed the assembly of each automobile into hundreds of small operations, and by 1920 his plants were manufacturing two million vehicles per year. Per *The Machine that Change the World*:

> *"By 1915, the assembler on Ford's mass-production line had only one task—to put two nuts on two bolts or attach one wheel to each car. He didn't order parts, procure his tools, repair his equipment, inspect for quality, or even understand what the workers on either side of him were doing. Rather, he kept his head down and thought about other things.*
>
> *"Ford divided labor not only in the factory, but in the engineering shop. Industrial engineers took their place next to manufacturing engineers… they were joined by product engineers, but these specialties were just the beginning… the fundamental mission of these new specialists was to design tasks, parts, and tools that could be handled by unskilled workers.*
>
> *"These professional engineers climbed the career-ladder by advancing within their profession… As time went on and engineering branched into more and more subspecialties, these engineering professionals found they had more and more to say to their sub-specialists, and less and less to say to engineers with other expertise. As cars and trucks became more complicated, this minute division of labor within engineering would result in massive dysfunction."*

Thus, by reducing the *complicated-ness* of each role through decomposition, Ford introduced unexpected *complexity* (being "a whole made up of complicated or interrelated parts" [6]) into the *business* of manufacturing millions of vehicles per year. Ford increased sales a thousand-fold, but this required a complex network of workers, suppliers, manufacturers, dealers, customers, unions, governments, education systems, and on and on. Individuals developed their own localized view and were subject to a hierarchical management structure which focused on individualized, rather than systemic, goals.

Again, per The Machine That Changed the World,[7]

> *By 1927, GM's Alfred Sloan "created decentralized divisions, managed 'by the numbers'… He demanded detailed reports at frequent intervals on sales, market share, inventories, and profit and loss.*
>
> *"Sloan found it unnecessary and inappropriate for senior managers at the corporate level to know much about the details of operating each division. If the numbers were poor, it was time to change the general manager. Candidates showing consistently good numbers were candidates for promotion.*

Ford decomposed work into small components with little view into the systemic nature of the product, and Sloan further abstracted automobile manufacture by evaluating results through only a few financial metrics. This decomposed, bottom-line approach continues today, and creates the organizational dysfunction which leads to scandalous products. Work and financial goals are planned at a high level, decomposed into individualized tasks, and performance is measured and compensated by the individual's ability to complete only their own tasks. But users of these products (those of us who commute on planes, trains, and automobiles) do not perceive value from the tasks individually, they perceive value from the product in its entirety. The value of the product based on its <u>*worst*</u> component or unexpected interactions between components. No passenger is pleased with a quiet ride if the airbag fails to deploy when needed; none find value in the in-flight entertainment if automated systems are uncontrollable by the pilots and the aircraft plunges into the sea.

Better Products Need Better Cultures

By chance, in April 2014 I was consulting with engineers at 'ClientX", a well-known product development firm, as GM's CEO Mary Barra testified to Congress about that company's failings with the "ignition switch". The GM failure was widely discussed at ClientX, even so they chose to follow the same failed processes which led to deaths in GM vehicles. Young engineers at the client firm feared that the more rigorous processes which Ms. Barra promised to adopt at GM would delay ClientX's product launches, and they felt their own career risk.

At GM, the ignition switch was just one component of a tiny piece of autonomy whose requirement was to disable the airbags when unneeded. As requirements were decomposed onto the airbag safety group, they implemented software so that the airbag would only deploy if the ignition switch was in the "Run" position. However, they did not make this decision known to that switch's designer, Ray DeGiorgio, or to safety investigation teams researching airbag problems over the following decade.

The following quote appears in a Fortune Magazine article, and is consistent with other media reporting which derived from the legal report generated by GM:

"the emerging narrative is of one rogue employee out of 220,000 who could hamstring an entire corporation and escape detection for more than a decade".

But if corporate systems are so fragile that "one employee can hamstring the corporation", we need to look beyond the employee and at the corporation's culture. In his book, *The Fifth Discipline,* Peter Senge emphasizes that "structure influences behavior", and to focus on one person's actions is to miss the systemic causes of that behavior.

As increasing technology leads to increasing complexity, corporate structures are unprepared. In polling recent students who work for GM, the corporation clearly takes the results of the legal investigation (known as *The Valukas Report*) seriously, but as a whole students highlight that Valukas came to the wrong conclusion. This issue is not limited to one unethical employee, or even one company, a lesson which is particularly important as automotive and other industries add higher levels of autonomy to their products. As GM's CEO testified to Congress, and TV and newspapers provided hourly coverage in the ClientX lobby, those engineers still chose to follow GM's failed processes, even as my team discussed the issue with them. A recently hired quality manager at ClientX said:

"Everyone does this. GM was caught".

And this manager is not wrong; in my consulting I've found numerous companies struggling with similar issues. (Specifically, to answer the subtly complex question: *"when is it necessary to renumber a part"?*) In consulting with a third company, the client opened a weeklong seminar with a slide deck developed 10-years earlier, the point being that it had still not been acted upon.

To build better products, we need better cultures, and for this we need early-career professionals to explore the unintended impacts of status quo prevention focus from the "career-safe" environment of a University classroom.

THE IGNITION SWITCH DEVELOPMENT PROCESS

In 2014, as news spread that airbags were failing to protect passengers in the final moments of their lives, CEO Mary Barra and the GM Board directed outside attorneys led by Anton Valukas to "investigate circumstances … due to the *flawed ignition switch*." Much of the following derives from that report.

The Valukas purpose was to determine GM's legal culpability, not evaluate their product development processes, and that team was specifically engaged to investigate the switch. Their investigation led to a Design Release Engineer named Ray DeGiorgio, who was characterized as a "rogue employee" when GM, Congress, and the media were looking for a culprit. Valukas reports that DeGiorgio committed three unethical behaviors related to development of the switch: the first in approving a switch in 2002 which did not meet its requirements, the second in approving a "form-fit-function" change in 2006 without also changing the switch's part number. (Thus, it was invisible to the rest of GM that a functional change was made.) Third, DeGiorgio was not fully forthcoming, and at times defensive, when he was questioned years later by the Valukas team.

A Counter-Narrative to Valukas

But there is a counter-narrative, consistent with Valukas' findings, but not understood by the Valukas team. It is as follows:

On-board software in a device called the "Sensing Diagnostic Module" (SDM) was responsible for deploying the airbags in a crash, and not deploying in non-crash circumstances, like a child playing on the front seat:

1) The SDM team developed software to only deploy if the ignition switch were in the "Run" position.
2) The team could instead have monitored the vehicle's velocity, as the fatalities occurred when the vehicle was moving at high speed. The true need for airbag protection is a function of velocity, not switch position.
3) That the ignition switch was a component of airbag safety was known to seemingly no one outside of that team. DeGiorgio and later crash investigation specialists remained unaware for years that the SDM monitored the ignition switch.
4) As accidents occurred, the mechanical switch was easier to observe than an invisible line of software embedded into on-board computers. Attention thus focused on the switch, which was reinforced by GM's board of directors as they engaged the Valukas team.

> A counter-narrative to Valukas is a more useful lesson as technology moves forward. Autonomous vehicles require close interaction of multiple subsystems meaning close communication between disparate groups.

This counter-narrative is the more useful lesson to learn as technology moves forward. Mechanical ignition switches have been replaced by pushbuttons, and fully autonomous vehicles require close integration of mechanical, electrical, and software subsystems. If our robot-driven cars are to conform to Asimov's First Law, they cannot be developed by dysfunctional organizations.

Valukas is placed on a path to follow a narrative of an unethical switch designer, leading to a conclusion that the primary cause of scandalous products are individuals who lack ethics. In the Valukas report introduction, "an outside expert took apart two switches and quickly found the cause", implying that there was *only* one cause, and that cause was something visible (a spring) in the switch, and not a line of software in an on-board computer. The idea that products would be perfect if we can eliminate bad individual actors is a fallacy. (In many cases a fatal fallacy.) We must recognize that behaviors are influenced by the structures in which they exist. If we want better and autonomous products, we need better cultures.

THE CORPORATE ENVIRONMENT AS THE SWITCH IS DEVELOPED

Per The Valukas Report:

> *"The Saturn Ion and Chevy Cobalt were developed against the backdrop of major challenges in the American automobile industry. In the early and mid-2000s, the so-called Big Three - GM, Ford, and Chrysler- all faced financial problems. From 2001 to 2007, GM 's global market share for automobiles declined… profits were unstable… turning into large losses in 2005… with a consolidated net loss of $10.6 billion.*
>
> *"In the face of these challenges, all three automakers engaged in efforts to reduce costs by cutting production, pressuring suppliers to lower costs, reducing health care and pension spending, and reducing their workforces. [In 2005,] GM announced a major cost cutting effort including the shuttering of nine assembly facilities and three service and parts facilities… and a reduction of more than 30,000 manufacturing jobs, [to reduce] assembly capacity by one million units by 2008. Between 2000 and 2008, GM 's salaried workforce shrunk by 33 percent, and the number of hourly workers fell by more than 50 percent.*
>
> *"GM also pushed its suppliers to reduce costs. As part of its 2005 initiative to reduce expenses, GM announced a plan to reduce material costs by $1 billion by 2008 and set cost-cutting targets for individual parts. The Engineering group was included in GM's cost-cutting efforts. The U.S. engineering organization was consolidated from 11 engineering centers in the United States into one unit."*

I earlier discussed how outcome goals may lead to a "prevention focus" and unethical behavior, and the economic environment described above makes outcome goals that much more concerning. Individuals follow the cultural norm of *"I don't want to be the reason that we miss our product launch date"*. Tens of thousands of people across the US automotive industry were losing their jobs, and GM, Chrysler and many suppliers would go bankrupt just a few years later. This is a ripe environment for prevention focus.

Changing Requirements of the Airbag Safety System

The National Highway Traffic Safety Association (NHTSA) required all automobiles to have airbags by model-year 1998, but in 1999 NHTSA found cases in which the airbag itself caused fatalities. They added requirements to minimize unintended deployments, and the model-year 2003 Saturn Ion was the first GM vehicle to incorporate these new airbag standards.

Within GM vehicles of the time, the component responsible for deciding if the airbag should deploy was the Sensing Diagnostic Module (SDM). It monitored vehicle speed, severity, and location of impact to avoid deployment in events like driving over rough roads. To conform to NHTSA's new requirement that a child playing in a parked vehicle not create a situation in which the airbag would deploy, the SDM was only enabled if the ignition was in the "Run" position. This design decision was based on the SDM teams' (mistaken) assumption that if the vehicle is approaching a crash at high velocity the switch *must* be in Run.

A Functional Diagram (Developed After the Fact)

Past students (many of whom are automotive designers) developed the diagram at right based on their reading of the Valukas report, 15 years after the fatal decisions were made. Tragically, had this diagram (including the blue arrow between the BCM and the SDM) been easily available throughout GM, the switch's role in passenger safety would have been quickly seen, and many lives saved.

(Note: this sort of communication dysfunction is less likely to happen after 2011, due to a set of functional safety standards introduced as [ISO 26262](). Following this standard would force the creation of similar diagrams.)

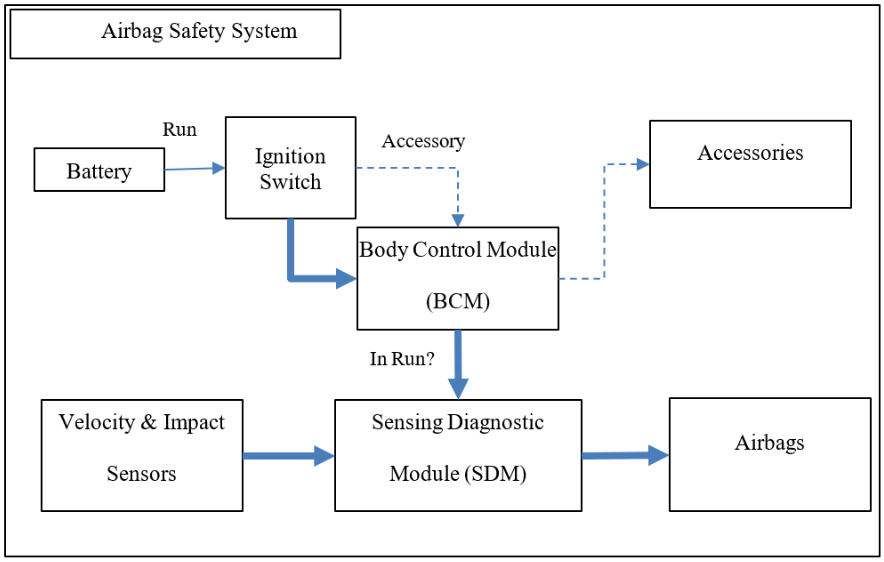

Figure 2: Airbag Safety System

In a product development process following the Vee-model in Figure 1, each box within Figure 2 would be assigned to an individual or small team. While Valukas' attention was placed within the ignition switch 'box', this and many tragedies are stories of dysfunction between the groups represented by each.

The Switch's Design Concept (1997)

GM project engineer Thomas Utter created an ignition switch specification in 1997 which included a force-displacement curve (Figure 3) on how the switch should behave. The highlighted text (highlight added by Valukas) indicates that the torque vs. rotation curve was not final, leaving open the possibility for suppliers to suggest changes. (The figure and text become critical in the eventual recall.)

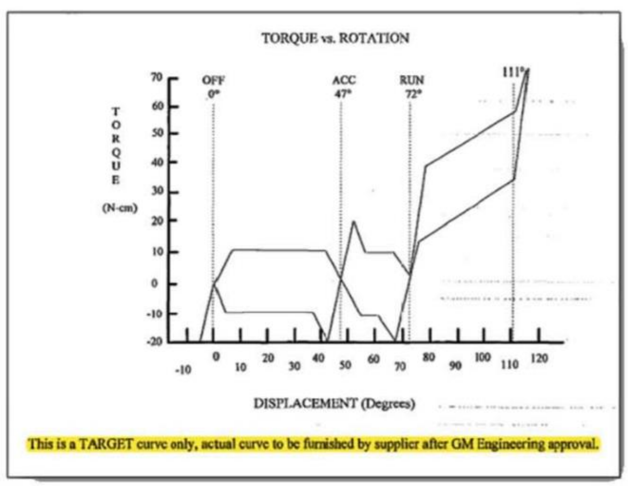

Figure 3: Switch Torque Profile

The specification only provides targets for the torque that the driver should feel as they turn the key. The internal components of the switch were a "black box design," meaning that GM personnel provided the supplier (Delphi) with the requirements and let the supplier develop details as necessary to satisfy those requirements.[8] Using the Vee-model analogy, the torque targets are created by Utter along the top-left of the Vee, leaving it up to Delphi to work out the details at the Vee's "bottom".

Also, on the left-side of the Vee, without the knowledge of either Utter or DeGiorgio, the SDM team chooses to include the ignition switch in the airbag deployment decision.

Ray DeGiorgio's Re-Design (2001)

By March of 2001, Ray DeGiorgio has responsibility for the switch and "finalizes" the Utter targets into a formal specification to indicate that he does not expect future changes. The final spec uses the same curves as shown in the figure, though DeGiorgio removes the (highlighted) notation about it being a "Target" curve, implying that the supplier will be contracted to provide switches conforming to this curve.

In this period, the switch has some mechanical issues but the electrical design "simply did not work when moving to an actual part"[9] and DeGiorgio decided to redesign it. Per Valukas: "electrical and mechanical problems continued, though the people involved viewed the electrical problems as being the more significant". By September 2001, the switch still failed to meet electrical engineering requirements.

Engineer Erik Mattson and Failed Torque Tests (2002)

In February 2002, Delphi Engineer Erik Mattson emailed DeGiorgio and others that torque measurements on prototype switches were well-below specified amounts. He explained that the increasing the torque was possible, but it risked cracking electrical components in the printed-circuit board (PCB).[10]

In a later deposition of Mattson, details of the email emerged:

> *"The cost for a stronger switch would be around $2,000 to do the engineering and get parts, Mattson said. But the parts came from Germany… and alongside the small cost would be probable delays of many weeks, as well as possible knock-on effects that could pull down its durability or could end up damaging a key rotor inside the switch."*[11]

The following day, (February 19) DeGiorgio responded to Mattson's email:

> *"If increasing the detent…force by 5 N-cm will destroy the switch [then] do nothing. Under no circumstances do we want to compromise the electrical performance of this switch, or our PPAP status."*

The Production Part Approval Process (PPAP)

PPAP (pronounced PEE-pap) is the "check the box" moment which elicits a preventive focus from DeGiorgio and Mattson. It is a standard process used by the US automakers to approve components manufactured by their suppliers. For each component, "PPAP" is the first step up the right-hand side of the Vee, and is described by Valukas as:

> *"the process through which parts are tested, validated, and ultimately released for production. The PPAP package should contain, among other things, two key authorizations: one from the supplier and one from GM (confirming that GM and the supplier agree that the part meets specification).*[12]

The thousands of teams working to develop component parts are each trying to meet their scheduled dates to achieve "PPAP status", and the delay of any component would delay the entire product line. Achieving PPAP status becomes an outcome-oriented goal for both DeGiorgio and Mattson.

(A side note: In recent years I've asked my students, "what does it mean if you fail to meet your PPAP schedule?" to which they've replied "Death" (figuratively). But this gets to the point of prevention focus; engineers responsible for shepherding a part design focus intensely on meeting a PPAP schedule and see it as a "life-or-death" for their careers. As with DeGiorgio, they may not have necessary information needed to see that there are (literally) life or death outcomes from their decisions. As he made his decisions about the switch, DeGiorgio did not have the necessary information to balance figurative "career-death" against literal passenger death.)

In the 19-February email, DeGiorgio instructed Mattson to take no action to increase the rotational torque out of concern that changing the spring would compromise electrical performance, reliability, and achieving PPAP on schedule. However, at the same time, he:

> *"notified Delphi that detent modifications would be required to increase torque in accordance with the Specification before the switch (being developed for the imminent Ion launch) could be used in the Cobalt, to be launched two years later.*
>
> *DeGiorgio signed his response,*
> *Ray (tired of the switch from hell) DeGiorgio"* [13]

Mattson responded back to DeGiorgio that same day, saying:

> *"Where in the [specification] is there an exact requirement of these forces? All I see is … 'This is a TARGET curve only, … It is "not impossible to change detent forces but it does have an impact on timing and [costs]…*
>
> *TALC samples were 9.6 N-cm, the new production intent version of the switch has 9.5 N-cm. We feel this is a match for the TALC switch… We can revise this again, but we all need to be aware of the impacts in timing, cost, and possible other issues that might be created when we are this close to PPAP."*

Mattson's response raises questions: Why was he referring (in February 2002) to the "TARGET curve only" text that DeGiorgio had removed a year earlier? Why was he not using the final specification? His comments indicate his own prevention focus. TALC refers to "Touch, Appearance, Lighting, and Color" and members of that group had authority over the look and feel of the switch. Note the impact of the last two paragraphs, "This is a match for the TALC switch", and "be aware of impacts … this close to PPAP". Mattson's sentiment would confirm DeGiorgio's prevention focus, nudging him away from a schedule delay if they address the torque issue. A schedule delay would have impacted both careers, and neither knew about the switch's importance to the SDM.

At this moment, Mattson had the opportunity to challenge DeGiorgio's unethical decision to "take no action" but he instead supported it, by questioning the validity of the requirements. Neither understood the connection to the SDM and viewed the likely outcome of below-spec torque as an unintended stall, which the company characterizes as a non-safety issue. There is no reason to believe that either understood that approving the below tolerance switch was a literal life-or-death decision. Cultural inertia is building between DeGiorgio and Mattson such that the ethical choice was increasingly difficult to make.

Per Valukas:[14]

> *"When interviewed (in 2014), DeGiorgio acknowledged that Delphi had not achieved the required torque for the Ignition Switch. Given the switch's history of electrical failures, however, he was hesitant to make any changes that might jeopardize the functionality of the switch's electrical architecture. Because he believed the Ignition Switch had performed properly and without incident during the numerous vehicle-level tests conducted on the prototype Ion, DeGiorgio approved production of the switch - even though the switch's torque was below the Specification.*
>
> *DeGiorgio explained that he signed his message "tired of the switch from hell" because he was frustrated by the numerous electrical issues exhibited by the Ignition Switch and the amount of time and energy that he had spent resolving them.*

When DeGiorgio made his first critical decision in 2002, the US auto industry was in crisis, resulting in a GM corporate goal to bring two new vehicle lines to market (the Saturn Ion and Chevy Cobalt). High-level goals were decomposed into localized requirements for DeGiorgio and Mattson. A focus on the electrical problems likely delayed the torque tests, and by the time those failures were realized a conforming solution would delay the product launch by many weeks, further exacerbating GM and Delphi's financial difficulties.

As goals became unattainable, with high stakes and insufficient time, unethical behavior became the easiest solution. DeGiorgio behaved unethically in approving the below-spec switch, and Mattson behaved unethically in creating confusion at the point of DeGiorgio's decision, but neither understood that the decisions they were making impacted safety. These were not nefarious actors; their behavior was consistent within the structure in which they worked.

There were future opportunities to correct this failure, but they required an admission of past wrongdoing, which again conflicts with a prevention focus.

Correcting for Past Errors

GM launched the model-year Saturn Ion in the fall of 2002, and in the following year received hundreds of complaints relating to the ignition switch:

- The primary initial problem was a "No Crank/No Start" issue, in which turning the key would not start the engine. This symptom appeared in cold weather and was difficult to debug; eventually found by placing a car in a refrigerated trailer. From this, DeGiorgio identified two solutions, a change to the grease, and a change to the PCB. The grease change was implemented immediately, but the PCB change was not. This resolved about 90 percent of the complaints, but not all.
- There was also a problem of moving stalls, which DeGiorgio and other engineers thought to be a duplicate of the No Crank/No Start problem. In truth there were two problems (grease and switch torque) with similar symptoms, as in either scenario the engine failed to run. But neither GM nor NHTSA consider stalls to be a safety issue, meaning a change to the switch would need a business case. There would need to be proof that revenues were lower, or costs were higher, because of occasional stalls. Had the SDM team made the switch team aware that the switch was a functional component of airbag safety, a business justification would not have been necessary.

The Chevy Cobalt, and the Cost of a Change

Changing a part after it has entered production can be an expensive endeavor as there are many downstream effects and thus it is difficult to justify the expense in business terms. In *The Machine That Changed The World*, Womack describes how suppliers set their prices to be below their own costs in order to get a contract, and then use a later change to renegotiate. This becomes the only path to supplier profitability, and even small changes become quite expensive to the OEM. Beyond this sleight-of-hand in price negotiation, new part designs incur costs in tooling, training, service manuals, etc. Cultural norms develop within OEM's which establish a high bar against any perceived need of change. For the Vee-model development process to perform correctly, requirements, tests, and PPAP approvals must also perform correctly. Admitting that the process isn't working is costly and leads to a prevention focus.

In 2004, the Chevy Cobalt went into production with the same switch as the Saturn Ion. But in this vehicle, the switch generated a series highly publicized reports of inadvertent shutoffs as drivers would hit the key with their knees. DeGiorgio was asked about a design change in June 2005, to double the switch's torque.

(This is an ethical moment for DeGiorgio, who had approved the low-torque switch three years earlier. It was an opportunity to admit to having violated policy in allowing the release of a below-tolerance switch.)

Instead, DeGiorgio provided two other proposals. One was to replace the switch entirely with a different model created for different vehicles. The other was to change the existing switch to include a second detent plunger. This could be incorporated within an electrical modification already being planned to address issues with the No Crank/No Start problems. However, GM engineering committees rejected both proposals, choosing instead to inform service technicians that drivers should remove unessential items from their keychains.

As part of the electrical modification, and after his torque-related change requests were rejected, DeGiorgio and Delphi discussed using a longer (thus stronger) spring in the original ignition switch. A longer spring was already being used in a different switch. DeGiorgio's primary concern was to address recurring electrical problems, but an internal Delphi document shows a "request from GM to be… in specification for the torque forces", meaning that DeGiorgio and Delphi were aware that the current switch failed to meet its torque specification.[15] Between DeGiorgio and Delphi, a plan took root to use the longer spring in the Ion/Cobalt switch, thus increasing its torque.

(Synopsis to this point: DeGiorgio, under time pressure in 2002, approved a switch that he shouldn't have. In 2005, he attempted to get approval for an engineering change which would fix the torque problem but didn't volunteer that he had approved a nonconforming switch in 2002. Shortly after his proposed change was rejected, he and Delphi introduced a 'quiet' change to the increase torque, as part of an unrelated PCB change. DeGiorgio is later blamed for not changing the part number when making the torque change, but this would have required him to admit to his ethical lapse in 2002. GM's change control board had already rejected his requests for part number changes, and it was not something that he could implement on his own.)

To move on, I need briefly to enter a discussion on how parts get numbers.

Form, Fit, and Function

Manufacturing companies specify parts as having a form (is its general dimensions), a fit (how it interacts with surrounding parts), and a function (its stated purpose). A specification which leads to a unique Form-Fit-Function (FFF) is identified by a corresponding part number. Viewed in reverse, ordering a part by its number implies that you will receive a particular form/fit/function which conforms to the part's specifications. Imagine if that were not the case the next time you order something online. Two sweaters which have identical form and function, but a different fit, are clearly not identical in their purpose.

In this scenario, GM would have purchased thousands of ignition switches per week from Delphi and assumed that every switch with an identical part number would have an identical form, fit, and function, and these would be consistent with the part's specification. As a 'black box' design, GM would have little or no interest in the switch's internal workings, so long Delphi manufactured switches which conformed to GM's requirements.

Delphi however, viewed each switch as an assembly of smaller components, including a PCB, spring, plunger, and a detent disc, as in Figure 4.[16]

Recall that in the first few months of production, Delphi changed the formulation of grease to improve the switch's reliability in cold weather. This would reasonably not require a part number change, and GM could continue ordering the same switch. The new grease would not change the specified form, fit, or function; but switches manufactured with the new grease would meet that function more reliably. If an already-sold vehicle needed service for the No Crank/No Start problem, a technician would see a service bulletin from GM indicating that they should replace the switch with a newer one of the same part number, manufactured after some date. Valukas does not describe the 2005 change being made to the printed circuit board, but it's not unusual to make a change for the sake of quality or cost which still maintains the part's initial form, fit, and function. Creating a new part number would not be expected in this case.

But changing a spring, and thus the switch's torque profile, *is* a functionality change – if the *torque* is different, the switch's *function* is different - especially in a crash. It is customary engineering practice in such a case to change the part number. Following our example, in replacing a switch for one with higher torque, the service technician would need to order the new number. (As eventually happened for 30 million vehicles in 2014, when GM issued a recall).

That Ray DeGiorgio directed Delphi to increase switch torque, but did not simultaneously change its part number, is an ethical failure which later confuses accident investigators, extends the duration of the investigation, and is the eventual "smoking gun" which creates a multi-billion-dollar legal liability for GM. DeGiorgio was removed from GM for cause, and faced his own legal challenges.

Managing Part Changes

In practice, when to change part numbers can lead to an open (and often heated) debate. There are many downstream effects so while process dictates when a part number should be changed, within the culture it is discouraged.

In 2014, the Valukas team interviewed GM CEO Mary Barra who is quoted as saying:

> *"…it was 'Engineering 101' that, given the significance of the change to the ignition switch, the part number should have been changed."*[17]

But in teaching a graduate-level engineering management course, I find that few of my students are familiar with part numbering processes. What first drew my interest was the difficulty so many of my clients showed in establishing and adhering to common and customary part numbering processes. Recall that I was working with ClientX the week that Ms. Barra testified to Congress about GM's lapses, but ClientX chose instead to follow those same lapses. Mid-level managers at ClientX feared losing their own jobs, excused the situation as "everyone does this", thus showing their own prevention focus.

In 2005 (nine years before Barra's statement) DeGiorgio had presented two alternatives for a change to GM's engineering committees, and both were rejected. Had either been approved, it would have triggered a change in the specification,

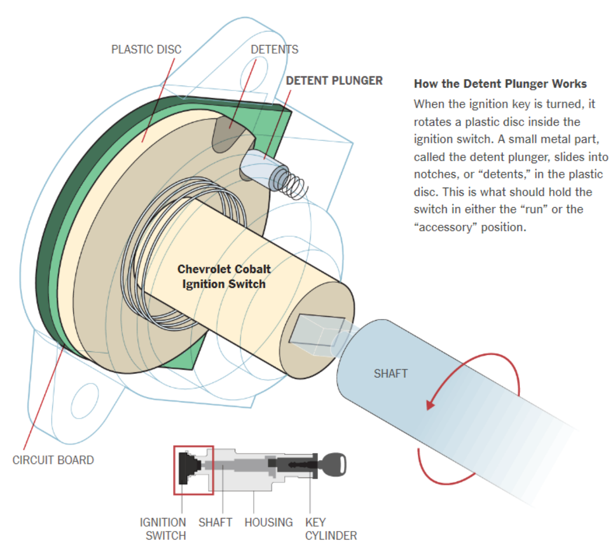

Figure 4: GM Ignition Switch © New York Times

meaning a change to its function, and therefore its part number. And this brings us to DeGiorgio's prevention focus, originally caused by approving the below-tolerance switch in 2002. To admit his lapse would have led to a recall, disciplinary action, and his likely dismissal. Without approval from the change committee, he lacked the *authority* to change the part number. This is not Engineering 101, and as a rule, engineering schools do not teach part numbering methods.

Most likely, DeGiorgio and Delphi changed the spring because unintended stalls were becoming a recognizable problem. With too weak a spring the ignition switch could fall out of Run, leading to unintended stalls which GM did not consider to be a safety issue. (DeGiorgio and Delphi did not know about the switch's connection to the airbags). Too strong a spring might crack the PCB, also leading to unintended stalls. Stalls were becoming a visible problem, but DeGiorgio lacked the authority to make a true change, and the alternatives he provided were rejected. The option presented itself to quietly change the manufacturing process to use longer springs, already being manufactured in another switch.

To Valukas' point:

> *"Had others at GM known that the Ignition Switch had been changed during MY 2007, it is highly likely they would have concluded their investigation much more swiftly and recalled the Cobalt and other cars earlier."*

But the report also notes that:

> *"In September 2006, Raymond DeGiorgio purchased an MY 2007 Cobalt for his son."*[18]

Which implies that DeGiorgio did not see the Cobalt as a safety risk.

Synopsis: DeGiorgio approved a below-tolerance switch in 2002, and by 2005 the switch was causing highly publicized problems. When asked for a solution he provided options, and had they been approved it would have generated a new part number, as is common practice. But no one in the decision chain, including DeGiorgio, recognized that the switch was a functional component of passenger safety. Quietly changing the spring became a convenient solution to an intermittent problem of "driver inconvenience".

VALUKAS ON GM CULTURE

My premise is that to achieve better products, we need better cultures, but the Valukas report does not begin its discussion of GM safety and cultural issues until pages 250-252, To wit:

> *"Some witnesses said that there was resistance or reluctance to raise issues or concerns in the GM culture… Mary Barra explained that problems occurred during a prior vehicle launch as a result of engineers being unwilling to identify issues out of concern that it would delay the launch."*

In fact, Ms. Barra made this comment in the same interview as the "Engineering 101" comment. Per Valukas:

> *"Similarly, an employee survey reflected an issue related to speaking up. In a survey administered at GM in 2013, GM participants' rate of reporting misconduct they observed was below the benchmark… A small number of participants also suggested a fear of retaliation."*

> *"Cost-cutting impacted all aspects of the business. Keeping projects on time - because of the impact on cost - became a paramount concern. One witness expressed concern that cost- and time-cutting principles emphasized timing over quality. Those principles were introduced to GM in the early 2000s."*

"Reductions in staff, especially in Engineering, meant that employees were forced to do more with less. In the time leading up to the 2010 bankruptcy, one measure was to decrease the Engineering headcount by adding to the responsibilities of the Design Release Engineer (the position held by Ray DeGiorgio). Witnesses stated that the reduction in force created a difficult environment in which people were overworked and the quality of work suffered."

Stalls are a "Moderate Issue."

An automobile may stall while in motion. Automobiles rely on maintenance, which is the responsibility of its owner. A stray object may be on the road ahead and kicked up into the front of the car, or a mouse may make a nest and start eating through wires which fail while the car is underway. Certainly, a great deal of work is done to avoid these instances, but it is not realistic to eliminate stalls entirely, and correcting for one problem may introduce another. For example, adding barriers to the underside of the vehicle to protect against rodents and road debris would increase weight and decrease fuel economy.

Stalls in the newly released Chevy Cobalt attracted media coverage in 2004 and thus attention within GM. In a press event introducing the Cobalt, a reporter unintentionally turned off the ignition by bumping the key with his knee, leading to a problem report within GM. The report was given a severity of "Code 3, Moderate Issue" and assigned to an engineering team, but the team eventually closed the report without a resolution, and the problem of moving stalls would linger without further investigation. No one in the resolution team recognized that the ignition switch was also a component of the airbag inflation system, which would given the report a severity of "Code 1: Safety Issue".

Per Valukas, GM "engineers working on the Cobalt did not view moving stalls as a *per se* safety problem", a view which is shared by other automakers.[19] In Senate testimony in 2014, a NHTSA representative said, "If a consumer can safely pull a vehicle over to the side of the road and restart the vehicle, it's a situation where the consumer can be safe." [20] GM policies at the time of the Cobalt investigations were that stalls could be classified as a "Moderate Issue" (though these policies were later changed in response to the switch recall). Fixing a Moderate Issue required making a business case, whereas a Safety Issue did not.

Thus, the dominant logic within GM and the auto industry was that stalls were inconvenient but not unsafe. Note also that passenger safety in a stall (where you may be hit from the rear) is the *opposite* of a front-end collision, in which safety would be increased through the airbag. The Valukas Report condemns GM for not replacing the switch to address the stall problem (which by chance would have corrected the airbag problem as well) but it was not until years later that the connection between the key switch and the airbags was understood.

So, the true situation in this timeframe is of two failure modes associated with the below-torque switch; occasional moving stalls which were not considered unsafe, and fatal airbag non-deployments with no known connection to the switch. The problem resolution team investigating moving stalls did not include a member of the SDM team.

Valukas interviewed the problem resolution team 10 years later and found that the investigation was "closed without resolution". It wasn't clear who closed the investigation, numerous individuals claimed that they did not have the authority to close it, but all thought that some other person did have authority. Valukas describes this as a "troubling disavowal of responsibility made possible by a proliferation of committees" and the so-called "GM Salute… which is crossing one's arms and pointing at someone else". [21]

To their credit, GM asked an outside legal team to investigate airbag non-deployments, and then made the report publicly available. Other companies caught up in scandals have not been so forthcoming. The investigation is well-researched, but the conclusions drawn by the Valukas team do not lead toward safer and more effective intelligent vehicles. Ray DeGiorgio was tasked with ensuring that a supplier's part conformed to stated requirements, and when they did not, he did not delay the product launch to get the problem fixed. DeGiorgio is blamed for not changing pat numbers when he changed the switch's function (with the longer spring), but he had no means of doing this without admitting the initial ethical lapse, and he had no means of knowing that the switch was at all involved in passenger safety.

The Role of the SDM Team

The better lesson to learn from airbag non-deployments is in the design of the Sensing and Diagnostic Module (SDM), and the SDM team's failure to inform appropriate stakeholders that their actions impacted safety.

The purpose of an airbag is to protect the occupant from sudden deceleration when the moving vehicle strikes an immovable object. Sensing velocity was core functionality of the SDM, and it is this input which should have been used to determine if airbags should be disabled. Clearly, it was possible for a vehicle to be in motion even if the ignition switch was not in the Run position, otherwise this scandal would not have occurred. Similar situations would have occurred if the ignition was not in Run, and freely rolling down a hill.

Valukas reports that an early model of the SDM (used in the 2002 Saturn Ion) was powered by the ignition switch being in Run, and by extension would disable the airbags when not in it. This was a questionable assumption at the time, made worse by a 2004 upgrade to the SDM which changed its power source to the battery, due to a concern that the SDM might de-power during a crash. In this later model, the SDM would look for an electronic message from the ignition switch, wait 150 milliseconds, and then disable the airbags. If this had been a delay of 5 or 10 seconds, numerous lives may have been saved. The failure mode prior to loss of life was the car hitting bumps seconds before hitting a tree or a light pole; the bumps being enough to knock the key out of Run. After a fatal crash, external investigators had physical evidence based on the switch, but evidence of a software failure was hidden from their view.

As litigation continued, GM assigned an investigation team in 2007. This team remained unaware until May 2009 – five years after the first fatality, that the statement

<IF IgnitionSwitch = "RUN">

was included in the SDM's decision to deploy the airbags. Had the SDM team had made a diagram similar to Figure 2 available to appropriate stakeholders, the safety role played by the switch would have been clear. It would have given Ray DeGiorgio and others the information needed to delay the initial PPAP approval, which was in this case the original sin; all other sins followed from this one. Even if the faulty switch had been released to market, ready access to Figure 2 would have allowed the investigation team to justify a recall based on Safety.

As late as 2012, 10 years after the first release of the SDM, and eight years after the first settled fatality, the investigation led to the SDM's electrical engineering team.[22] This team's response to Valukas:

> *"[we] have taken the position that (our team) does not support further steps… to allow airbag deployment while the car was in Accessory".*

Valukas goes on to say:

> *"The electrical engineers believed, correctly, that the SDM was working as it had been designed and feared any alterations to the SDM, a corporate common component, might cause problems in vehicle lines that were not experiencing the issues."*

But while the SDM was working *as the SDM team designed it*, the design was itself flawed. More to the point, they did not identify key stakeholders in their design decisions, thus making them unaware. The SDM team's assertion that it "does not support further steps" is yet another example of a prevention focus.

The merits of Valukas' argument may establish a legal responsibility, but they are misleading if the goal is to create better products for the future, particularly as we move towards autonomy. The central premise of this article (and the class I teach) is that the root cause of scandalous products lies within organizational dysfunction, which is created through the decomposition of requirements, an example of which is the Vee Model as shown in Figure 1.

The Requirements Fallacy

To Valukas' point, if the Ignition Switch had stayed in "Run" to the point of impact, airbags would have deployed in circumstances in which in fact they did not, possibly saving lives. But the Valukas team may have missed an equally culpable set of decisions involving the functionality of the Sensing Diagnostic Module. Given that the SDM had access to real-time information regarding both vehicle velocity and the ignition switch, why did the SDM enable the airbags based on the ignition switch position, instead of the vehicle velocity? The Valukas report indicates that GM's product investigators did not understand the functional connection between the switch and the airbags until 2009; why were so few people aware of the role that the SDM team gave to the ignition switch?

In his book, *The Fifth Discipline*, Peter Senge highlights a parable that "Dividing an elephant in half does not produce two small elephants".

> *"Living systems have integrity. Their character depends on their whole. The same is true for organizations; to understand the most challenging managerial issues requires seeing the whole system that generates these issues.*
>
> *"Some issues can be understood by only looking at major functions, … but there are others where the dynamics of the (organization or) entire industry must be considered. This key principle, called the "principle of the system boundary," is that the interactions that must be examined are those most important to the issue at hand, regardless of parochial organizational boundaries. What makes this principle difficult in practice is the way organizations are designed to keep people from seeing important interactions. One obvious way is by enforcing rigid internal divisions that inhibit inquiry across divisional boundaries.*

The concept of the Ion and the Cobalt was decomposed into thousands of requirements scattered across hundreds of independent groups. DeGiorgio was responsible for a part requirement and failed to achieve it but was in an environment where the symptoms of the part failure seemed minor, and the personal cost of highlighting the failure seemed major. Blaming an individual for an unethical decision without understanding the context of the cultural norms and available information surrounding those decisions will not lead to safer products in the future.

Mobility at speed is inherently dangerous, and the products which mobilize us (including planes, trains, and automobiles) are designed, manufactured, and serviced by hundreds of thousands of people across numerous corporations. In the early 20th century, Henry Ford developed a mass-production approach based on the decomposition of work, while Alfred Sloan introduced financial metrics as a means of evaluating success, creating a "prevention focus" on individuals throughout organizations. Work is decomposed into consecutively smaller groups, individuals are financially incentivized to achieved localized goals, but in turn lose visibility in how end customers perceive the overall product.

If we want better products, we need better cultures.

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[1] Valukas p. 112

[2] https://en.wikipedia.org/wiki/General_Motors_ignition_switch_recalls

[3] https://sebokwiki.org/wiki/System_Life_Cycle_Process_Models:_Vee accessed 25-Sept-2019.

[4] Merriam-Webster definition of *complicated*.

[5] *The Machine That Changed the World*

[6] Merriam-Webster definition of *Complex*.

[7] *The Machine That Changed the World* p. 44

[8] Valukas p. 40

[9] Valukas p. 42

[10] Valukas p. 46

[11] https://www.law360.com/articles/774388/gm-could-have-fixed-ignition-defect-for-2k-jury-hears

[12] Valukas pp. 50-53

[13] In an interview with the Valukas team in 2014, DiGiorgio indicated his “switch from hell” comment related to the numerous electrical issues, and the time and energy spent resolving them.

[14] Valukas p. 49.

[15] Valukas p. 98

[16] https://www.nytimes.com/interactive/2014/06/05/business/The-Fault-in-the-Cobalt-Ignition-Switch.html

[17] Valukas, p. 100

[18] Valukas Footnote 416.

[19] Valukas p. 72

[20] https://www.wsj.com/articles/nhtsa-declines-to-label-stalling-cars-as-safety-issue-1410906464

[21] Valukas, p. 69

[22] Valukas p. 170