PRODUCED BY
MIT Technology Review CUSTOM

IN PARTNERSHIP WITH
SAMSUNG

QUALITY CONTROL:

How Samsung Is Using Data to Mitigate the Battery Challenge

Samsung has rebounded from its battery-related challenges by expanding its fault resolution capabilities. It is now positioned to revolutionize the manner in which the global smartphone industry mitigates future issues.

IN EARLY AUGUST 2016, Samsung Electronics enjoyed a prominent position in the global smartphone industry and was poised to launch an innovative, new flagship product. The Galaxy Note7—with its unique sleek form factor and such industry-leading features as its curved Quad HD Super AMOLED display—had been highly anticipated by industry watchers, bloggers, and consumers worldwide for months.

By the end of that month though, reports of Note7 incidents began to surface, ultimately precipitating a global recall. Samsung quickly identified the problem: a battery short circuit caused by a deflection of the negative electrode. CT and X-ray scans revealed the "jelly roll" (a design used in most rechargeable lithium-ion batteries) was compressed in the battery pouch, which weakened the separator between the two electrodes. This created multiple paths to short circuit.

Samsung engaged a second supplier—one that was already providing a portion of the original Note7 batteries on a global scale without incident. That second Note7 battery supplier confirmed that it could meet the worldwide demand for the Note7 replacement devices. However, a separate, distinct battery failure soon emerged in these replacement batteries. This one was caused by abnormally high burrs on the positive electrode tab due to ultrasonic-welding defects.

"The lithium-Ion business is highly varied and stratified, with many different types of suppliers, making batteries for everything from e-cigarettes and hover boards to smartphones."

- Jack Gold, Principal Analyst at industry researcher J. Gold Associates, LLC.

Ultimately, Samsung withdrew the Note7 from the market less than two months after its launch, with industry reports estimating the company has lost some $10 billion in sales. Almost as quickly as the recall process played out, Samsung implemented a safety-management program unparalleled in its scope and size for the mobile industry. Augmenting existing battery tests and creating new levels of testing, Samsung developed a holistic quality and safety framework known as the 8-Point Battery Safety Check, which both built upon and improved existing benchmarks.

Samsung instituted these inspection and review processes across both Samsung's and its battery suppliers' quality assurance processes—from producing the individual components that make up the device itself through the process of putting those components together and assembling the phone to the very end, when the completed device was subject to additional tests.

"The lithium-ion business is highly varied and stratified, with many different types of suppliers, making batteries for everything from e-cigarettes and hover boards to smartphones," says Jack Gold, principal analyst at industry researcher J. Gold Associates, LLC.

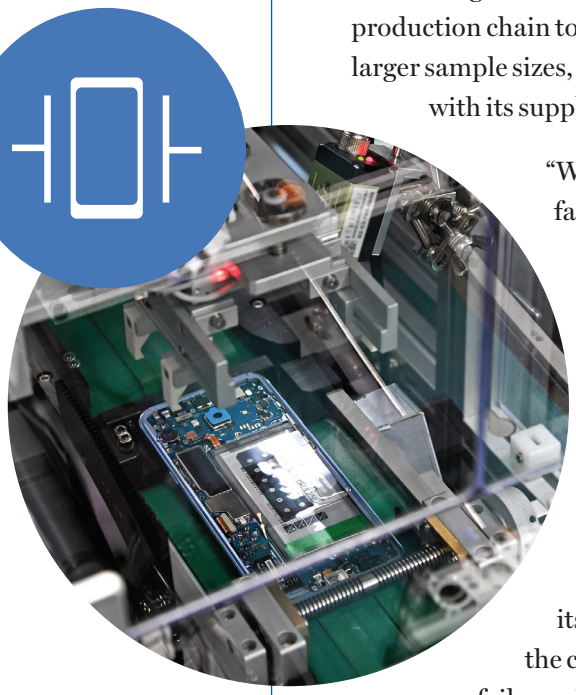
Gold says that Samsung "got a bloody nose" from the Note7 battery incidents, which in his opinion prompted a response completely unique for manufacturers of finished devices. "They looked at failures, and tried to determine exactly where in the process those failures occurred," he says.

Determining the root cause was only half the battle. From there, Samsung worked on creating a new, comprehensive testing protocol based on the findings of their investigation. Gold says this was perhaps made more pressing for Samsung because it is one of the few smartphone manufacturers that actually have more control of its production processes. "Figuring out which tests should be conducted is the important piece," he says. "If you are building a device, this is what you should check."

The electronics giant developed this testing regime in consultation with an independent Battery Advisory Group. This group includes four experts—three from academia and one from the industry—who now regularly review Samsung's processes and responses to issues related to battery materials, design, and dynamics.

"We have made significant investments in order to cast the widest possible net [to find solutions]," says Justin Denison, senior vice president, Product Strategy and Marketing at Samsung Electronics America. The company has custom-built mass-scale testing facilities, which helps its engineers detect production issues and validate the quality and safety of devices before they are released. Samsung is not only achieving its primary goal of boosting product quality, but is seeking to elevate the manner in which the entire industry manages fault monitoring and quality control.

Samsung's enhanced safety program includes expanded testing processes throughout the production chain to ensure that devices and all device components are safe. It is now using larger sample sizes, often involving lots in excess of 100,000 units, and increasing integration with its suppliers' testing processes.



"We have increased the sampling size of many of the tests by a significant factor," says Dr. Tae Moon Roh, executive vice president, head of Hardware R&D of Samsung Electronics Mobile Communications Business, during a recent tour of Samsung's smartphone factory in Gumi, South Korea.

Millions of lithium-ion batteries flow through Samsung's global supply chain every month. "We realized we had to enhance our processes, and find new methods, if we were to create a system that could embrace both static detection and be dynamically responsive at such scale," says Dr. Roh.

Samsung also undertook a far-reaching initiative aimed at increasing its ability to mitigate the risk of failure. This complex project has increased the company's ability to systematically and comprehensively detect battery failures. More importantly, it has also created an immense volume of data on the phenomenon of smartphone battery failure itself. In other words, their operational scale has provided Samsung with an invaluable knowledge base that may help accurately predict and proactively mitigate production issues yet to come and share those findings across the industry.

An Industry under Pressure

Samsung's battery challenges were set against a backdrop of growing speed and complexity in the smartphone industry. The intensity of this production environment placed extraordinary pressure on all participants throughout the supply chain.

The smartphone product cycle—as with all consumer electronics in general—has to move at an increasingly fast pace because of several factors:

- the endless race all manufacturers run to maintain competitiveness;

• advances in the capabilities of software, application, and mobile-network infrastructure; and

• the constantly increasing demands of consumers for new and improved smartphone features and performance.

"The pressure this places on battery and component producers has meant tolerance for failure has decreased [massively across the industry]," says Gerbrand Ceder, professor of materials science and engineering at the University of California at Berkeley, and a member of the Battery Advisory Group. By this, he means that Samsung and players in the smartphone world not only have incredibly small windows of opportunity to detect failures in the production system, but continuous evolutions in technology and form factor trends are making those windows smaller.

Added to these market dynamics are the fundamental issues of energy and material science. These include the constant tension between the density of a battery (the composition of electrode and other active materials within a lithium-ion battery) and its power. While there is not a strict comparison to Moore's semiconductor law for batteries, Ceder believes the average energy density of smartphone battery has essentially doubled over the last decade, to an average of 700 watt hours per liter.

"The battery is, effectively, the most important component of a smartphone," observes Bookeun Oh, vice president, Battery Group of Samsung Electronics, "and this makes production safety very important." He points out that the various performance attributes of lithium-ion battery—traditional ones such as longer life, as well as evolving attributes such as flexibility—play an increasingly important role in design and product strategies. Thus, the battery gives smartphone makers "multiple ways to realize innovation," he says. Oh notes Samsung is currently focused on developing batteries with longer life.

The confluence of increasingly powerful batteries, made up of increasingly complex materials, placed within increasingly thinner devices with increasingly bigger screens may add stress to a smartphone maker's battery fault detection and management processes, but not its production risks. "The increase in battery density and its inherent failure risk, for instance, do not have a linear relation," says Roh.

An Unsurprising Surprise

While neither changes in market forces nor material science were the distinct cause of the Note7 battery failures, this constellation of industry and technological dynamics provides an important context. The battery is an increasingly important aspect of future product strategy and design. Emerging battery technology innovation will focus on two factors. The first is, quite simply, longer battery life. The second is flexible new requirements such as new materials, shape, design, or new market demands. Samsung is currently focusing on battery life, which has a direct impact on user experience and benefit.

The constant evolution of these trends has meant a level of stasis in the production risk profile. Technology advances on the production side and the product side have balanced each other out. "Technological advances have allowed overall risk levels to remain the same," says Roh.

Ceder affirms these important observations. "Fault management can be addressed one of two ways: you can either create a zero-fault environment…or design your operating environment for failure and vigorously fix designs and processes when failures are caught." Zero-fault conditions, he adds, are "practically impossible to achieve." This is particularly true in a production environment of the size Samsung and other major producers manage.

Samsung's response to the challenge was to further enhance their quality assurance processes—casting a wider net, and improving systems to detect and catch those failures before devices ever reach consumers. This has meant both designing new and enhanced tests and increasing the sample sizes of devices tested, as well as folding in the macro-view of the Battery Advisory Group.

More Tests, More Collaboration

Samsung's efforts to revamp its testing processes represent significant investments in time, material, and production. Two major factors have helped the company move quickly and efficiently. For one, batteries are not a substantial cost center in the overall equation of smartphone production, despite their significance to the phone. They are a critical component, but not one of the more costly components.

A second and more profound factor was determined in the nature of smartphone battery production. While massive in scale and highly automated, there's an unmistakable level of specificity. "Each battery produced for a particular smartphone model is a highly customized affair—and every battery supplier and every smartphone maker [consequently] redesigns the battery for every product model," says Denison.

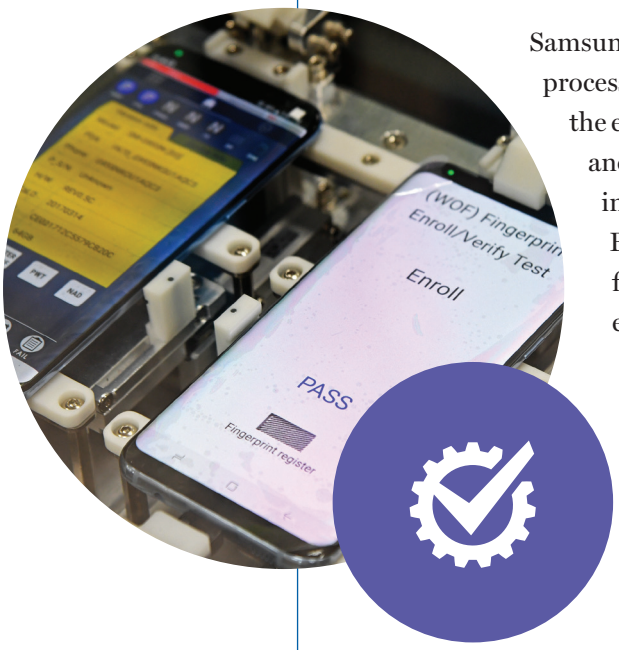
"What our investigation taught us is we have to innovate in our processes as well. Whether it's in design, engineering, or quality assurance, we're constantly looking for areas in which we can improve," he says.

Samsung was able to leverage the significant change-management expertise already baked into supply chain operations to enhance its safety-management processes. Samsung's 8-Point Battery Safety Check, which incorporates eight separate and distinct tests (see sidebar, "8-Point Battery Test", page 9), not only institutionalized a series of reviews throughout the supply chain. It also standardized multiple tests involving large-scale sampling of completed devices. This strategy appears unique to the industry.

Five of these tests, including a durability test subjecting batteries to punctures and overcharging, were already part of Samsung's safety regime. The company has enhanced these tests with increased frequency and additional testing stages across the production process: pre-production, "in-line" assembly, and post-production inspection.

Samsung has also added three entirely new battery stress tests: a charge and discharge test conducted three separate times at each production stage; a total volatile organic compound test, and something called the Accelerated Usage Test involving "intensive exaggerated usage scenarios," says Denison.

The process starts by ensuring incoming components meet Samsung's quality requirements. It performs six tests on all incoming lots of batteries, which typically involve anywhere from 10,000 to 15,000 units, and half of the tests conducted at this stage are destructive tests. If even a single failure is observed during this testing, the entire lot of batteries will be sent back to the supplier, and Samsung and the supplier will evaluate the root cause of the battery issue.



Samsung made these tests smaller and more experimental to test the testing process itself. There are about 100 Samsung mobile engineers dedicated to the eight-point testing process across its facilities globally, supplemented by another 100 task force team members and partners who oversee the interfaces between the various tests and the overall production process. Eight-point tests are conducted on every battery lot, over a three- to five-day period, for every Samsung mobile phone line, consistently across every manufacturing facility globally.

The entire 8-Point Battery Safety Check testing process is governed by a software algorithm. Many of the tests are seamlessly integrated into the highly automated product assembly line itself. Three tests are conducted at discrete, operator-assisted stages along the brief journey each smartphone takes from base-board to completed device (see chart).

The other tests, while co-located with the production process, are conducted in discrete stations. Some of those stations are designed to facilitate "deep dive" investigations of sample sizes of 150 batteries, through hand-checked visual and x-ray tests. Other stations subject batteries to onerous, and ultimately destructive, overheating and puncture tests.

More is Much More

Samsung implemented additional tests along its production chain as well. There are more and larger sample sizes: 10 to 20 times larger than a year ago. Some tests consume as much as three percent of Samsung's monthly battery inventory.

The size of Samsung's response has convinced analysts and consumer rights advocates that the company takes its fault detection capabilities seriously. But Samsung's larger capability for fault detection in and of itself does little to improve the ability to predict them, or to innovate in ways that minimize future occurrences.

What Samsung's efforts—testing at a level of quality and scale far beyond industry requirements—have culminated in may be the world's largest collection of data on in-device failure and performance issues. This unprecedented dataset helps Samsung to more accurately and

efficiently adjust battery manufacturing processes and materials used to prevent future battery failures, and advance the field of battery technology.

"Every single battery that flows through our supply chain has a QR code [quick response code, or bar code] on it, to allow us to monitor the quality and performance of each battery going through our device production process," says Denison. This data is then added to a massive database. The scale of the testing allows for a data pool that could transform a wide detective net into a predictive tool.

"There is an unprecedented amount of information and insight that can be generated from the manner and scale with which Samsung is analyzing in-device charging activities," says Ceder.

Samsung realizes that this data resource is not (yet) an asset in and of itself. "We are building a meaningful database with a goal to develop a fully predictive fault management process," says Roh. He believes that this tipping point is still two to three years away.

It will be a busy few years to get to that point. "Building probability is the most important factor," says Roh. He describes creating that probability capability for Samsung's battery safety management program as the combination of two linked data science processes—creating statistically significant sample sizes for device performance conditions and generating massive amounts of probability data on battery attributes, materials, and inputs.

The rigorous testing conditions reflect the effects of long usage, disassembly, and distress on a battery's density, its electrodes, separators, and electrolytes. Each time a wedge of metal perforates a lithium ion battery during a test scenario, Samsung is not testing whether or not the battery will crinkle in half and fail—it most certainly will. It's gathering one more data point on the absence of an explosion, and the specific reactions volatile materials have to crushing.

Over the long term, Samsung believes it is building a resource the company can leverage throughout the industry as a whole. Roh estimates that millions of lithium ion batteries flow through the world's smartphone supply chain every year. "Samsung is constantly increasing its volume of new sample-testing data, and if this is applied [to an even larger sample pools], there is the potential to determine optimal battery quality [for the industry as a whole]." he says.

Samsung believes that the depth and breadth of its safety check process, and more importantly the depth of data it is generating on battery failure processes, is a resource itself and informs a set of best practices the company plans to share with the industry. The degree to which this is an achievable aspiration, however, depends upon "the extent to which the rest of the industry—producers and consumers—are willing to take that on and absorb the costs of doing so," says Gold.

He likens this project to the Artificial Intelligence (AI) industry's growing reliance on big data. "What you learn in AI is directly related to how much data you have. It's an iterative failure process," says Gold. "If the industry gets together on building a common framework and data resource for failure management, they are going to continuously learn a lot more."

This iterative data development process reveals the core of Samsung's battery safety management philosophy. It is intentionally a continuous work in process. Despite the specificity implied in its name, "the 8-Point Battery Safety Check is not a fixed system," says Roh. It is instead the current manifestation of Samsung's commitment to multi-point testing, and the process is purposefully designed to evolve over time as technology, materials, and consumer demands change.

Product and component failures are inevitable in any manufacturing process. Producing complex electronics in large numbers allows for the ability to replicate specific incidents. With smaller production volumes, it may be more difficult to distinguish between legitimate issues and one-off failures. In the wake of the Note7 recall event, though, Samsung turned the size, scale, and complexity of its supply chain into a tangible asset.

To simply build a better engine for detecting a needle in a haystack is not in and of itself revolutionary. Nor is it even truly possible. By increasing the number of tests and the scale of the related sample sizes, however, Samsung has developed an innovative solution for failure mitigation that will have massive ramifications across the entire industry. Samsung's response has created a quality control collaboration platform in which the entire industry may participate and from which it may benefit. •

8-POINT BATTERY TEST

Once the battery lot is approved for production, additional testing is performed on the batteries and devices as they move through the production process, including three tests in the production stage: a visual inspection, Delta OCV test, and TVOC test. Samsung also conducts a completed device check after the initial production phase, which includes a massive charge and discharge test and accelerated usage test. Samsung runs individual tests at various stages of production and is able to collect data from the tests throughout the process.

Samsung's quality control and testing processes are increasingly linked to those of its battery suppliers and subcontractors. A fundamental component of the eight-point framework is a reliance on deep collaboration between Samsung's incoming quality control teams and those of its suppliers.

One of the final tests in the eight-point testing sequence leaves a distinct impression as to the scale required for this massive undertaking—and demonstrates the long-term benefits that such extensive testing will accrue. The facilities for the Accelerated Usage Test clearly live up to the name of the test. In the Gumi facility, thousands of sampled phones are arrayed in racks in a metallic heat-shielded chamber, while 30 different usage scripts are transmitted at random to each device. They're also running multiple applications simultaneously in various combinations, for extended periods of time. Watching this test unfold is like watching a massive, robotic, steel-encased synthesizer performing at a mellow concert. Each rack erupts with stochastic bursts of activity—a camera flash here, a haunting lick from a music video there. All performance data is gathered by a picocell (a small mobile phone base station) in the corner of the room, and fed into Samsung's ever-expanding data lake.

SEE GRAPHIC, NEXT PAGE.

Durability Test
More frequent battery testing, including overcharging tests, nail puncture tests and extreme temperature stress tests

ENHANCED

Visual Inspection
Visual inspection of each battery using standardized and objective criteria

ENHANCED

X-Ray Test
Examine the inside of the battery to look for abnormalities

ENHANCED

Charge/Discharge Test
The batteries undergo a large-scale charging and discharging test

NEW

TVOC Test
Make sure there is no slightest possibility of leakage of the battery component of the completed device

NEW

Disassembling Test
Take apart the battery to assess its overall quality, including examining the condition of the battery tab welding and insulation tape

ENHANCED

Accelerated Usage Test
Intensive test simulating heavy consumer usage scenarios over an accelerated timeframe

NEW

△OCV Test
Monitor for any changes in voltage throughout the manufacturing process, from component level to completed device (OCV: Open Circuit Voltage)

ENHANCED

PRODUCED BY

MIT Technology Review CUSTOM

About MIT Technology Review Custom

Built on more than 115 years of excellence in technology journalism, MIT Technology Review Custom is the arm of global media company MIT Technology Review that creates and distributes custom content. Our turnkey solutions include everything from writing, editing, and design expertise to multiple options for promotional support. Working closely with clients, our expert custom-editorial staff develops a range of high-quality, relevant content, delivering it to users when and where they want it—in digital, print, online, and in-person experiences. Everything is customized to fit clients' content marketing goals and position them as thought leaders aligned with the authority of technology that matters.

www.technologyreview.com/media