Sound Familiar?

SURPRISE!

I bought Fitbits for the whole family.

YOU JUST WEAR ONE ON YOUR WRIST OR BELT, AND IT COUNTS THE NUMBER OF STEPS YOU TAKE IN A DAY.

WE’LL MAKE IT A COMPETITION!

YOU’RE ON!

FEWEST STEPS WINS, RIGHT?

1,373 STEPS

2,604 STEPS

4,011 STEPS

5,000 STEPS!

27,983

94,000 STEPS?? HOW DO YOU GET 94,000 STEPS IN ONE DAY?

YEAH!

THE SECRET IS GRIT, DETERMINATION AND MAX SPIN.

YOU TOOK A FITNESS CLASS?

I ACCIDENTALLY WASHED MY FITBIT WITH MY JEANS

I’M TOTALLY TRYING THAT.

WALT!
Wearable Electronics are hot, hot, hot!

Figure: Global Smart Wearables Hardware Revenue ($m) Split by 8 Key Regions 2018: $19 Billion

Source: Juniper Research
Wearables Market

BI INTELLIGENCE

- Smartwatches
- Fitness Bands and Other Activity Trackers
- Rest of Wearables Market

Millions Of Units Shipped Annually

Wearable Electronics Applications

World of Wearable Technology Applications:
Towards Function With Style
Apple Watch

Expect 40-42 million units to be sold in 2015

Why????

The typical iPhone user looks at his phone 110 times a day.

“Behavioral Shift”

100 apps at a cost of $350

Other apps: Pinterest, city mapper, BMW, Honeywell (house temp), Lutron (home management), Nike, American Airlines, Starwood Hotels
Apple’s Not Alone

“Even though wearables are relatively new in terms of market maturity, it is clear that the market, for example the smart watch in particular, will be – as per smartphones – a somewhat crowded affair.” – Nitin Bhas, Juniper Research (link)
Yet an alarming 83% of consumers have difficulty using their intelligent devices.

Owners of wearable health services:

- 24% said the devices were too complicated to use.
- 22% said their wearables didn't set up properly.
- 21% said the devices don't work as advertised.
Wearable Users

- Survey finds that an especially high % of consumers have challenges using wearable health devices
  - 24% said the products are too complicated to use
  - 22% said they did not set up properly
  - 21% said they don’t work as advertised

How do they select?

- Reliability is not on the list
  
  “Trusted brand” is as close as it gets to quality or reliability

![Diagram showing factors in purchase decision for intelligent devices]

**FIGURE 4 | FACTORS IN PURCHASE DECISION FOR INTELLIGENT DEVICES**

Which of the following factors have been or would be the most important when making your decision to purchase an intelligent device?

- **Ease of use**: 33%
- **Features and functionalities**: 29%
- **Trusted brand**: 28%
- **Design – look and feel**: 18%
- **Compatibility with existing owned devices**: 16%

**BASE DEFINITION:** All respondents owning or planning to buy an in-vehicle entertainment system, a wearable health device, a wearable fitness monitor, a home surveillance system, a smart thermostat or a smartwatch in the next 12 months (n=9110)

Samsung

- Issues with GearFit
- Not compatible with many cell phones
- Failure to connect
- Poor apps
- Finding new apps very difficult

- Launched prematurely
Players

Fitness and Wellness

Infotainment

Healthcare and Medical

Industrial & Military

Source: IMS Research, World Market for Wearable Technology - 2012
Wearable Tech is Everywhere.....
Wrist Wallets

- The wallet is migrating to the phone
- Apple is leading this technology
- Security issues still abound
- Lots of new companies jumping in in 2015
- Batteries in belts and wristbands, sensors in shoes
New Applications

NeuroOn: World’s First Sleep Mask for Polyphasic Sleep

FreeWavz: Smart Earphones With Built-In Fitness Monitoring

runScribe: Wearable for the Data-Driven Athlete

Carry Less, Adventure More: Survival Belt
New Applications

Beddit Sleep Monitor

January 5, 2015

Smart Sunglasses

Montblanc TimeWalker Urban Speed e-Strap add-on to your current watch
Family Oriented

Disney’s MagicBand is a battery assisted RFID tag allows you to:
- Unlock the door of your Disney Resort Hotel room
- Enter theme and water parks (with valid admission).
- Check in at FastPass+ entrances.
- Connect Disney PhotoPass images to your account.
- Charge food and merchandise purchases to your Disney Resort hotel room (only available during your hotel stay).

No reliability data evident

How Wearables Intersect with the Cloud and the IoT, Joseph Wei, CPMT Wearables Workshop
Wearable GPS Tracker for Kids

TINITELL - Wristphone for kids

- 2G GSM SIM card for connectivity, to power the voice calls and GPS tracking
- Battery good for an hour’s talk time on a single charge or seven days on standby
- It’s also water resistant and sandbox proof, to ensure it’s robust enough for outdoor child’s play

Website states unit is water resistant. No other reliability information

How Wearables Intersect with the Cloud and the IoT, Joseph Wei, CPMT Wearables Workshop
Wearing the Cure

- 29.1 million people in the US with diabetes
  - 350,000 using wearable insulin pumps
- Lux Research: clinical wearable devices should surpass their consumer counterparts in revenue by 2020

Medtronic's MiniMed Paradigm Revel Insulin pump senses blood sugar in real time

Beauty and Wearable Tech:
Miss Idaho Proudly Displays Her Insulin Pump
Will We Use Health Wearables?

• $200 million went to wearable technology from investors for digital health
• 7.6 million devices shipped in just the US – a 200% increase over last year
• Linkage to insurance companies could lower costs but privacy and data protection issues need to be resolved
• However, consumers want low cost and many want their employer to cover the cost
Want to Share Your Health Data?

Figure 6: Many US consumers don’t want to share health data with friends and family. Consumers were asked what kinds of information they would share with friends and family.

- I don’t feel comfortable sharing any information about myself: 43%
- Exercise levels: 25%
- Health: 23%
- Mood/happiness level: 20%
- Weight tracking: 15%
- Dietary intake: 14%
- Sleep pattern recognition: 12%
- Daily medication intake/schedule: 12%

Fewer than 1 in 4 want to share their health information.

Source: HRI/CIS Wearables consumer survey 2014
What Do Consumers Want from Health Wearables

Figure 3: Health tops list of information US consumers want from wearables
Consumers were asked what information they want to receive from wearable technology.

- Exercise smarter: 77%
- Collect and track medical information: 75%
- Eat better: 67%
- Finding retail deals: 46%
- Controlling home appliances: 32%
- Access to entertainment: 29%
- Plugging into social media: 26%

Source: HRI/CIS Wearables consumer survey 2014
Why is Reliability a Challenge?

Everything is Hot

Figure 2. Power density trends of commercial and research systems and the Power Density Barriers.

Everything is Mobile

M2M Technology

Everything is Everywhere
“Another month, another bad experience with regard to reliability of wearable tech – this time with the Fitbit Flex. When the silicon wristband was only about a month old, it started coming apart.....”

“Did you try turning it off, and then on again? How about charging it?”

“After the first time you go through that dance, you realize it will never ever work. The failure mode is 100% catastrophic from the point of view of the user.”

http://wearabletechwatch.net/2013/09/06/reliability-is-letting-wearable-tech-down/
How Have Wearable Consumer Electronics Failed?

- **Sweat**
  - Documented in blogs that Apple iPod Nano’s have shorted out due to sweat

- **Strain relief**
  - Wearable on clothing, attached by a cord to power device, failed prematurely due to a lack of strain relief

- **Plasticizer**
  - First-generation of Amazon Kindle wiring insulation cracked/crumbled due to the use of non-optimized plasticizer formulation

- **Cyclic Fatigue**
  - Initial video game controllers experienced fatigue of solder joints on components attached to the backside of the push buttons
Terrible Wearables: Hall of Shame

- “In taking blood pressure readings, the Withings blood pressure monitor failed every time (but one), all at the same point”

- Contacts rubbing skin raw
  - Heat & sweat
    - http://www.n3rdabl3.co.uk/2014/07/lg-g-watch-charging-points-cause-injury-users/

http://wearabletechwatch.net
Terrible Wearables: Hall of Shame

- Fitbit Recalls Force Activity-Tracking Wristband Due to Risk of Skin Irritation
  - Complaints of itchy, irritated wrists
  - Allergic contact dermatitis
    - Either the nickel that's in the stainless steel part of the device
    - Or adhesives or other materials used in the strap
Terrible Wearables: Hall of Shame

- “Sunscreen melted my Nook”
  - A tiny warning on the can reads it can damage some fabrics materials or surfaces.
  - [http://bcove.me/hh5yfn26](http://bcove.me/hh5yfn26)
Pavlok: Is This a Wearable Device for You?

- Habit-forming wearable that will shock you! Literally.....
- Designed to shock the user when they do a pre-programmed bad habit
  - Wasting time online
  - Going to fast food restaurants?
  - Hitting snooze button on alarm clock
- Failure waiting to happen???
Uh Oh!!!!

- Pretty detailed approach to making your own wearable product.
  - Circuits
  - Components
    - Microcontrollers
    - Sensors
    - Actuators
  - Wireless
  - Conductive Materials
  - E-Textile Toolkits

- However, reliability is not addressed
What is Reliability?

- Reliability is the measure of a product’s ability to
  - ...perform the specified function
  - ...at the customer (with their use environment)
  - ...over the desired lifetime

- To ensure reliability, we have to think about
  - What is the product supposed to do?
  - Where is going to be used?
  - How long should it last?
What are Wearable Electronics?

- Wikipedia: “...miniature electronic devices that are worn by the bearer under, with or on top of clothing.”
  - That’s It?!

- Alternative Definition
  - Technology attached to the human body or clothing that allows the wearer to monitor, engage with, and control devices, themselves, or their social network.
What is ‘Next Generation’ Technology?
- Materials or designs currently being used, but not widely adopted (especially among hi reliability manufacturers)

Carbon nanotubes are not ‘Next Generation’
- Not used in electronic applications

Ball grid array (BGA) is not ‘Next Generation’
- Widely adopted
Next Generation Technology (cont.)

- Why is knowing about ‘Next Generation’ Technologies important?

- These are the technologies that you or your supply chain will use to improve your product
  - Cheaper, Faster, Stronger, ‘Environmentally-Friendly’, etc.

- However...
One of the most common drivers for failure is inappropriate adoption of new technologies.

- The path from consumer (high volume, short lifetime) to high reliability is not always clear.

Obtaining relevant information can be difficult.

- Information is often segmented.
- Focus on opportunity, not risks.

Sources are either marketing mush or confusing, scientific studies.

- Where is the practical advice?
Next Gen Technologies: The Reality

- Market studies and mobile phone markets can skew reality of market adoption
  - Annual sales of >100 million may be due to one or two customers

- Mobile phone requirements may not match the needs of wearable electronics

- Market studies exclusively focused on volume
  - More relevant may be number of customers
Examples of Next Gen Technologies in Wearables

- Embedded components
- Ultra-small components (i.e., 01005 capacitors)
- New substrate materials
  - Polyethersulfone, polyethylene terephthalate (PET), polyethylene naphthalate (PEN)
  - Polyimide is not a next gen technology
- Printed connections
  - Silver inks, copper inks, nanosolders, conductive polymers
- Organic displays
- Power Via Supercapacitors
“The Smaller the Better” - 0201 Ceramic Capacitors

- Based on volume, 0201 capacitors were 25% of the multilayer ceramic capacitor (MLCC) market in 2010

<table>
<thead>
<tr>
<th>Metric</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>0402</td>
<td>01005</td>
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<tr>
<td>0603</td>
<td>0201</td>
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<tr>
<td>1005</td>
<td>0402</td>
</tr>
<tr>
<td>1608</td>
<td>0603</td>
</tr>
<tr>
<td>2012</td>
<td>0805</td>
</tr>
<tr>
<td>3216</td>
<td>1206</td>
</tr>
</tbody>
</table>

MLCC Annual Production ~0.5 Trillion

Metric | English
--- | ---
0402 | 01005
0603 | 0201
1005 | 0402
1608 | 0603
2012 | 0805
3216 | 1206
0201 Ceramic Capacitors: The Reality

- Actual high usage applications
  - Ultra small modules (primarily hearing aids) / high frequency

- Major users were limited to approximately 8 to 10 high volume companies in very benign environments and very limited lifetimes

- Attempts to integrate 0201 capacitor technology into more demanding applications, such as medical implants, resulted in quality issues, unexpected degradation, and major warranty returns
Why Care About Reliability? A Warning Lesson for Wearables

- “Durability”
- Case Study: Compact Fluorescent Lamps (CFLs)

Market Share has Dropped by >25%
CFL Reliability: Perception and Reality

- Prof. Siminovitch of UC – Davis has identified three (3) areas of dissatisfaction
  - Color quality
  - Dimming
  - Product longevity

- Rensselaer Polytechnic Institute (RPI) found early failure rates of CFLs between 2 to 13 percent
  - Returns higher in thermally challenging environments (reflectors, high switching)
  - Indications that power supplies play a major role in failures

Numerous other websites / blogs have reported issues with CFL reliability


Will LED Light Bulbs Best Your CFLs and Incandescents?, Popular Mechanics, August 4, 2010,
Ensuring Wearable Electronics Reliability

- DfR at Concept / Block-Diagram Stage
  - Specification creation

- Part Selection
  - Derating and uprating

- Design for Manufacturability
  - Reliability is only as good as what you make

- Wearout Mechanisms and Physics of Failure
  - Predicting degradation in today’s electronics
Bringing it All Together

- Two key specifications important to capture at concept/contract stage that influence reliability

Reliability expectations

Use environment
Reliability Goals

- Identify and document two metrics
  - Desired lifetime
  - Product performance

- Desired lifetime
  - Defined as when the customer will be satisfied
  - Should be actively used in development of part and product qualification

- Product performance
  - Returns during the warranty period
  - Survivability over lifetime at a set confidence level
  - MTBF or MTTF calculation should be primarily an administrative or marketing exercise (response to customer demands)
What is the desired lifetime of wearable electronics?

**Rough equivalents:** Clothes, shoes, watches, glasses, cell phones

- Clothes: ??
- Shoes: 3 months to 5 years (600 miles)
- Watches: 3 to 20 years
- Glasses: 2 to 5 years
- Cell phones: 12 to 36 months

With a new technology, there is an opportunity to influence expectations
Product Performance: Warranty Returns

- **Consumer Electronics**
  - 5-25%

- **Low Volume, Non Hi-Reliability**
  - 1 to 2%

- **Industrial Controls**
  - 500 to 2000 ppm (1st Year)

- **Automotive**
  - 1 to 5% (Electrical, 1st Year)
  - Can also be reported as problems per 100 vehicles
Identify and Quantify Failure Inducing Loads

- Temperature Cycling
  - $T_{\text{max}}, T_{\text{min}}, \text{dwell, ramp times}$
- Sustained Temperature
  - $T$ and exposure time
- Humidity
  - Controlled, condensation
- Corrosion
  - Salt, corrosive gases (Cl2, etc.), UV
- Power cycling
  - Duty cycles, power dissipation
- Electrical Loads
  - Voltage, current, current density
  - Static and transient
  - Electrical Noise
- Mechanical Bending (Static and Cyclic)
  - Board-level strain
- Random Vibration
  - PSD, exposure time, kurtosis
- Harmonic Vibration
  - G and frequency
- Mechanical shock
  - G, wave form, # of events
Field Environment: Body & Outdoor Temperatures

- Maximum temperatures likely not a significant concern
- Typically far below ratings

However, very cold temperatures (below -20C) could be a challenge
- Especially in combination with a mechanical load

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Avg. U.S. CLIM Data (%)</th>
<th>Avg. U.S. Weighted by Registration (Source: Confidential)</th>
<th>Phoenix (hrs/yr)</th>
<th>U.S. Worst Case (hrs/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>95F (35C)</td>
<td>0.375%</td>
<td>0.650%</td>
<td>11% (948)</td>
<td>13% (1,140)</td>
</tr>
<tr>
<td>105F (40.46C)</td>
<td>0.087%</td>
<td>0.050%</td>
<td>2.3% (198)</td>
<td>3.8% (331)</td>
</tr>
<tr>
<td>115F (46.11C)</td>
<td>0.008%</td>
<td>0.001%</td>
<td>0.02% (1.4)</td>
<td>0.1% (9)</td>
</tr>
</tbody>
</table>
Field Environment: Mechanical

- **Vibration**
  - Not typically affiliated with human body, but outliers can occur (especially with tools, transportation)
  - Examples: Jackhammer, reciprocating saw
  - Have induced failures in rigid medical devices

- **Mechanical Shock**
  - Drop loads can reach 1500g for mobile phone (some OEMs evaluate up to 10,000g)
  - Likely to be lower for lighter wearables, but could be repeated (i.e., affiliated with shoes)

Fig. 7. Typical acceleration and pressure patterns recorded while subject was running.
Bending (Cyclic / Overstress)
- Often considered one of the biggest risks in regards to wearables
- Certain human movements that induce bending (flexing of the knee) can occur over 1,000/day

Case Study
- Some next-gen substrate materials experience a change in electrical properties after exposure to bending
- Aggravated by elevated temperature

Field Environment: Mechanical (cont.)
Corrosion: Handling / Sweat

- Composition of dissolved salts in water
  - Can include other biological molecules

- Main constituents after the solvent (water)
  - Chloride, sodium, potassium, calcium, magnesium, lactate, and urea

- Chloride and sodium dominate
  - Iron, copper, urocanate, and other metals, proteins, and enzymes are also present

- Main concern regarding sweat is as a source of chloride
Handling / Sweat (cont.)

<table>
<thead>
<tr>
<th>ID</th>
<th>Type of Exposure</th>
<th>F (μg/in²)</th>
<th>Cl (μg/in²)</th>
<th>NO₂ (μg/in²)</th>
<th>Br (μg/in²)</th>
<th>NO₃ (μg/in²)</th>
<th>PO₄ (μg/in²)</th>
<th>SO₄ (μg/in²)</th>
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<tbody>
<tr>
<td>1</td>
<td>Raw stock aluminum</td>
<td>0.00</td>
<td>2.14</td>
<td>0.43</td>
<td>0.00</td>
<td>0.26</td>
<td>1.00</td>
<td>0.07</td>
</tr>
<tr>
<td>2</td>
<td>After polish and clean</td>
<td>0.00</td>
<td>0.47</td>
<td>0.45</td>
<td>0.00</td>
<td>0.21</td>
<td>1.07</td>
<td>0.09</td>
</tr>
<tr>
<td>3</td>
<td>Handling (office environment)</td>
<td>0.00</td>
<td>14.35</td>
<td>0.49</td>
<td>0.00</td>
<td>0.41</td>
<td>1.30</td>
<td>0.10</td>
</tr>
<tr>
<td>4</td>
<td>Handling (after exercise)</td>
<td>0.00</td>
<td>25.63</td>
<td>0.39</td>
<td>0.00</td>
<td>0.41</td>
<td>0.92</td>
<td>0.09</td>
</tr>
<tr>
<td>5</td>
<td>Handling (after wiping brow)</td>
<td>0.00</td>
<td>46.61</td>
<td>0.39</td>
<td>0.00</td>
<td>0.36</td>
<td>1.20</td>
<td>0.14</td>
</tr>
</tbody>
</table>

ID:
- Chloride
- Sodium
- Potassium
- Calcium
- Magnesium
- Lactic acid
Rain & Water Immersion Challenges

- Water & rain must be addressed for wearable electronics to survive
- Some cell phone manufacturers coat the product with either a conformal coating or a superhydrophobic coating to protect the electronics
Corrosion: UV Exposure

- Ultraviolet (UV) exposure typically not sufficient to induce degradation in electronic materials

- However, combination of temperature, moisture, and UV can break polymeric chains
  - Exact combination, and specific portion of the UV spectrum, is not always well characterized

- Stress corrosion cracking has been caused by sunscreens
**UV Exposure**

**Annual UV Intensity – Global Picture**

<table>
<thead>
<tr>
<th>City</th>
<th>Latitude</th>
<th>Average Total Energy at 340nm (W/hr/m^2/nm)</th>
<th>Average Annual Total Radiant Dose at 340nm (kJ/m^2/nm)</th>
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</thead>
<tbody>
<tr>
<td>Singapore</td>
<td>1</td>
<td>426</td>
<td>1532</td>
</tr>
<tr>
<td>Paris, France</td>
<td>48</td>
<td>499</td>
<td>1796</td>
</tr>
<tr>
<td>Sao Paulo, Brazil</td>
<td>22</td>
<td>553</td>
<td>1991</td>
</tr>
<tr>
<td>Tokyo, Japan</td>
<td>35</td>
<td>570</td>
<td>2053</td>
</tr>
<tr>
<td>Guatemala</td>
<td>14</td>
<td>648</td>
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<td>Miami, FL</td>
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<tr>
<td>New York NY</td>
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<td>2381</td>
</tr>
<tr>
<td>Barcelona, Spain</td>
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<td>Melbourne, Australia</td>
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<td>Townsville, Australia</td>
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<td>743</td>
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<tr>
<td>Madrid, Spain</td>
<td>40</td>
<td>748</td>
<td>2694</td>
</tr>
<tr>
<td>LA, CA</td>
<td>34</td>
<td>767</td>
<td>2761</td>
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<tr>
<td>Phoenix, AZ</td>
<td>33</td>
<td>869</td>
<td>3129</td>
</tr>
</tbody>
</table>

Of Cities listed, Phoenix has highest avg annual exposure. Note: Model is isolated to UV. Humidity is not included.
Other Challenging Environments for Wearables

- Washer / Dryer
- Cleaning fluids
- Mud / Dust / Water
Battery Technology

Batteries for wearables will implement different materials. Will have either physical cell or chemical cell configurations. Will take on multiple form factors:
- Cylindrical
- Pouch
- Prismatic
- Thin Film

Battery category types

Physical cell
- Primary cell
  - Lithium
  - Alkali

Chemical cell
- Secondary cell
  - Lithium
  - Alkali
- Fuel cell
  - Acid
  - Li-polimer
  - Li-Zn
  - Li-metal
  - Li-MH

"Wearable Energy Sources," Materials and System Inc, IEEE Wearable Technology Seminar
Flexible Chips

FleX™ Properties & Benefits

**Flexibility.**
For integration into flexible systems or conformal on mounting of non-flat surfaces.

**Durability.**
No silicon substrate improves tolerance to both mechanical and thermal shock.

**Size.**
Ultra thin form factor is useful in multi-chip packages and 3DIC.

**Performance.**
Transistors run 50%-100% faster on FleX wafers than on full thickness wafers.

© 2012 FLEX Feb. 6-9

American Semiconductor Inc.

Flexible thin high performance chips
Processors, wireless communication
Environment (Best Practice)

- **Use standards when...**
  - Certain aspects of your environment are common
  - No access to use environment

- **Measure when...**
  - Certain aspects of your environment are unique
  - Strong relationship with customer

- **Do not mistake test specifications for the actual use environment**
  - Common mistake with mechanical loads
DfR’s Wearables Center of Excellence

- DfR can assist you with the design and development of wearable electronics with:
  - Proper test plan development - selection of appropriate test methods to assess reliability
  - Material selection and compatibility
  - Testing to ascertain reliability
    - Drop Shock
    - Exposure to sweat
    - UV exposure
    - Sherlock ADA assessment
  - Root cause failure analysis to obviate issues
Conclusions

- Wearable electronics are an exciting revolution in our engagement with ourselves and the world around us.

- However, there are clear risks
  - Wearables use new technology that hasn’t been fully characterized
  - They’ll be placed in environments not fully considered by the designers

- Results if wearable manufacturers don’t use industry best practices & physics of failure to qualify their technology:
  - Unexpected failures
  - Delays in product launch
  - Advisory notices (medical tech)
Thanks!!

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443-834-9284 (cell)
gcaswell@dfrsolutions.com