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Smart Clothing Market Analysis

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Abstract: The market for wearable technology has been slowly growing since the 1970s and has recently exploded with the popularity of fitness trackers and smartwatches. Although the wearables market is now a $28 billion per year industry[1], smart clothing represents only a fraction of that market. Unlike personal wearable devices who offer data insights to the device owner, the power of smart clothing can be best realized when companies engage both device owners for personal data insights and perform big data analysis for commercial application.

Introduction

Much like the evolution of smartphones and tablets, wearable technology has been well received by early adopters and is now poised to grow into a leader of the consumer electronics market. Wearables are devices worn on the body for extended periods of time that have advanced circuitry and independent processing capability.

Wearables are evolving as part of a growing trend to move data analysis and communication from the smartphone directly to the body. Technologists are using a combination of sensors, machine learning, and big data analysis to provide consumers more data about their bodies and lives than ever before. This emerging field of products will have a dramatic impact on human-computer interaction.

The wearables market has several categories of personal devices, all of which are worn or attached to the body. The categories include smart watches, fitness trackers, smart glasses, body sensors, wearable cameras, location trackers, gesture devices, and smart clothing. These devices serve a wide range of purposes from healthcare to lifelogging, to safety notifications. Smart clothing, or e-textiles, have conductive fibers or sensors attached to or woven into the clothing material. Like other wearables, smart clothing sends data to a secondary device where the user can evaluate the information.

Despite the rapid growth of wearable technology in fitness tracker and smartwatch categories, other categories are lacking dramatic growth. In particular, smart clothing represents less than 1% of the global wearables market.[2] The lack of expansion and adoption in this category is due to many factors:

- Technical challenges with sensor size, sensor accuracy, and device power
- Cultural challenges in data privacy, device cost, and style

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[1] "Gartner Says Worldwide Wearable Devices Sales to Grow ..." 2016. 17 Apr. 2016 <http://www.gartner.com/newsroom/id/3198018>

[2] "Gartner Says Worldwide Wearable Devices Sales to Grow ..." 2016. 17 Apr. 2016 <http://www.gartner.com/newsroom/id/3198018>

One of the largest challenges to smart clothing adoption is the lack of compelling use cases for personal electronic consumers and the market value of developing and selling devices to end users. To realize the potential of smart clothing, companies must develop products and services that provide both personal data insights to end users as well as providing big data analytics that provides and delivers commercial value to companies building it.

This research explores the development of wearable technology, the current market size of wearable technology and smart clothing, and barriers to smart clothing adoption. To best illustrate the value that big data analytics can offer commercial applications, this research explores smart clothing use cases in three market segments: professional athletics, military industry, and healthcare.

Wearables and Smart Clothing Landscape

Although the wearable industry gained momentum in the 2000s, a handful of 20th century technologies are the originators of wearable technology. From the emergence of wearables in the 1970s to the current $27B industry, wearables have evolved to a global market serving many industries.[3]

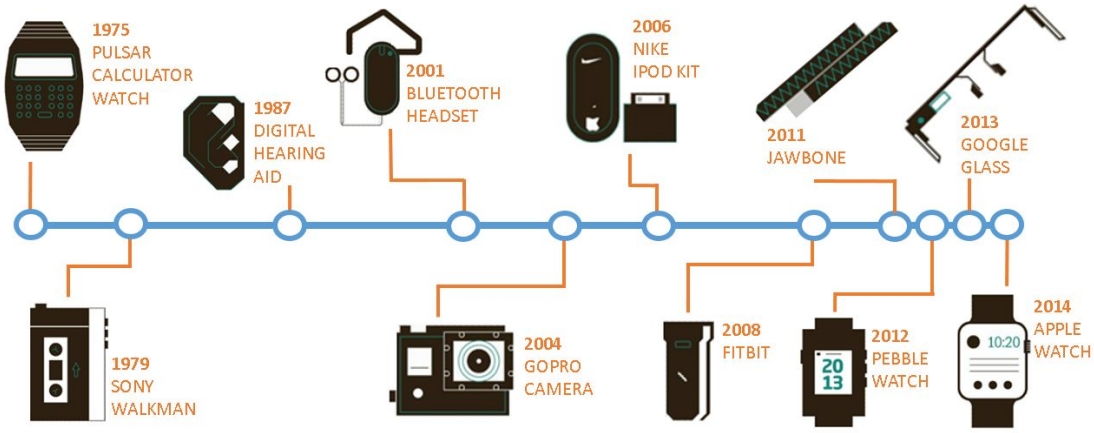
History of Wearables

If you apply the following two-part criteria for defining a wearable device, you can see that the wearable marketplace dates back to the 1970s. Wearables must be:

- Comfortably worn on the body for extended periods of time
- Independently powered and use sensors or microcomputers to process information

In addition to the notable reduction of size of the wearables device over time, from the Sony Walkman's 0.5 lb to the 0.3 ounce Fitbit Zip, the "smart" component of wearables has dramatically increased.[4]

[3] "Gartner Says Worldwide Wearable Devices Sales to Grow ..." 2016. 17 Apr. 2016 <http://www.gartner.com/newsroom/id/3198018>
[4] "Fitbit Zip™ Wireless Activity Tracker." 2012. 18 Apr. 2016 <https://www.fitbit.com/zip>



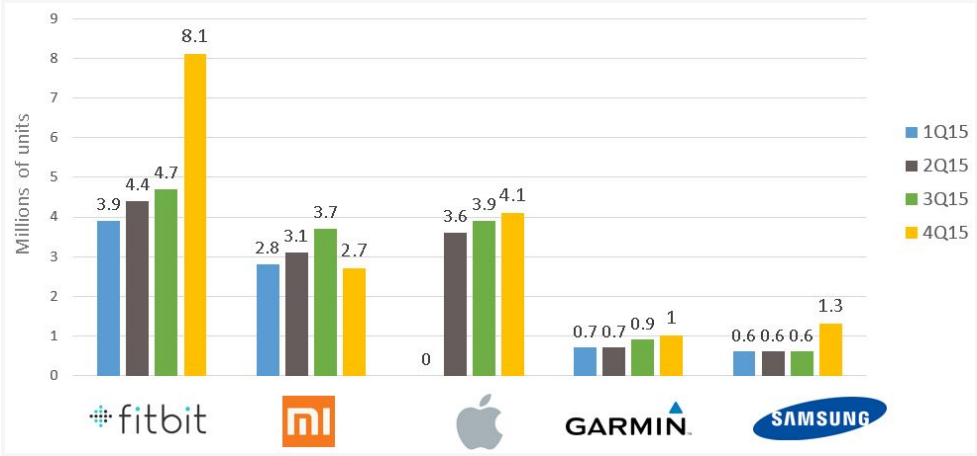
In the last 10 years, “smart” wearables have advanced in two primary areas:

- the ability to collect personal data (Nike iPod, GoPro)
- The ability to provide real-time data insights to users (Fitbit, Jawbone, Pebble)

These advancements, coupled with the ubiquity of smartphones, have primed the market for smart, wearable, personal devices such as the Apple Watch. However, notable missing from the current timeline are smart clothing products. Until recently, technology, cultural, and market conditions have not been aligned to support the adoption of smart clothing.

Wearable Technology Market Size

As evidenced by the top five manufacturers of wearable devices in 2015, the current market is dominated by fitness trackers and smartwatches.[5]

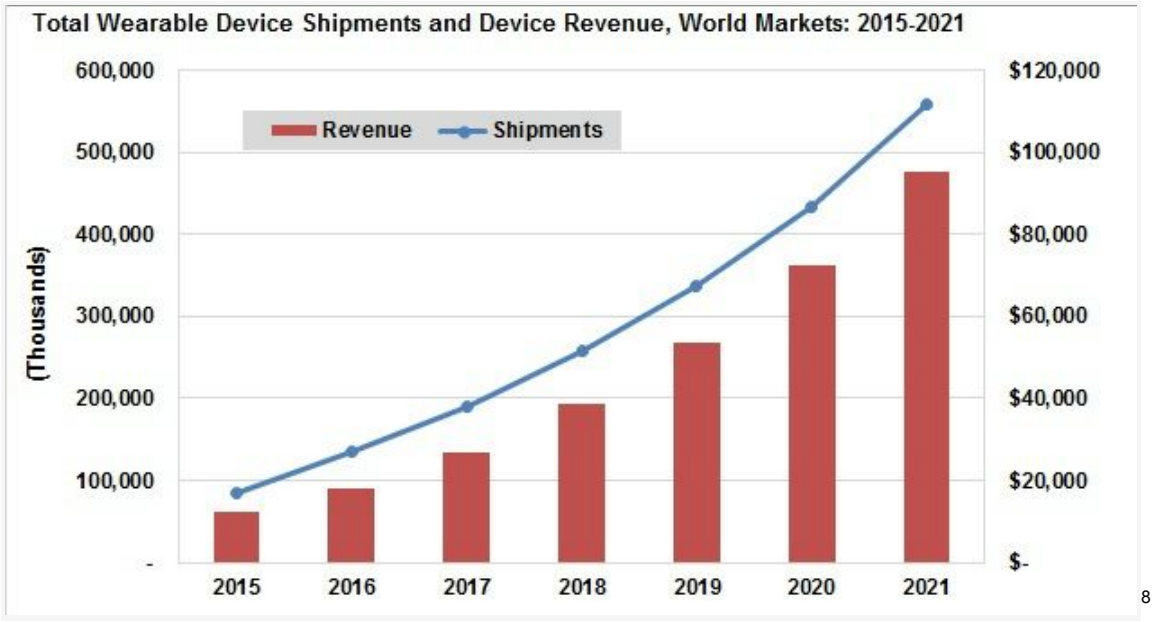


[5] "Worldwide Wearables Market Soars in the Third ... - IDC." 2015. 18 Apr. 2016 https://www.idc.com/getdoc.jsp?containerId=prUS40674715

Remarkable in the 2015 sales is the rapid growth and adoption:

- The #1 app on the iTunes app store on Christmas Day 2015 was Fitbit, indicating how popular the gift was.
- Xioami, which sold no fitness trackers in 4Q14, sold 2.7 million devices in 4Q15.
- Despite lower than predicted unit sales, the Apple Watch generated $5.5 billion in revenue. [6]

The wearables market had higher than expected growth in 2015, where unit sales have doubled since 2014. As early as 2014, the wearables market was expected to have steady growth trajectory from 17 million device shipments in 2013 to 187.12 million units in 2020 (CAGR of 34%).[7] With the recent success of fitness trackers and the emergence of the Apple Watch to drive smartwatch sales, market analysts have adjusted wearable device sales to project even greater device shipments and revenue.



[8]

[6] "Wearable Device Market Forecasts: Smart Watches, Fitness ..." 2015. 18 Apr. 2016 http://www.prnewswire.com/news-releases/wearable-device-market-forecasts-smart-watches-fitness-trackers-smart-glasses-smart-clothing-body-sensors-wearable-cameras-and-other-wearable-devices-for-consumer-enterprise-healthcare-industrial-public-safety-sports--300198196.html

[7] "Wearable Device Market Forecasts: Smart Watches, Fitness ..." 2015. 18 Apr. 2016 http://www.prnewswire.com/news-releases/wearable-device-market-forecasts-smart-watches-fitness-trackers-smart-glasses-smart-clothing-body-sensors-wearable-cameras-and-other-wearable-devices-for-consumer-enterprise-healthcare-industrial-public-safety-sports--300198196.html

[8] "Wearable Device Forecast Research Report - Tractica." 2016. 18 Apr. 2016 https://www.tractica.com/wp-content/uploads/2016/03/MD-WDMF-1Q16-Executive-Summary.pdf

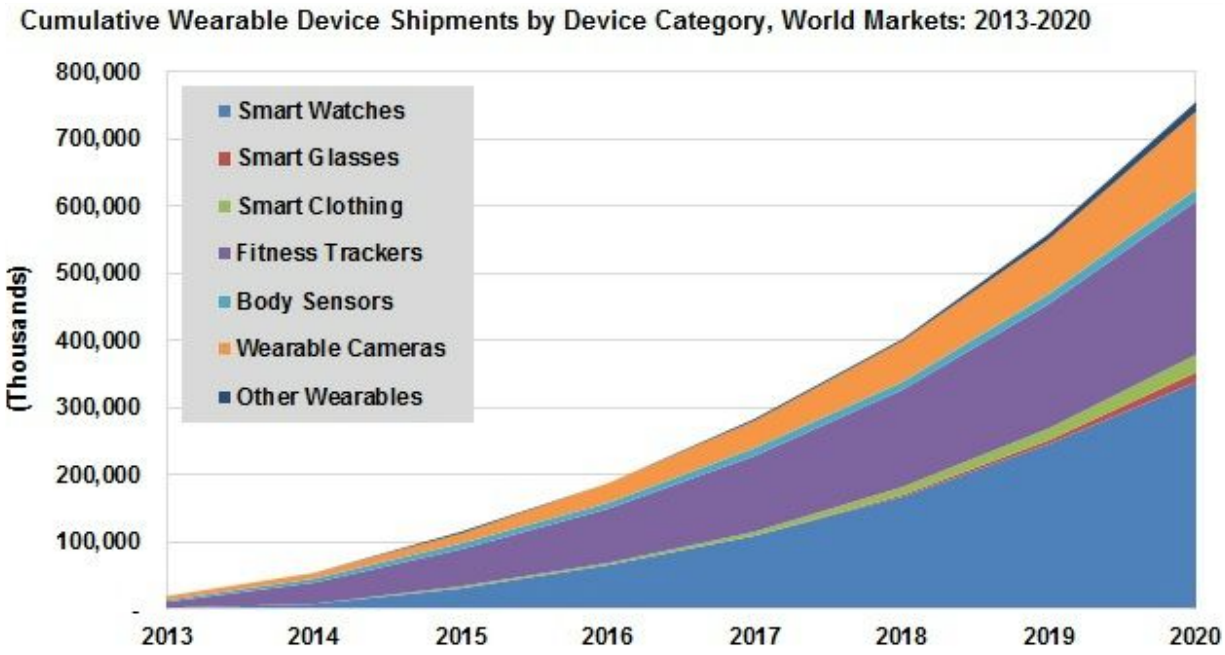
Smart Clothing Market Size

The 2015 global smartphone market is an impressive $399 billion, but pales in comparison to the clothing market with $1.2 trillion in garment sales. For 2019, this gap is predicted to widen to $520 billion smartphone sales and a whopping $2.2 trillion in garment sales.[9]

"Clothes will always outsell phones."

~ Dr. Michael Burrows, Dupont

Given the pervasiveness and continual growth of the clothing market, you would assume that merger of wearable technology with clothing would be an obvious area for market expansion. However, growth in this area is predicted to be slow with smart clothing account for less than 1% of the market.



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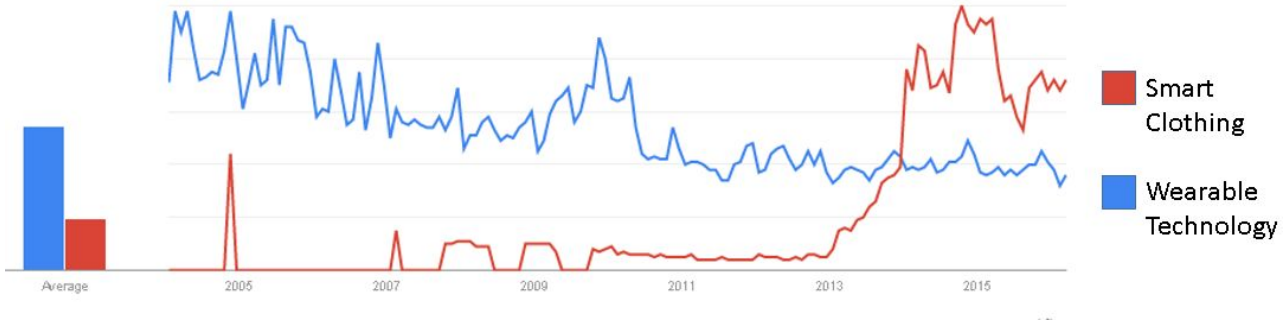
[9] "The Economic Impact of the Fashion Industry." 2015. 18 Apr. 2016 https://maloney.house.gov/sites/maloney.house.gov/files/documents/The%20Economic%20Impact%20of%20the%20Fashion%20Industry%20--%20JEC%20report%20FINAL.pdf

[10] "Cumulative Wearable Device Shipments to Surpass 750 ..." 2015. 18 Apr. 2016 https://www.tractica.com/newsroom/press-releases/cumulative-wearable-device-shipments-to-surpass-750-million-units-by-2020/

The slow adoption might be due to a lack of obvious use cases for consumers starting with a basic lack of public awareness. Although recent Google searches show “Smart clothing” increasing in popularity, users still are not largely aware of the market offerings.



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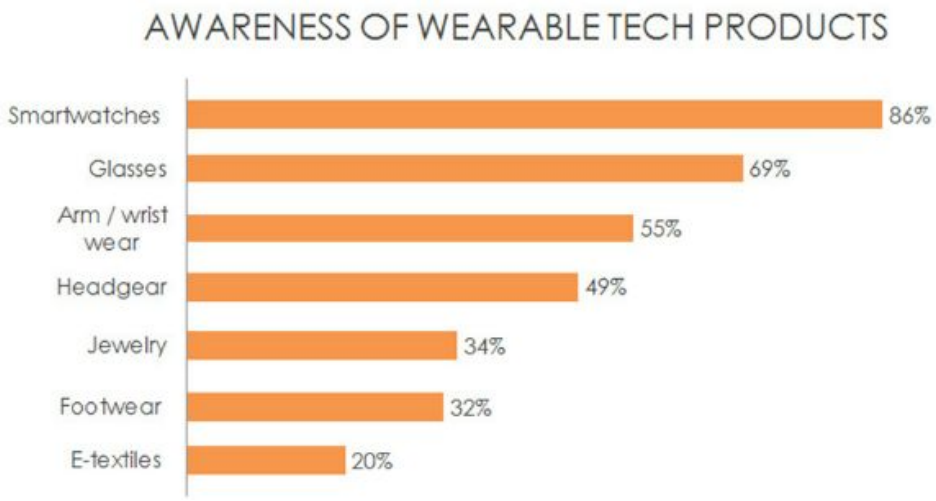
According to a recent survey of 2,407 consumers in developed and emerging markets, of wearable technologies, people are least of smart clothing and e-textile products.



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[11] "Google Trends - Trending Searches." 2011. 18 Apr. 2016 https://www.google.com/trends/hottrends

[12] "The relationship between consumers, wearable technology ..." 2015. 18 Apr. 2016 http://www.lightspeedgmi.mx/resource-center/newsletter/relationship-consumers-wearable-technology-fashion-brands/

Vendor Landscape

Considering that wearable technology is a relatively new industry, the landscape is populated with vendors across many market. Companies in the wearables market have gravitated to four primary marketplaces:

- Infotainment - real-time data transmission for entertainment
- Fitness and wellness - monitoring of activity and emotions
- Military and Industrial - real-time data transmission in military or industrial environments
- Healthcare and Medical - monitoring of vital signs and sense augmentation

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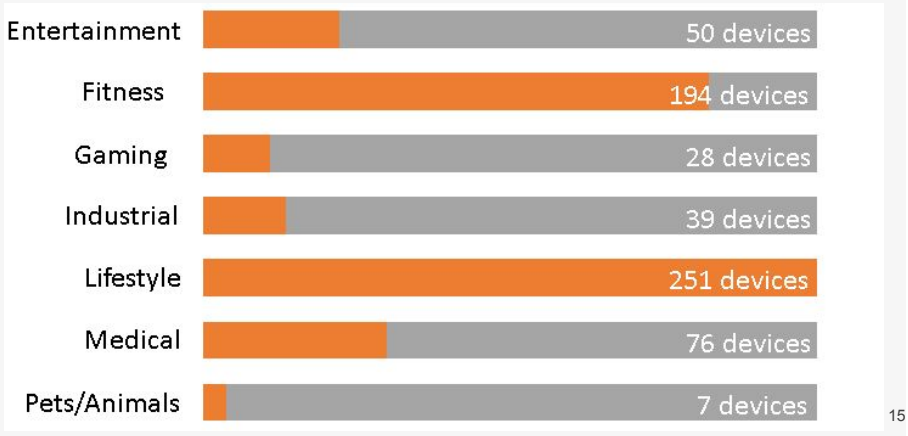
Within the landscape, several mature companies have incorporated wearables into their existing products to improve the value of their offerings. For example, Adidas now includes sensors in many of their athletic shoes and smart bands in many of their fitness clothing items. These devices have focused on the existing audience of personal consumer. Other companies have emerged with product offerings solely in the wearable

[13] "Wearable Technology – Market Assessment." 2015. 17 Apr. 2016 <http://cdn2.hubspot.net/hub/396065/file-2568104498-pdf/Blog_Resources/IHS-Wearable-Technology.pdf?t=1427903372862>

market. For example, Fitbit offers 9 products that all perform fitness tracking and gather biometric data for personal consumers.[14]

Established electronics companies (Samsung, Sony, Medtronic, Motorola) will need to compete with wearables-focused companies (Jawbone, GoPro, Pebble) to introduce attractive, affordable, and compelling products to establish dominance in this competitive landscape.

Amongst the current 423 wearable device products on the market, a majority are related to fitness and lifestyle.



The following table shows the products that are offered in the four leading market categories.

Category	Product Offerings	
Infotainment	• smart glasses • virtual reality goggles • heads-up displays	• smart watches • Bluetooth headsets
Fitness and Wellness	• smart clothing • activity monitors • fitness and heart rate monitors • pedometers	• sleep sensors • smart glasses • smartwatches • emotional monitors
Military and Industrial	• smart clothing	• heads-up displays

[14] "Fitbit Official Site for Activity Trackers & More." 2009. 17 Apr. 2016 <https://www.fitbit.com/>
[15] "Wearable Technology Database | Vandrico Inc." 2015. 18 Apr. 2016 http://vandrico.com/wearables/

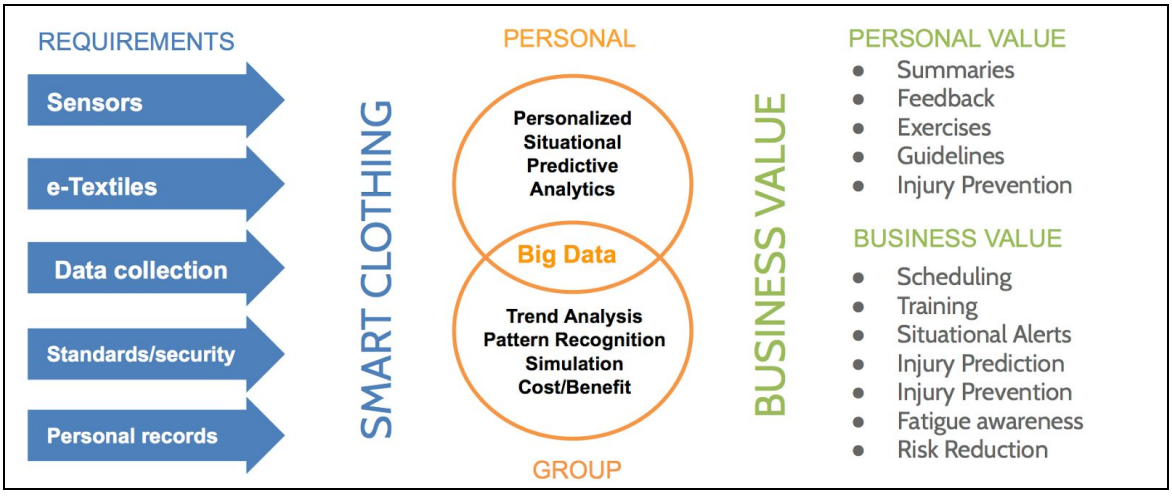
	• hand-worn terminals	• smart glasses
Healthcare and Medical	• smart clothing • biometric monitors • chemical monitors • drug delivery products	• smart glasses • hearing aids • smart watches • defibrillators

Smart clothing products are included in three of the four wearables categories, but have limited product offerings.

Smart Clothing Ecosystem Value Chain

We will look at the high-level model of how a business providing the analytics and analytics platform for the smart clothing industry combined raw materials and standards as input, adds value through various processes and is able to price and sell its products to customers.

Value chain is a term coined by Harvard Business School professor Michael Eugene Porter to denote the interrelated, and often sequential, operating activities businesses perform during the process of converting raw materials into finished products sold to customers. As products make their way through a company's value chain, each link provides another opportunity to add value that can increase profits[16].



[16] http://www.investopedia.com/video/play/value-chain/

The Inputs

- Sensors *(eg., DataGloveTM, Heddoko, Hexoskin, OMSignal, Athos,..)*
- E-Textiles *(eg., Fibretronic, ELITEX®, Feratec®, Tyvek®, ...)*
- Data Collection systems and methodologies *(eg., Bluetooth, RFID, AWS,..)*
- Standards for data sharing and security *(e.g., HIMISS, NCHHSTP)*
- The personal records of thousands of individuals

The Value provided by big data analytics

- To the individual: personalized situational and predictive analysis to improve function, protect from injury and increase longevity in profession
- To the business: trend, analysis, pattern recognition and simulation to decrease costs and increase productivity
- IoT data platforms and analytic tools *(e.g. C3 IoT, Meshify, AWS, Oracle, ...)*

The Outputs

- Training schedules and summaries
- Alerts to fatigue, injury, exposure
- Workload maximization
- Risk reduction
- Cost/Benefit Analysis

The business ecosystem within which these commercial applications lie are just part of larger ecosystems and thus there are key partnerships that will be essential to the success of this industry. These partners may differ between particular applications but could include

- Clothing manufacturers (inc. specialists), (eg., *Nike,Athos ....*)
- Insurance providers (e.g., *Cygna, Medicaid, Kaiser, etc.*)
- Unions, (e.g., *National Nurses United, National Basketball players union, etc.*)
- Big data storage providers (*e.g., Amazon AWS, Apple, Oracle, etc.*)

We assert that the value chain for both personal and commercial applications of smart clothing hinges on the data analytics platform. The future of smart clothing is not simply tracking an individual's biometrics, behavior and environmental exposure. It is more about analysing and using the data to provide both the individual and group insights. It is about combining and learning from the data, to make sense of it and creating something actually useful for users. For the individual it is about understanding where and when to make a change in behavior. For example, using situational awareness and predictive algorithms learned through analysing data from both the individual and the group, we can create personalized training programs, alert the user when injury is imminent, provide rest and nutrition guidance. For commercial applications big data analytics helps

the organizations harness their data and use it to identify new opportunities. That, in turn, leads to smarter business moves, strategic military plans and more effective teams.

Three areas where data analysis tools such as machine learning, pattern recognition and statistical methodologies can make an impact are,

1. **Cost reduction:** injury prevention, effective scheduling of teams etc.
1. **Faster, better decision making**
2. **When to purchase new system, products and services.**

Given our data analytics assertion we are discussing a platform-based ecosystem we are effectively connecting pairs of markets in a 2-sided marketplace[17].

In this case, the data analytics platform will tie two distinct groups of users together, individual professional athletes and their teams, nurses and hospitals, the individual soldier and the military. In all cases, if successful this platform will catalyze a virtuous cycle where more demand from one user spurs value and demand for the other. In more two sided markets there is an unequal pricing structure where one “side” subsidies the other. In this case the early cost of smart clothing is unlikely to be acceptable to the individual so the commercial user will be required to subsidize the individual market. This model is already evident in the Athos business model, which we will be discussing later. The challenges of this marketplace model include

- Getting the pricing balance right.
- Deciding if the space will be able to sustain multiple competitors or is it winner-takes-all. Currently the data platform and analytics landscape is fragmented.
- The threat of envelopment. Smart clothing analytics is just one area where data analytics platforms are emerging. We have the healthcare industry, retail and many other potential consumers of big data analytics. A player in the smart clothing business will have to be mindful of adjacent players

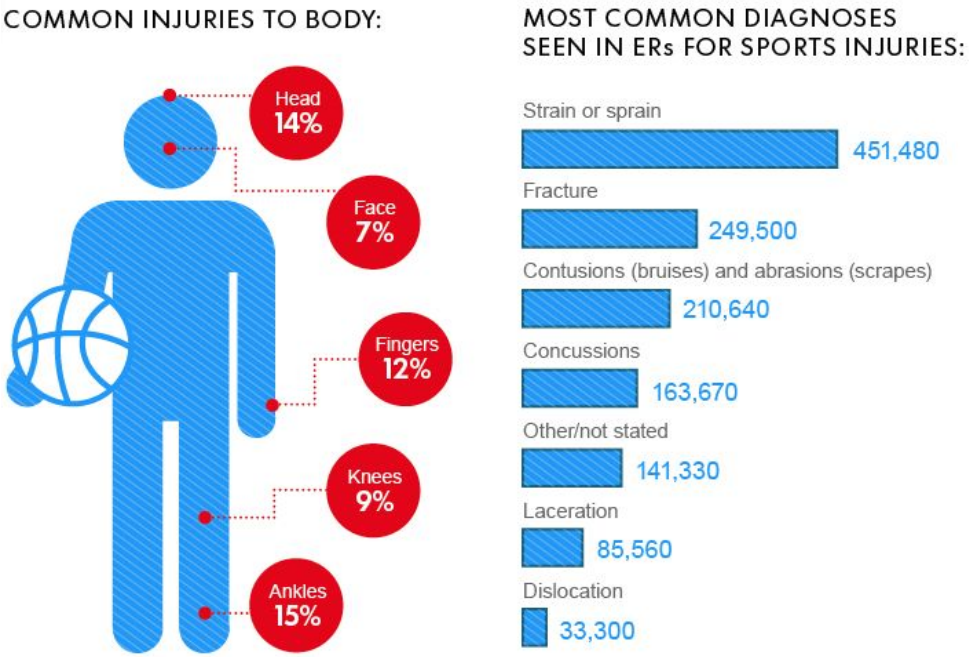
Smart Clothing Use Cases

Smart clothing products exist in the marketplace that provide consumers personal data insights in athletics, military, and healthcare categories. However, smart clothing products that go beyond personal to business and commercial applications are in their infancy. For each of the three categories, this research presents compelling commercial applications, with an analysis of the market size and opportunity.

[17] Thomas Eisenmann, Geoffrey Parker, and Marshall W. Van Alstyne, Strategies for Two-Sided Markets, Harvard Business Review, Oct 2006

Use Case: Athletics

Personal injuries are all too common for amateur athletes and sports enthusiasts. A staggering $33B[18] was spent treating sports injuries for young adults in 2014.[19]



A key insight from this data is that more than 50% of the injuries were preventable[20]. Most sports-related injuries are caused by overuse as well as a lack of proper warm up, which results in sprains and strains.

For the professional athletics industry, the cost of preventable injuries can jeopardize the success of their business. Professional athletes are among the highest paid humans on the planet. Injuries to highly-paid athletes result in significant cost, not just from player treatment and rehabilitation, but also from the costs associated with lost ticket and merchandise sales.

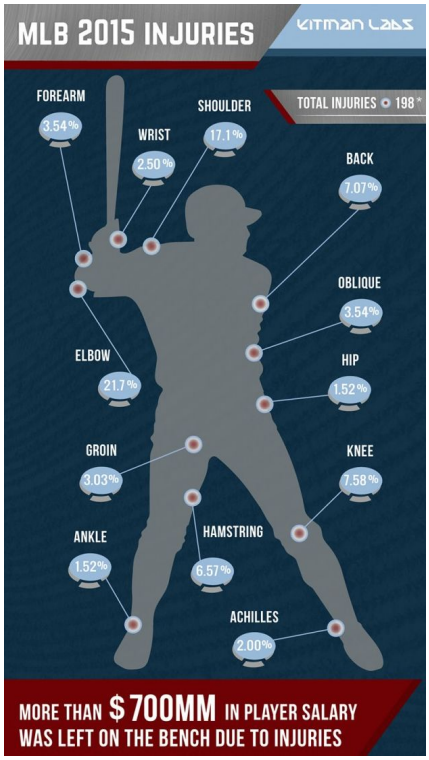
Smart clothing products have the potential to reduce or eliminate most of the preventable injuries. Further, applications that have big data capabilities to analyze data from smart

[18] 2014 report from the ASPE Office of Health Policy (https://aspe.hhs.gov/sites/default/files/pdf/76816/ib_SportsInjuries.pdf)
[19] Numerous website have this graphic including http://sportszone.work/top-youth-sports-injuries/
[20] http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3070508/

clothing might be able to predict injuries before they happen based on predictive analytics.

In 2014, star basketball player, Kobe Bryant, cost the Lakers a staggering $28 million when he suffered a fractured lateral tibial plateau and had to miss most of the season.[21] While rehabilitation costs for Bryant were significant, the Lakers' business was impacted greatly by lost ticket sales in what was the lowest attended Lakers season in more than 10 years. There are many other examples from the MLB and NBA that further cement the costs involved for professional sport injuries.

In 2015, the MLB lost $700 million in player salaries due to injuries.[22] The additional cost in terms of team wins and fallout in attendance is more difficult to calculate, but is certainly a concern to the profit-driven industry. The NBA lost somewhere in the same ballpark every year over the past 10 years[23].



[21] "Kobe Bryant Declared Out for Remainder of the ... - NBA.com." 2014. 26 Apr. 2016 http://www.nba.com/lakers/releases/140312kobebryant_outseason

[22] "Infographic: 2015 Baseball Injuries, Broken Down ... - Forbes." 2015. 26 Apr. 2016 http://www.forbes.com/sites/maurybrown/2015/10/16/infographic-breaks-down-where-700-million-in-baseball-injuries-are-at/

[23] NBA injury analysis: http://instreetclothes.com/nba-injury-analysis/

Current Athletic Smart Clothing Product Offerings

New to the wearables market, there are a few companies developing smart clothing for amateur and professional athletes. Founded in 2012 and now in Series C round of funding, Athos is currently working with the Golden State Warriors to use smart clothing sensors to optimize player performance and prevent injury.[24]

Athos makes athletic smart garments which are fully integrated with wearable technology that tracks heart rate, breathing levels, and monitor muscle activity.[25]

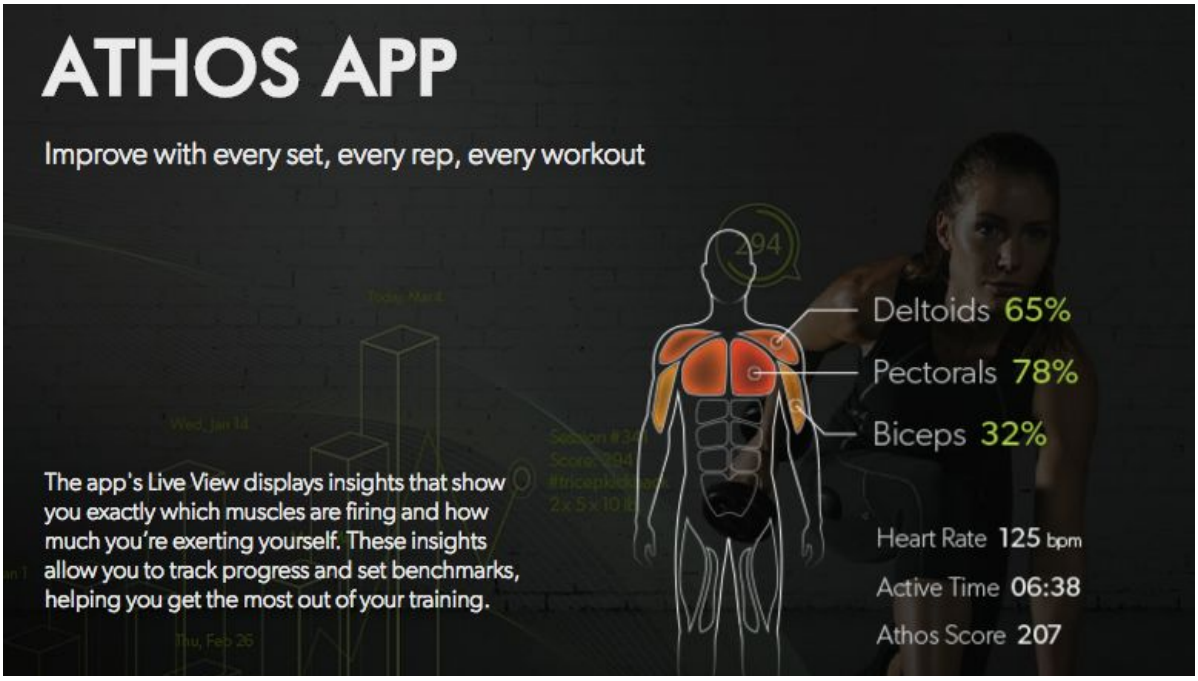


Figure: Athos App provides data around muscle engagement and core metrics.

The Warriors are using this technology to monitor athlete workouts and using the data to determine physical readiness to play the game. Over time, the collection of this data from their athletes will enable the Warriors to use big data analytics to answer key questions about their team:

- What is the most effective starting lineup for today's game?
- What player is most likely to get injured in the game and needs to be on the bench?
- What do collisions mean to the player in terms of concussions?

[24] "Athos | CrunchBase." 26 Apr. 2016 <https://www.crunchbase.com/organization/athos>
[25] "Athos - Wearable Technology for Fitness." 2013. 26 Apr. 2016 <https://www.liveathos.com/>

While much of the data that Athos provides can benefit the individual athlete, the key insights that big data analysis provides will enable the teams that choose the right players to win.

Athletics and Big Data

Michael Lewis' 2003 book Moneyball[26] detailed how statistics and data analysis are changing the professional athletics. Moneyball tells the story of how Oakland Athletics General Manager, Billy Beane, relied on statistical analysis to build a winning team instead of hiring expensive superstar players.

Today, most teams do similar big data analysis on their teams and potential recruits. During practice and game play, there are multiple streams of data coming in from cameras and sensors that monitor every aspect of the player's physical shape. This data can be directly applied to improve individual player performance, and analytics from the large dataset can also be used to form predictive analytics that improve overall team performance. Teams can leverage machine learning and data mining to analyze multiple player datasets to gain insights to help with decision making.

In March 2016, the MIT Sloan Sports Analytics Conference[27] featured multiple talks about the use of big data in the industry. While most of the datasets are around player statistics, for example, performance during the various parts of the game, competitive records between teams/players, effective positions in the field, health datasets are starting to enter the discussion.

There will always be an element of risk taking in sports, but with the support of big data analytics, the team managers will be better able to protect their players and ensure the success of their business by gauging the risk to reward ratios.

Athletics Market Size

Smart clothing consumption is expected to rise for athlete and professional sports teams over the course of the next few years.

[26] Michael Lewis - Moneyball (http://www.amazon.com/Moneyball-Art-Winning-Unfair-Game/dp/0393324818/)
[27] http://www.sloansportsconference.com

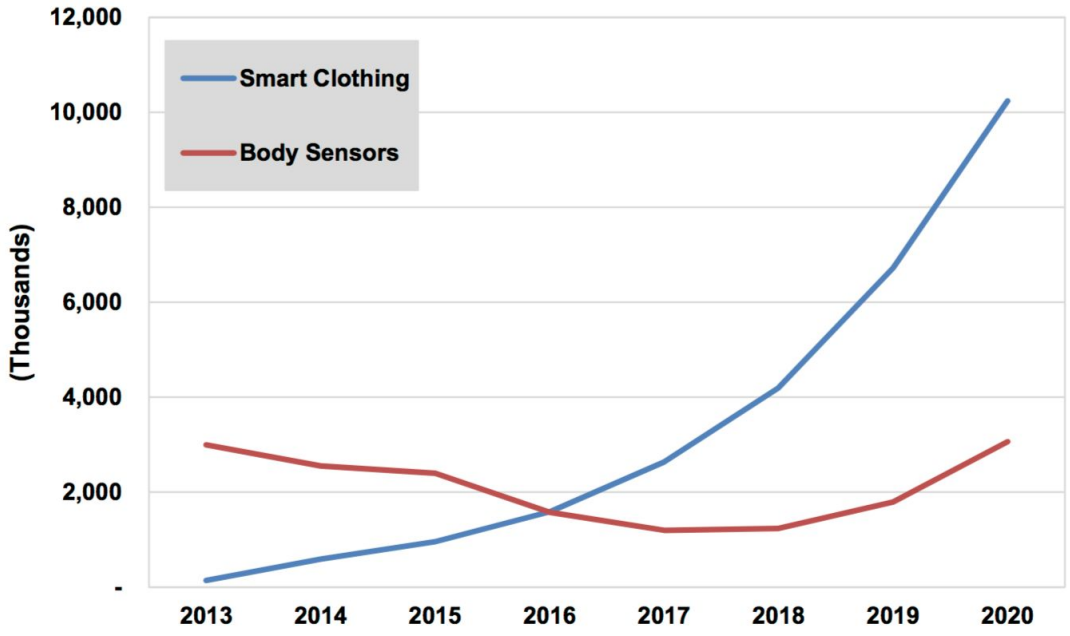


Figure: Body Sensors and Smart Clothing Shipments[28]

In 2014, 12 million sports-related injuries cost $33 billion in healthcare costs[29]. In the NEISS study discussed earlier, researchers found that 50% of the injuries were preventable. With its injury prevention data insight, the opportunity for smart clothing to address these injuries could be a $15 billion market.

In the professional sports industry, including the NHL, NBA, Premier Soccer Leagues, and MLB, player salaries are a significant portion of team investment and a significant risk of financial loss. Each of these leagues lose on average $200-700 million dollars[30]

[28] Smart Clothing and Body Sensors http://www.marketresearch.com/product/sample-8982825.pdf
[29] 2014 report from the ASPE Office of Health Policy (https://aspe.hhs.gov/sites/default/files/pdf/76816/ib_SportsInjuries.pdf)

[30] NBA http://instreetclothes.com/2014/07/17/2013-14-nba-season-injury-review/
NFL https://en.wikipedia.org/wiki/Health_issues_in_American_football
NHL http://www.thehockeynews.com/articles/55372-Injuries-cost-NHL-218M-a-year-in-lost-salaries-a-wallop-to-bottom-line-study.html
Premier League soccer http://www.dailymail.co.uk/sport/football/article-3318743/Premier-League-clubs-paying-price-injuries-racking-whopping-270m-bill-season.html

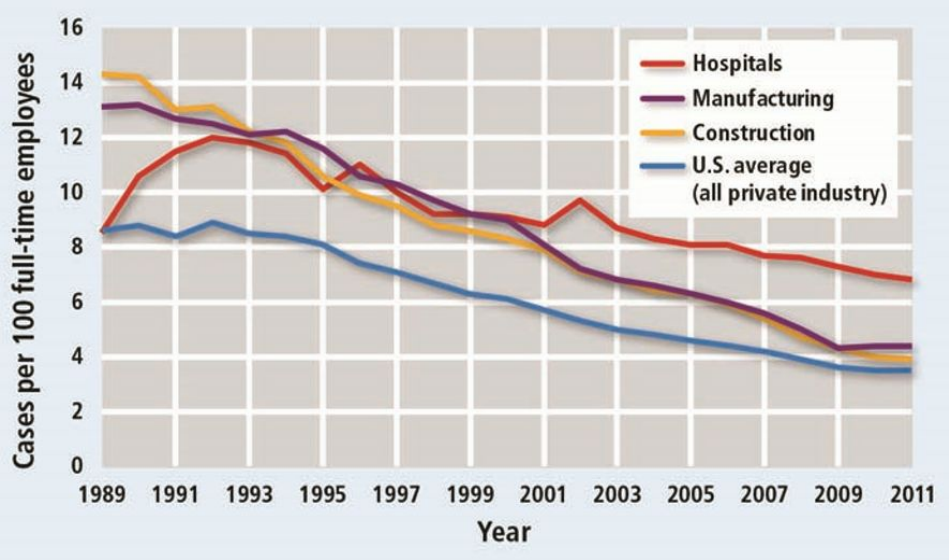
per year on player salaries. This, along with the reduced attendance and merchandise sales across all sports, could add an additional $15 billion to the market.

Increasing use of smart clothing by athletes and pro-sports teams will bring in large amounts of biometric data. The resulting insights from this data into performance improvements and injury prevention will address this potential $30 billion market.

Use Case: Healthcare

Healthcare costs have been rising at a dramatic rate for decades and one of the major components of this cost is injury to the hospital nursing staff. Because the nursing staff is the primary workforce providing patient care, a single injury has a ripple effect that magnifies the cost to the hospital. In addition to cost increases, hospitals have a moral and legal obligation to provide their nursing staff with a safe workplace.

Smart clothing is a technical solution to the problem of identifying injury prone situations and predicting catastrophic situations before they occur. Personal data insights from smart clothing combined with predictive analytics can create a data-driven feedback and monitoring system that will dramatically reduce the injury to the nursing staff and improve patient care.

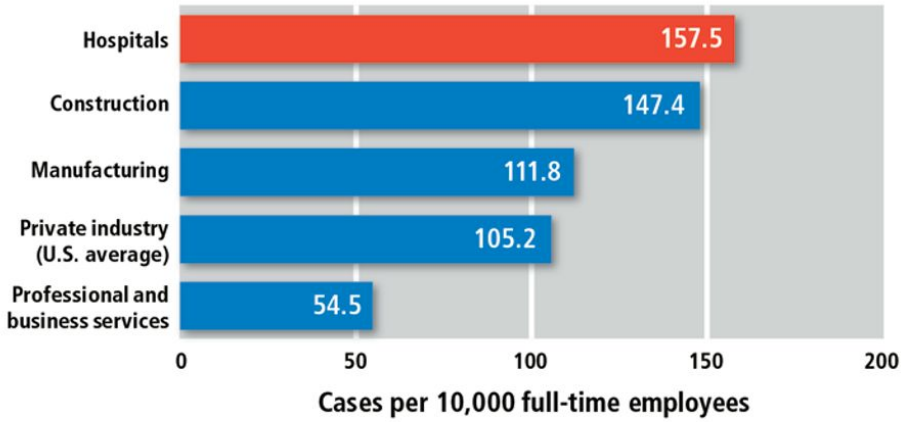


Number of Injuries Per 100 Employees

Although construction and manufacturing seem like professional with high risk of physical injury, workplace safety data from BLS (Bureau of Labor Statistics) and OSHA,

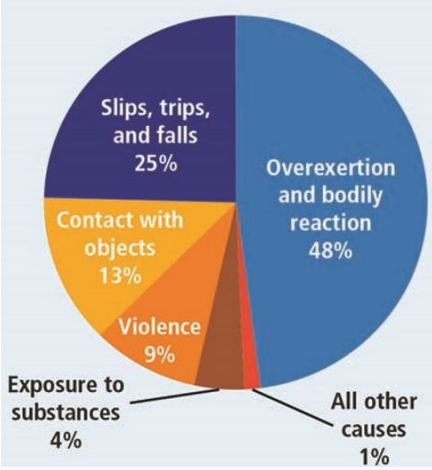
as shown in the graph above, indicate that hospital workers, specifically nurses, have the highest rate of workplace injury with 6.8 per 100 employees.

Despite the significant safety improvements in the last decade, the cost of each injury has continued to grow. Treatment of the injured worker as well as days away from work have resulted in significant expenses for hospitals. The OSHA publication estimates "injuries results in days away from work" to be 1.57 injuries per 100 hospital workers. This is also among the highest rate of workplace injuries as shown in the graph below.



Injuries and Illness resulting in days away from work, 2011[31]

As shown in the graph below more than 50% of the injuries to hospital workers are preventable as they are due to overexertion, slips, trip and falls.[32]



Studies and analysis by OSHA[33] clearly show that the majority of the injuries and associated costs can be substantially reduced by training, better hospital designs, and improved monitoring of the employees behaviour and the workplace conditions. Better data from hospitals about potential situations where injuries occur or might occur combined with customized predictive analytics for the healthcare worker and hospitals, will start to change the tide of injuries and make hospitals a safer place to work for the nursing staff.

[31] https://www.osha.gov/dsg/hospitals/documents/1.2_Factbook_508.pdf

[32] https://www.osha.gov/dsg/hospitals/documents/1.2_Factbook_508.pdf

[33] https://www.osha.gov/

The goal of smart clothing for the hospital worker is to enable big data analytics that can be used to predict dangerous situation in the hospital and for the nurse in real time. It can be used to build a monitoring and recommendation system that can alert the hospital to take on projects to better train their personnel and evaluate the benefit of new facilities, such as beds and cranes.

Current Healthcare Smart Clothing Product Offerings

Dorsavi[34] has created sensors that can be easily integrated with clothing and has a solution to identify low back and muscular stress. Dorsavi targets the workplace safety market. They use human professionals to view the output of the sensors and provide the appropriate feedback. The collection of biometrics and body mechanics is displayed on a computer and trained therapist interprets and provides guidance.

Other injury-prevention solutions, such as advanced beds, cranes, and training firms that review hospital injury reports can help to reduce injury to nurses. However, a chief barrier to adoption is lack of data for the hospital administration to make accurate cost-benefit analysis. The solution identified below can include such products and make them more useful by incorporating them in comprehensive big-data analytics system that address this issue.

Healthcare Profession and Big Data

The customized smart clothing forms the basis of a solution that use big-data analytics to help turn the tide of injuries.

Smart clothing and Sensors: Clothing worn by nursing staff will incorporate sensor technology that will have the capability to monitor body mechanics and biometrics and transmit the information to centralized system securely. The clothing should impose only a minimum additional overhead compared to normal clothing worn by nursing staff. The key sensors technology that enables smart clothing are sensors that measure heart rate, motion and body mechanics. These sensors communicate with a big-data analytics systems.

Personalized Analytics: The key to reducing injuries to nursing staff is to monitor, detect and predict dangerous situation before they happen. The smart clothing continuously monitors the body mechanics and biometrics of the person and the backend system combines it with the person's history and the current conditions to create the appropriate alert. For example, it can summon a second helper for a patient lift or help with a move. It also provides feedback after the action has been completed. The most useful aspect

[34] "Home - dorsaVi US." 2011. 26 Apr. 2016 <http://dorsavi.com/>

is the potential training advice it can recommend to the nursing staff. In addition it can provide critical warning before a major catastrophic injury that results in weeks away from work. The system constantly learns about the individual's abilities and weakness and becomes better over time.

Customized Hospital Analytics: As indicated the injuries are a major cost both direct in the forms of insurance and lost productively and indirect in terms of patient care. The biometrics and body mechanics data from its worker allows the hospitals to pin-point the reasons for common injuries and benefits of upgrading the patient lift and move tools. The system will also be able to provide key feedback on training that can specific and customized to the individual. With this information the hospital administrations can perform precise cost benefit analysis between investing in new infrastructure (e.g cranes in rooms) and injury costs. Furthermore the data from smart clothing can be combined with sensors in patient rooms and hospitals to create a comprehensive early warning system focused on preventing injury to hospital personnel. Today hospital have "check lists" for each patient we can imagine a scenario where the connected smart clothing has a check list for the nurse before every injury prone procedure.

Market Size

Hospitals pay a high price for the injuries to their nursing staff. The major cost of the injury is borne by the hospital. The table below shows the cost of a single incident as estimated by OSHA[35] report. While there are many variables and many unknowns, it is clear that a few majors incidents account for the majority of the cost. The medical cost are under-represented because most hospitals care for their own employees, the true cost are significantly higher than reported.

Single Incident Cost

Medical Cost	$11,854.00
Indemnity Cost	$10,587.00
Lost Time (Wages)	$22,440.00
Replacement Nurse	$27,000.00

Using the figures in the OSHA report the total financial cost due to these type of injuries can be estimated. The table below derives the total cost for two scenarios. As a

[35] https://www.osha.gov/dsg/hospitals/documents/1.2_Factbook_508.pdf

conservative estimate, the total cost of injuries is $1.7 billion. Accounting for lost wages and replacement of the injured employee, the cost grows to $3.5B. The smart clothing based big-data analytics solution addresses this cost.

Estimate of Total Hospital Costs

Number of Nurses	5,000,000	
Percent Injured	1.58	
	Low Estimate	**High Estimate**
Medical Expenses($)	11854	11854
Indemnity Cost ($)	10587	10587
Lost Wages($)	0	22440
Cost of Replacement($)	0	27000
Percent Replaced(%)	0	1
Total Value ($)	$1,772,839,000.00	$3,566,929,000.00

There are many other business costs that cannot be measured easily. Metrics related to patient care are the most important metrics to hospitals. With workplace injuries, there is also a mental toll on the worker and their families, which can lead to lowering the quality of patient care.

With healthcare market growing due to Affordable Care ACT and people living longer, it is clear that more nurses will be required. The nursing profession is expected to grow at 16% between 2016 and 2024.[36] This means that there will be more demand for solutions to reduce injury to nurses and employers will be investing heavily in their nursing staff and require them to be productive in order to manage a hospital in a cost effective manner. New hospitals and new employees will be more likely to try new systems that help them to be cost effective and safer.

Smart clothing for nurses is a solution for a widely-documented problem of injuries to nurses at hospitals. Most of the key technologies for the solution are already available,

[36] http://www.bls.gov/ooh/Healthcare/Registered-nurses.htm#tab-6

but companies have yet to build a comprehensive system to address this particular problem.

While there are some challenges and barriers to adoption, smart clothing solutions in healthcare is a significant market size and has a high probability of being able help in improve the productivity of the nurses and reduce healthcare costs. There are large hospital chains that will invest in such systems and can become models for the larger industry.

Use case: Military

Smart clothing has become an integral part of the development of new military uniforms targeted at increasing visibility into the health of the individual soldier as well as providing overall battlefield insights. Although the law enforcement sector in the United States including police, FBI, and other security agencies share requirements that are of similar nature to the military's, we will direct our focus primarily on the U.S military given its needs, budget, and market size are superior to other law enforcement agencies.

Current Military Smart Clothing Product Offerings

The military has partnered with both industry leaders, other government agencies, and academia to support and advance the development of potential smart clothing solutions that would be beneficial to the U.S. military by giving them a technological and tactical advantage over its foes. The research and development efforts can generally be classified into three distinct areas:

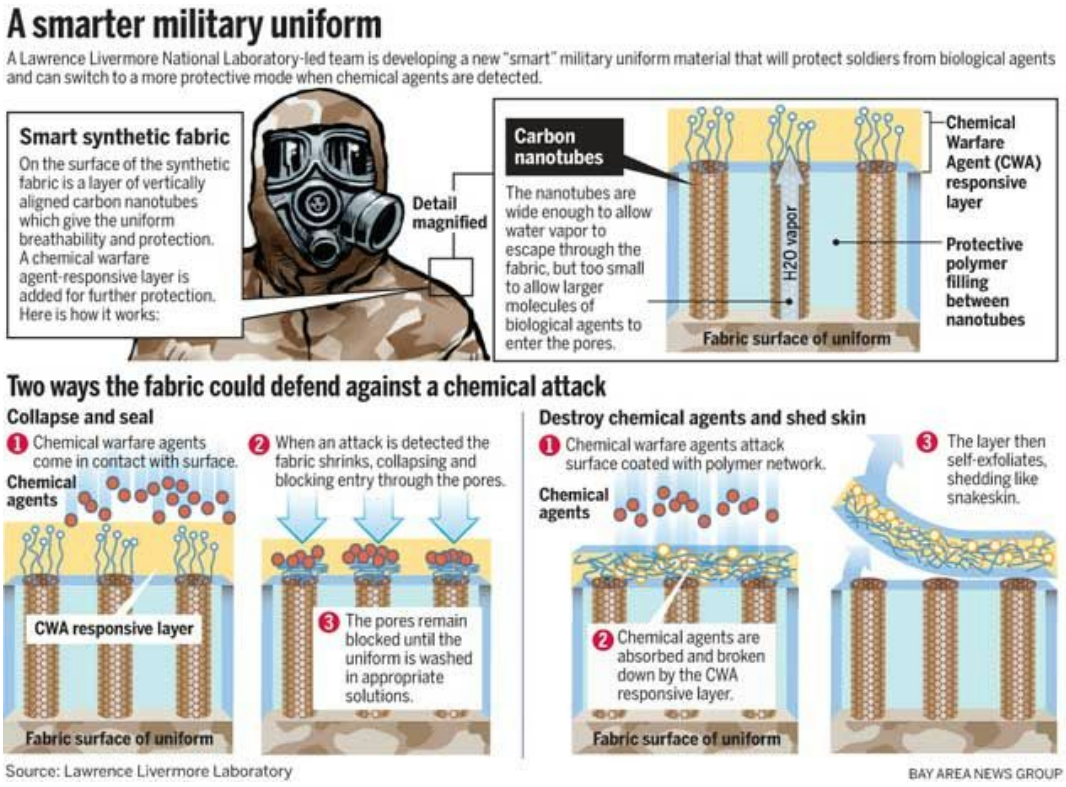
- protection against injury
- wound detection
- health/stress monitoring

Naturally, there are additional areas that fall outside of the aforementioned categories but are nonetheless extremely important to achieving a competitive edge.

Battlefield injuries are known to range from the impact of bullets, shrapnel and explosions to injuries caused by chemical, biological, radioactive and electromagnetic exposure. Historically, data identifying potential injuries were gathered via the placement of numerous sensors across various body locations to collect a limited number of highly indicative markers and information.

Research at Lawrence Livermore National Laboratory has been leading the development of a fabric for uniforms that can both protect against biological warfare and chemical warfare. This fabric mimics two aspects of the human skin - how it conducts

sweat and how it detects agents from the world at large. It has minute holes, large enough for sweat to come out, but small enough to prevent viruses and bacteria from coming in. The polymer of the fabric itself can react to chemicals, thus detecting potential chemicals used in warfare. Upon detection it either closes the holes or just peels off to protect the person wearing it.



DuPont has created a flame-resistant fiber called Nomex[37]. Uniforms made of this fiber offer permanent protection against fire and is already used extensively within the firefighting community. The fiber doesn't wear or melt and provides a reliable defense against fire and heat even after prolonged exposure. This technology is presently already incorporated in specialized outfits of divisions within the armed forces.

[37] DuPont, "Military Clothing — Thermal Protection When Danger Flares Up", 2016 http://www.dupont.com/products-and-services/personal-protective-equipment/thermal-protective/uses-and-applications/military-thermal-protection.html

The U.S. army in collaboration with Foster-Miller and Malden Mills Industries[38] has developed garments for military personnel referred to as under-armor that collects various vital signs and uses that data coupled with algorithms to detect stress, health, wounds/injuries and mission status. Unlike typical monitoring systems requiring various devices to be strapped onto different body parts, these smart clothing prototypes have sensors built into them making them virtually unintrusive - in fact, they are designed with comfort of the soldier in mind.

As the military uniforms are outfitted with increasingly power hungry gadgetry, the need to generate and store energy becomes a crucial part of the equation to sustain the proper operation of the technology. The increased power requirements of the modern uniform are therefore driving an emerging area of research that focuses mostly on generating and capturing energy within the textiles[39]. Today, soldiers are forced to carry heavy batteries to power their electronic devices and subsystems.

The Army is exploring ways to make power generation, storage, and conductivity an integral part of smart garments. Among early attempts to reach that lofty goal, the Army designed, produced, and dispensed specialized blankets that contain solar cells used to generate electricity. In addition to capturing solar energy, a new generation of sensors that have the ability to transform kinetic energy into electricity in a soldier's gait to energy.

In order to remove the cumbersome need to carry cables to connect electronic equipment to their power sources, research teams have made it their goal to using conductive material in the garments to transmit electricity from the battery packs to electronic devices, thereby eliminating cables and their associated weight.

Military and Big Data

The benefits of smart clothing has both personal and group aspects to it. From an individual perspective, the benefits are immediate and obvious. They get protection from dangerous chemicals, viruses, bacteria, fire and radiation agents that can cause serious injury. They also get protection, if not completely, against bullets and explosions. All these result in the prevention of trauma, which the soldier doesn't have to endure.

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[38] Bridgette Meinhold, “U.S. Military Develops High-Tech Undies to Monitor Soldiers’ Vitals“, Jan 26, 2012
http://www.ecouterre.com/u-s-military-develops-smart-undies-to-monitor-soldiers-vitals-during-combat/

[39] Sigrid Tornquist, “E-textiles for military markets“, Jan 11, 2014
http://advancedtextilessource.com/2014/01/e-textiles-for-military-markets/

The group aspect has two parts to it, the military as a whole and country at large. By utilizing smart clothing, the injuries can be reduced, thus reducing the cost of treatment, particularly lifetime treatment of those injured, which is borne by the whole country.

The group aspects of smart clothing at a military wide level aren't obvious, thus aren't quite visible. In fact, this area doesn't seem to have been explored as much as the smart clothing themselves. However, the military is using the data collected via smart clothing from various soldiers to study the results of military engagements[40]. Such studies result in better planning of future missions to minimize casualties.

They will extend to the point of dynamic communication and tactic alteration based on the information received from various soldiers in the group and the result identified from processing them. In order to do this the military has to, and does, employ sophisticated algorithms that process data collected in real-time to produce insights. This is where the technology of big data intersects with smart clothing. As the amount of computing power and software needed would be extensive and sophisticated, we believe that this is where bulk of the market opportunities in smart clothing for military exist.

Market size

The U.S. military consists of 1.4 million active personnel, which spans across the army, marine corps, navy, air force, and coast guard. In addition, there are more than 800,000 reserve personnel[41].

Component	Military
United States Army	541,291
United States Marine Corps	195,338
United States Navy	317,237

[40] Bridgette Meinhold, "U.S. Military Develops High-Tech Undies to Monitor Soldiers' Vitals", Jan 26, 2012
http://www.ecouterre.com/u-s-military-develops-smart-undies-to-monitor-soldiers-vitals-during-combat/

[41] Wikipedia, "United States Armed Forces",
https://en.m.wikipedia.org/wiki/United_States_Armed_Forces

United States Air Force	333,772
United States Coast Guard	42,357
Total Active	**1,429,995**
Army National Guard of the United States	342,000
United States Army Reserve	198,000
United States Marine Corps Forces Reserve	38,900
United States Navy Reserve	57,400
Air National Guard of the United States	105,500
United States Air Force Reserve	69,200
United States Coast Guard Reserve	7,000
Total Reserve Components	**818,000**

The casualty and injury rate of military personnel are directly proportional to the number and scale of the United States' involvement in conflicts. The most recent wars in Iraq and Afghanistan alone have reached an injury toll in excess of 850,000 soldiers[42].

850,000 injured U.S. soldiers stemming from two wars alone is a large number that pales in comparison to the worldwide total number of injuries and casualties originating from wars across the globe today. It is estimated that the U.S. government spends an average of $2 Million per injury for medical support and benefits over the lifetime of the soldier[43]. The resulting total post war bill for injuries borne by the taxpayer for the United States' involvement in Iraq and Afghanistan amounts to a mind boggling $1.7 Trillion. This represents an enormous burden to the taxpayers and on the U.S. and global economies.

Taking a conservative approach and assuming that 10% of total injuries recorded in the conflicts in Iraq and Afghanistan could have been prevented through the use of smart clothing, one could imagine rallying behind a total saving of $170B. Not only does this represent a large break for the taxpayer, but it would have avoided 85,000 human tragedies.

It is a well known fact that men and women targeting a career in law enforcement drastically increase their exposure to work injuries related to assaults. In 2014 alone, according to the FBI, the number of recorded assault related injuries of law enforcement officers reached a staggering 13,528[44]. Although the total number of injuries in law enforcement for a similar time span to the Iraq and Afghanistan conflicts only ads up to about 152,000[45], it represents a significant burden to society and surfaces a noteworthy smart clothing market. Although significant, the law enforcement smart clothing market

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[42] Bilmes, Linda J. "The Financial Legacy of Iraq and Afghanistan: How Wartime Spending Decisions Will Constrain Future National Security Budgets." HKS Faculty Research Working Paper Series RWP13-006, March 2013

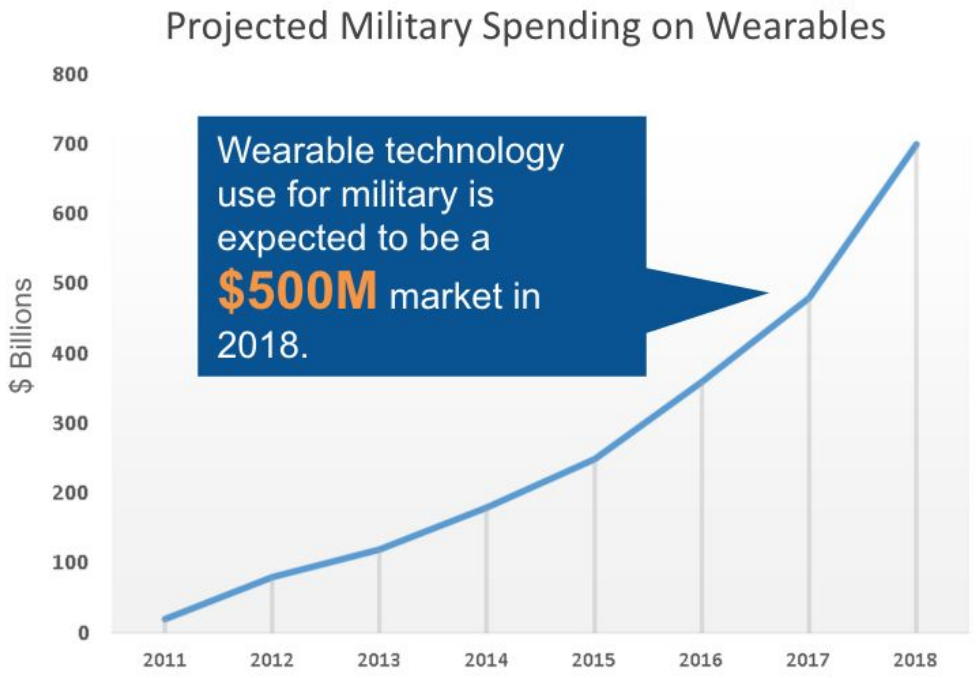
[43] Bilmes, Linda J. "The Financial Legacy of Iraq and Afghanistan: How Wartime Spending Decisions Will Constrain Future National Security Budgets." HKS Faculty Research Working Paper Series RWP13-006, March 2013

[44] FBI National Press Office, "FBI Releases 2014 Statistics on Law Enforcement Officers Killed and Assaulted", October 19, 2015 https://www.fbi.gov/news/pressrel/press-releases/fbi-releases-2014-statistics-on-law-enforcement-officers-killed-and-assaulted

[45] FBI National Press Office, "FBI Releases 2014 Statistics on Law Enforcement Officers Killed and Assaulted", October 19, 2015 https://www.fbi.gov/about-us/cjis/ucr/leoka/2014/tables/table_76_leos_asltd_type_of_weapon_and_percent_injured_2005-2014.xls

can be combined with the military smart clothing market that targets similar requirements and where technological advances are easily transferrable for similar use cases. The law enforcement and military markets are both sensitive to protecting the individual ahead of the actual price tag of the technology.

In 2016, the U.S. military spending on textiles and clothing is estimated to reach $1.5B[46]. This number is likely to increase as demand for leading edge technologies in the smart clothing sector becomes more prominent. The interest and appetite for technological advances in smart clothing for military use is not proper to the United States alone, but is a common need shared among almost all military institutions on a global scale. The smart textiles market for military uses is expected to grow at 10.4% CAGR globally between 2014 and 2019[47]. The graph below shows the projected spending in wearable technology for military uses. It is projected to reach $500M by 2018. The growth trend depicted below confirms both the reality of this market and its global reach and interest.



[46] Jeffrey C. Rasmussen, "The state of the industry", March 18, 2016
http://advancedtextilessource.com/2016/03/the-state-of-the-industry-2016/

[47] Technavio, 2016
http://www.technavio.com/pressrelease/standardization-of-smart-textiles-accelerating-growth-prospects-in-the-global-smart

Sensors & Data

Sensor technology has evolved quite rapidly in the past few years due to an increase in demand in mobile devices where smaller more accurate multi-dimensional sensors have become standard hardware issue instead of a differentiating factor. This trend has resulted in a few key advancements that have helped increase the visibility of the smart clothing market as a true investment contender. Among the important sensor developments and technological advances are miniaturization of sensors, a steep reduction in production cost, and improved reliability. In previous generations of sensors, it wasn't uncommon to have require the sensors to be strapped around various body parts to enable accurate and localized measurements. By definition, the large sensor sizes and awkward placements eliminated sensor technology for use in clothing for many years. In addition, sensors were inherently expensive and thus cost prohibitive to be adapted for everyday wear in clothing. As an increased number of the aforementioned technological and cultural barriers have been addressed and overcome, it resulted in an explosion in sensor availability for clothing. The available sensors fall into three main categories consisting of physiological, kinetic, and agent detection.

Physiological sensors include sensors that measure perspiration rate, urine composition, saliva composition, heart rate, blood pressure, sweat chemistry, sleep/rest quality, muscle engagement, blood oxygenation and body temperature, just to name the most common ones. These are predominantly used to detect injuries, stress and trauma.

Kinetic sensors include sensors that measure steps, pressure, acceleration (accelerometers), direction (gyroscopes), location (GPS). These sensors are used to detect stress, injuries, generate electricity, provide tactical coordination for troops on the ground and for commanders back at mission control.

Environment/agent detection sensors include sensors that measure radiation, chemicals, viruses, bacteria, fungi, atmospheric pressure, humidity, and temperature. Their primary purpose is to provide data to detect dangers and help avert them.

All these sensors take various forms and use various materials. Use of nanotechnology is on the rise for such sensors - given the customizability and drastic reduction in size, it is a natural fit for smart clothing. Such sensors are coated or embedded in the clothing. In addition, threads have been modified to become sensors. Various clothing material like cotton, polyester, etc. have been modified to sense various items - new materials have been produced as well.

Barriers to Adoption

The technical and cultural challenges to the adoption and integration of big data are not unique to the smart clothing marketplace or the industries that we have considered. The solutions, in general, are also not unique[48]. In The Economist article, "The Hype and the Hope"[49], the Economist Intelligence Unit describe several key common barriers to adopting big data successfully:

- lack of communication between departments or organization
- poor big data skills
- inadequate software
- lack of willingness to share data
- overly-complicated reports

These problems affect different industry segments at different rates. With the exception of the telecommunications and retailing sectors, the adoption of big data has been slow. The same Economist article found that the healthcare, pharmaceuticals, and biotechnology industries are the slowest adopters of big data. However, there are some additional complications in the healthcare industry. Shillabeer and Roddick[50] cite several inherent conflicts between the traditional methodologies of data mining approaches and medicine which are caused by both the siloed aspect of the medical industry and the complexity of privacy issues. We will discuss the resulting data standards implication and privacy and security concerns in this section

For smart clothing to increase adoption and fully realize the market potential, the offering need to overcome several issues and pursue potential solutions that are common across all big data opportunities.

Technical Challenges

So what exactly is big data? The McKinsley Global Institure defines big data as "datasets whose size is beyond the ability of typical database software tools to capture, store,

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[48] Canlas, R.D. "Data Mining in Healthcare: Current Aplications and Issues." 2009 http://www.cclfi.org/files/Data_Mining_Health.pdf

[49] https://www.hds.com/assets/pdf/the-hype-and-the-hope-summary.pdf

[50] Shillabeer, A. and Roddick, J.." Establishing a Lineage for Medical Knowledge Discovery. ACM International Conference." 2007. Proceeding Series. (311) 70, 29-37 http://dl.acm.org/citation.cfm?id=1378250&dl=ACM&coll=DL&CFID=767313862&CFTOKEN=68786879

manage and analyze". Gaffney and Huckabee[51] have also described big data in terms of volume, velocity, variety, and veracity.

- **Volume:** The volume of data being created today is growing exponentially with the increase in large-scale internet applications, explosion in ubiquitous sensing technology and the internet of things (IOT). This is illustrated by the monitoring devices throughout the manufacturing, retail, healthcare, fitness and military industries.

- **Variety:** The variety of data is also increasing. Just considering the fitness industry, we have wearables that track, geo location, velocity, acceleration, breathing rates, heart rates, heat and skin chemicals. This collection of data elements requires standardization and normalization in order for meaningful comparisons, integration or learning to occur. The ability to pull together and analyze this wide variety of data is critical to success.

- **Velocity:** Complex analytic capabilities and tools will be required to tackle the speed at which this data is being generated and enable analysis and action to be take in a timely or near to real time way.

- **Veracity:** Analysis of data is only as good as the data we gather. Thus, methodologies, processes and systems to ensure data integrity, accuracy and trustworthiness are essential. This is a fundamental requirement in the health and safety environments that we have selected to investigate.

To understand the technical challenges of implementing big data, solutions need to address data standards, interoperability, privacy and security, and the analysis of big data. In addition, the smart clothing field introduces additional technical challenges, such as building sensors suitable to be embedded in clothing and how to connect to those sensors to retrieve aggregate and analyze the data.

Standards: the language of big data

A fundamental requirement of the big data industry is that communication of data must occur within and between organizations. Many current systems use proprietary data formats. However, the challenge is to harmonize data formats towards a preferred open data format with appropriate metadata to provide necessary context regarding the data

[51] Gaffney, B. & Huckabee, M. (2014). Part 1: What is Big Data? Source: HIMSS Data and Analytics Task Force, July 8, 2014. http://www.himss.org/ResourceLibrary/genResourceFAQ.aspx?ItemNumber=30730

acquisition and initial analysis. One possible solution will be to adopt an established open standard, like Hierarchical Data Format 5 [HDF5, 2014][52]. A second data challenge will be arise when data systems attempt to compare data from sensors produced or calibrated differently. For example when manufacturers use different thresholds, sample rates, or filters.

Privacy: Securing data

While there are many cultural questions regarding privacy (we will address later) there are also technological challenges to securing both raw, personal data and the insights that are derived.

Data brokers collect data from numerous sources for everyone in the US. It is alarming how much data is collected and the potential for security breaches, particularly from wearable devices[53].

One glaring technological issue is Hadoop, an open-source software framework for storing and processing big data in a distributed fashion. Hadoop wasn't built with security in mind; it was developed solely to address massive data storage and faster processing and is widely adopted across the "big Data" industry[54]. It's weakness illustrated the three most common security threats:

1. **Unauthorized access:** In Hadoop, all data is accessible by all users of the cluster and thus is only as secure as its least secure user. The health Insurance Portability and Accountability Act of 1996 (HIPAA and the Payment Card Industry (PCI DSS) have created rigorous standards but Hadoop systems have had challenges complying to requirements including such access controls, authorization and auditing
2. **Data Provenance**: To be secure we must be able to know and verify the source of every bit of data. This is the providence of data, or garbage in garbage out! If we cannot trust the origin and veracity of our data then we cannot trust the insight.
3. **DIY Hadoop:** Finally, because Hadoop is open source, it can be adapted, changed, tuned and modified by basically anyone. Thus, it is a constant battle to identify new security holes that emerge.

In addition to securing the data produced by wearable sensors, the sensors and devices themselves pose a threat to workplace security. It is estimated that 90 million wearable

[52] The HDF Group. HFD5. 2014. http://www.hdfgroup.org/HDF5/
[53] Maddox, T. "The scary truth about data security with wearable devices." TechRepublic. 2014 http://www.techrepublic.com/article/the-scary-truth-about-data-security-with-wearables/
[54] MIT Technology Review: 2015 Securing the Big Data Lifecycle, MIT Technology Review: http://files.technologyreview.com/whitepapers/Oracle-Securing-the-Big-Data-Life-Cycle.pdf

data devices ("WDD") will be shipped to customers in 2014. Many of these customers will bring them into the workplace, which will challenge employers to adapt employment, intranet security and IT policies to these new visitors[55].

The Federal Trade Commission has become the de facto regulator of privacy and data security through its broad authority to regulate "unfair or deceptive acts or practices in or affecting commerce" under Section 5 of the Federal Trade Commission Act. In this role, the commission has already brought enforcement actions under Section 5 against companies engaged in information privacy, data security, behavioral tracking and other data-related commercial activities when those companies failed to adequately disclose data collection practices, abide by promises made in their privacy policies, or provide a "fair" level of security for consumers.

Analysis: Mining data for valuable content

Interpreting data from wearable sensors is challenging. As discussed, the data will be heterogeneous, coming from a variety of sensor types with different modalities. A second challenge is the non-uniform nature of the data. It may arrive sporadically, with temporal gaps, and excess noise. This increases the analysis complexity and can lead to false confidence in results. There is a significant amount of effort and research currently directed towards understanding how to interpret the type of multiparameter, longitudinal data produced by heath monitors and wearable systems[56]. However, the challenge remains to automatically labeling a vector of features values indicative of health of an individual amongst the population at large.

Connectivity and Portability

As discussed wearable sensors have the capability of generating large data sets. As an example consider the following set of wearable sensors and inertial sensor to triaxial accelerometry, gyroscopy and magnetometry at 100 Hz, and barometric pressure at 2 Hz, and assuming two bytes per sample per signal, this will generate approximately 156 MB of data per day[57]**.** Then there is battery power which is a factor limiting the volume of data. Thus, we have a tradeoff between transmission and preserving battery life, one solution is to preprocess data on the sensor to extract only salient information to transmit, but that does necessarily imply that some information could be lost. An

[55] Cain, J., 2014, Wearable Devices in the Workplace Challenge Data Security and Privacy. https://www.mintz.com/newsletter/2014/Advisories/4200-0814-NAT-PRIV-ELB/index.html
[56] Kohlmann M, Haux R, Marschollek M, Wolf KH, Gietzelt M, Song B. High intensity, multimodality and incoherence: grand challenges in the analysis of data for health-enabling technologies. Stud Health Technol Inform 2013;192:967.
[57] Redmond, S.J.., et al. "What Does Big Data Mean for Wearable Sensor Systems?" Contribution of the IMIA Wearable Sensors in Healthcare WG. IMIA Yearbook of Medical Informatics. 2014

important challenge will be to design low-power circuit and sensor design, and power scavenging technologies. Alternatively, some situation may allow for wirelessly retrieval of all data if devices are charged daily

Power, heat dissipation, washability, miniaturization, comfort, flexibility are all factors in the portability challenge. Although there have been significant developments in power supply technology, it is still a critical issue in the field of smart clothing and in particular e-textiles. It will remain a challenge although there is interesting work in developing wearable systems capable of accumulating energy dissipated by the body allowing us to power our own sensors[58]. Alternatively, Thermotron of UNITIKA[59], is a particular fabric able to convert sunlight into thermal energy and storing heat. Inside the Thermotron there are microparticles of zirconium carbide which allow the fabric to absorb and filter sunlight. The inner layer of the fabric withholds the heat generated and prevents it from becoming lost, thus providing us with methodologies to use our own heat or the external power source of the sun in powering sensors.

In smart clothing in general and the types of use cases we have discussed it will be required that sensors and usually multiple sensors communicate with external devices in near-to or actual real time. For example, to alert the nurse or military personnel to impending danger or injury. Even without the real-time requirement the data from the sensor needs to be communicated back to the data analytics platform in a time sensitive fashion. Thus wireless communication is essential component to the success of the smart clothing industry. Current options all have some drawbacks:

- Bluetooth: has relatively high power consumption (50-100mW), has a master-slave protocol that support only 7 slaves to one master, and required handshaking to establish connection.
- Radio Protocols (e.g. IEEE 802.15.4): In cases where more than 7 sensor nodes are needed or when extreme low power is required, an ad-hoc/peer-to-peer protocol may be more effective. Allowing radios to move in and out of the local sensor network without breaking the flow of communications. As these radios require less than 1 mW to communicate over a 30 meter range they may be adequate for health industry and some sports applications but not suitable for military or other more distributed applications.
- RFID: for certain applications that require passive communications RFID tags can be used to identify people, places, and things. However, this would not solve the whole communication challenge.

[58] Matteo Stoppa and Alessandro Chiolerio, Wearable Electronics and Smart Textiles: A Critical Review, Sensors 2014, 14, 11957-11992; http://www.mdpi.com/1424-8220/14/7/11957/pdf
[59] http://www.unitika.co.jp/e

We have discussed many types of sensors in our use cases but challenges remain in to achieve low-cost unobtrusive and widely acceptable devices including higher user comfort, use in the workplace, motion artifact reduction, textile and fabric innovation and improved signal-to-noise ratio. Smart clothing poses a very complex data gathering challenge. The sensors will be heterogenous collecting different types of data in different ways, they must be washable to be functional and they need to include a communication mechanism such as an antenna.

Cultural

The concept of using wearable technology to monitor health opens many questions even when the data and insights are restricted to the doctor patient relationship. However, it becomes infinitely more complex when the insight and/or data is shared with a second or third party such as an employer, will people accept this intrusion into their lifestyles and personal details? This will depend on the situation of the individual and how they balance safety and health with privacy. If the benefit to the individual is not immediately apparent, such as detection of a dangerous virus or gas, then the cost to privacy may prevent the widespread adoption of wearable technology in the workplace. Ultimately, there will be a balance to be met between securing personal data and making insights available to second parties such as employers. It will be required that government regulates misuse and mandate how data can be legally used and what punishments are appropriate for the various transgressions which will inevitably arise. The reticence does not only emerge on the employee, or individual's, side or this two-sided marketplace, the employer also has to be concerned with legal liabilities. What if the data analysis fails to spot an athlete's brain injury, a nurse with poor posture or a soldier in some imminent danger, will the employer be liable. Alternatively, what if the system does spot the risk by the employer does not act? "*The boundary between use and misuse of big data truly is a social quandary requiring democratic debate to arrive at a consensus of what is considered acceptable to the majority*"[60].

- **Expense:** 14% say that wearable tech is too expensive[61]
- **Privacy:** 52% say that loss of privacy is the biggest concern for wearable technologies[62]

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[60] Redmond, S.J.., et al. "What Does Big Data Mean for Wearable Sensor Systems?" Contribution of the IMIA Wearable Sensors in Healthcare WG. IMIA Yearbook of Medical Informatics. 2014

[61] "Tech-Styles: Are Consumers Really Interested in Wearing ..." 2014. 28 Apr. 2016 <http://www.nielsen.com/us/en/insights/news/2014/tech-styles-are-consumers-really-interested-in-wearing-tech-on-their-sleeves.html>

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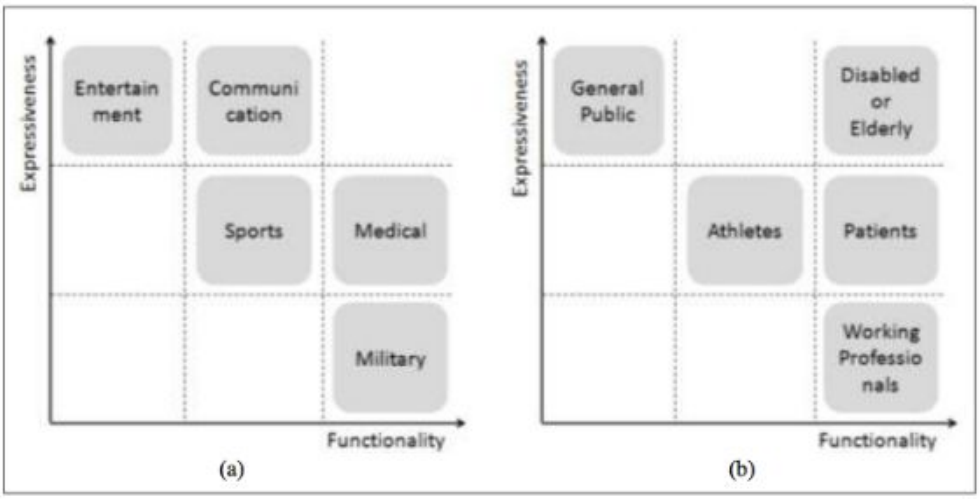
- **Style:** 53% say that want wearable tech to be more stylish[63]
- **Utility:** 51% say that they won't buy a wearable because they lack compelling use cases[64]

The user value for clothing comprises functional and symbolic attributes. Functional value is to provide protection and comfort, while symbolic value is the impression the wearer gives to other people by exterior appearance[65]. The challenges to culture adoption are based on both the functional and aesthetic appeal. Key psychological considerations are discussed by Suh[66], and include thermal comfort (heat and moisture regulation), tactile comfort (physical sensation) and mobility (movement, fit, and size) and fashion issues. As can be seen from Suh's diagram, the cultural barriers depend upon the application under consideration. The use cases we have discussed place functionality above expressiveness as we have focused on the professional in his/her workplace.



Mapping of Smart Clothing Market Segments: (a) by product-oriented segment, (b) by user-oriented segment[67]

[63] "Tech-Styles: Are Consumers Really Interested in Wearing ..." 2014. 28 Apr. 2016 <http://www.nielsen.com/us/en/insights/news/2014/tech-styles-are-consumers-really-interested-in-wearing-tech-on-their-sleeves.html>

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[67] Suh et al, Minyoung Suh, Kate Carroll, and Nancy Cassill, Critical Review on Smart Clothing Product Development, Journal of Textile and Apparel Technology and Management, Volume 6, Issue 4, Fall 2010, http://ojs.cnr.ncsu.edu/index.php/JTATM/article/download/702/728

Special Barrier Considerations Pertaining to the Military

The barriers for adoption of smart clothing applications in the military sector are quite different from those of the general population. It is therefore important to take a closer look at the barriers that set the military industry apart from other industries.

Unlike the majority of civilian use cases, it is much easier for the military to overcome some of the barriers of adoption that plague other industries. These include expenses, privacy concerns, legal implications, style, and utility. Today's military budget is massive and enables the various branches of the armed forces to provide each soldier with the best equipment available to ensure their safety and survival. Privacy and legal aspects of personal identifiable information (PII) and collected data are not a concern within the confines of the military as the military operates beyond civilian law in most of these aspects.

Utility, cultural, style, and psychological barriers, although omnipresent, will be overshadowed by the large individual benefits provided by the recorded and collected data. In a military environment, the data, its analysis, and the results may have life and death implications on the soldier. Once educated about the many upsides of the smart clothing, it is expected that soldiers will naturally gravitate towards their use.

Smart clothing applications targeting the military sector are faced with some unique barriers that may not impact the civilian use cases. Reliability represents one of the main barriers that will eliminate many developers and smart clothing manufacturers. The garments, sensors, algorithms and computers must work at all times independent of circumstances and environments while producing consistent results. Let's illustrate this with a scenario in which a smart garment that was supposed to detect, protect, and alert against biological warfare was defective in 10% of the deployments - chaos would ensue. The military will therefore pay a premium to ensure the reliability of life saving smart garments.

The last barrier worth pointing out is the need for specialized sensors in military applications that may not necessary translate into civilian applications. Collection of urine samples or detection of radiation aren't relevant to civilian smart clothing use cases but represent a vital weapon in the military smart clothing arsenal. Thus, military oriented and oftentimes secretive research has to be performed to address the specific needs of our armed forces. In addition, specialized computer algorithms have to be

developed and perfected to analyze data (both from special sensors and regular ones like sweat detection).

Special barrier considerations pertaining to the military revolve mostly about technology limits and reliability instead of cultural, stylistic, privacy, or legal as could be the case in other smart clothing industries.

Path to Market Success

We recommend the following to enable market success:

1. Develop early uses cases in domains where issues of privacy, security and legal issues are minimized. Athletics, hospitals and military are organizations that already deal with such issues and have systems to address them.
2. Create the right partnerships with sensor companies. This will be crucial because clothing sensors have unique requirements such as waterproof, washability, and comfort.
3. Create partnerships with clothing designers and manufacturers to develop a truly wearable product. Plugging in the clothing into the wall will not be an option for charging. The clothing will need to be treated like clothing and not a like a piece of electronic equipment
4. Hire the people with advanced skills in machine learning and mathematics. This will be required to develop the algorithms that will be necessary to build solutions for each problem domain.
5. Harness the open-source technologies that have already implemented many of the advanced algorithms using machine learning and real-time analytics
6. Address the challenges of real-time processing of big-data by developing a partnerships with hardware and software vendors.

Ultimately, the design and versatility of the big-data processing platform from connectivity of clothing, integration of environmental sensors and the analytics capabilities that are custom made for each domain will determine market success.

Conclusion

Big data analysis is necessary to realize the full potential of smart clothing. There are many smart clothing products and use cases where providing personal biometric or environmental data to end users can improve the health, safety, and happiness of

consumers. However, these use cases have limited market value and will probably have limited growth in the next 5-10 years.

Companies who develop products that use big data to identify trends and can use the predictive analytics to improve the performance, health, and safety of larger populations will achieve market success. These commercial applications, particularly in professional athletics, military, and healthcare have significant market potential.

A secondary market of IOT big data platforms will grow to serve these commercial customers and use cases. Startups such as C3 IoT and Meshify offer platforms for IoT applications, including big data analysis and business intelligence tools. These platforms "aggregate volumes of disparate data from enterprise systems and external sources; apply advanced machine-learning algorithms for rigorous, predictive, and continuous analysis; and present actionable insights that address mission-critical business imperatives."[68]

With the larger wearable industry driving technical innovation in sensor size and capability as well as a new market of IoT platforms, smart clothing is positioned to have the tools for market success. By focusing on commercial application, cultural challenges of style and expense become less of a barrier.

Although consumer wearable and smart clothing technologies have larger public attention, business and enterprise application will give the market financial value that drive growth in years to come. An investment in developing products that serve commercial use cases will offer investors and shareholders the quickest rate of return.

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