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Applying TRIZ and Bass Model to Forecast Fitness Tracking Devices Technology

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Abstract--**65% of the world's population lives in countries where overweight and obesity kills more people than those who are underweight. Healthcare organizations, private corporations and individuals are investing in proactive health and weight management. Advances in sensor technologies have enabled development of affordable wearable technology devices, the most rapid expansion being fitness trackers which entered the market in 2012. This paper describes the application of a combination of TRIZ and Bass modeling to forecast the technology growth projections for fitness trackers. For the TRIZ modeling, the fitness tracking system was divided into three subsystems and each was analyzed per the technology trends from current literature. The subsystems' combined assessment was then visualized via a radar plot. The analysis showed the technology to be in an emergent state with primary growth in the hardware and software subsystem areas. For the Bass model adoption rate projection, the market size was estimated to be 69% of the US population who are active health trackers. The innovator and imitator parameters were calculated using information from analogous products such as cellular phone, home PC and ultrasound imaging. The Bass model showed the market peaking at eight and saturating in fifteen years.**

I. INTRODUCTION

The World Health Organization reports in an August 2014 factsheet that worldwide obesity has nearly doubled since 1980, 35% of adults aged 20 and over were overweight in 2008 and classifies obesity as preventable [1]. The Centers for Disease Prevention and Control (CDC) reports in 2011-2012, 35.1% of adults were obese and 69% overweight [2]. Clearly, there is a prevalent problem. With widely circulated information on the health impact of being overweight and these staggering statistics, individuals are beginning to pay more attention to diet and physical activity that are instrumental to maintaining weight.

Technology can play a useful role in solving in this healthcare problem. We have used sensors for various applications; but research in these technologies have been predominantly for applications in the areas of expensive and complex to use medical, financial and defense security systems, for e.g. ultrasound imaging, counterfeit detection and explosive detection. However, with recent advances in technologies, we are able to now manufacture Micro-Electro-Mechanical-Systems (MEMS) and Optical sensors at lower costs and make these affordable to the general public. This has led to a new realm of devices generally referred to as wearable technology that is targeted towards a myriad of users and biometric applications.

This research study is meant to identify the best approach for technology forecasting for activity or fitness trackers, which is one class of wearable devices. Fitness trackers can be used to track physical activity and aid in health and weight management. The specific forecasting questions being researched are, (1) the window of opportunity in the market for this technology and, (2) the specific technology component that would maximize the return on the investment. The research will be helpful to derive R&D budget for fitness trackers.

II. LITERATURE REVIEW

A. Technology overview

Wearable device as defined in this paper is a device that is worn on the person. Fitness trackers are a specific class of wearable devices that is used to track physical activities of an individual throughout the day and night. A high level architecture diagram is shown in Figure 1. Fitness trackers come predominantly in two form factors, (1) fitness bands, or, more recently are (2) incorporated into Smartwatches.

The core electronic components of a wearable device include battery, a variety of sensors, memory, a system controller and wireless connectivity. The sensor types in wearable devices can vary significantly, for e.g. accelerometer, temperature sensor, galvanic skin response, piezoelectric/piezo-resistive sensors [3]. Auxiliary components include a display. Tertiary components would be additional smart components such as camera, microphone, etc. The primary challenge that the device designers face is how to maximize functionality and size. With the significant advances made in MEMS [4] and semiconductor fabrication technologies, we have been able to increase the density and diversity of sensors and the other controllers on wearable devices. Strides in polymeric materials are further enabling developing these as flexible devices [5]. Advanced systems are being built to measure electrical and mechanical signals using organic/inorganic matrix arrays, hybrid composites, graphene and nanowires or nano-assemblies integrated on flexible substrates.

The information collected from the wearable device is uploaded upon demand, and possibly live, into the cloud where the data is analyzed and summarized into meaningful information that is returned to the user. Onboard electronics can also store and act upon information between data uploads. The data generated can be classified as Big Data, based upon the volume, velocity, variety and veracity. Strides in the area of predictive data analytics and the cloud architecture can also be applied to fitness tracking data and enables the user to receive, real-time information that can aid in proactive healthcare management. However, the application of big data techniques on personal healthcare data also brings new challenges in this area, such as data formats, communication and storage management. This will drive new standards on how the data is collected, shared and secured on wearable devices [6].

The next major component in this technology is the form factor. While wearable design is typically considered the arena of fashion designers; this specific technology requires strong attention to form factor as it needs to be something that a person wants to wear every day. This requires the definition of key parameters [7] for wear-ability and strong collaboration between technologists and clothes/accessory designers. The form factor is also complicated by the ideal location on the body for collecting biometric information as shown by the graphic in Appendix B, Section 3.

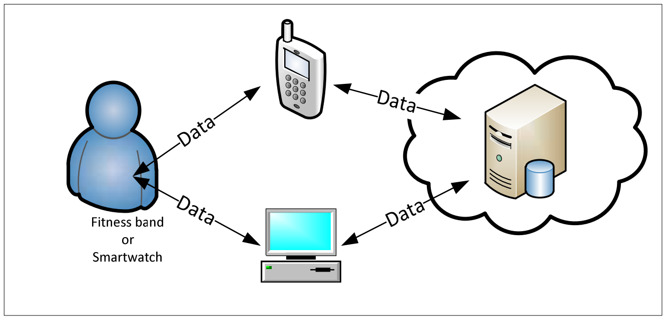

Figure 1. Wearable Device/Fitness Tracker Architecture

B. Market overview

According to a study published by the Consumer Electronics Association [8], interest in purchasing wearable fitness devices quadrupled from 3% in 2012 to 13% in 2013.

Fitness trackers are an emerging technology market, having started to show up in 2012. Overall the technology maturity level is in the Late Innovators or Early Adopters phase as shown in Appendix B, Section 1. ABI research reports that in Q1 2014, activity trackers continues to have a lead over the smartwatches that have recently started showing up in the market as well in 2013; the ranking and shipment volume for 2014 is summarized in Table 1 [9]. Some sample fitness trackers are shown in Appendix B, Section 2.

TABLE 1. RANKING AND SHIPMENT VOLUME FOR Q1 2014 [9]

Activity Tracker Vendor	Q1 2014 Rank	Smartwatch Vendor	Q1 2014 Rank
Fitbit	1	Samsung	1
Garmin	2	Sony	2
Nike	3	Pebble	3
Jawbone	4	Casio	4
Total Units Shipped	2,350,000	Total Units Shipped	510,000

CCS Insight predicts the shipments of wearable technology devices will hit 22 million by end of 2014 and forecasts to reach 135 million by 2018. Of the 135 million sales, 68 million will be Smartwatch devices and 50 million fitness trackers [10]. An IHS Electronics and Media Whitepaper from September 2013 predicts wearable technology to climb from about US $10Million revenue forecast in 2013 to about US $30 Million in 2018 and US $55 Million on the upside [11].

III. METHODOLOGY

A. Forecasting Technique

Current forecasting methods and their applicability to the study are addressed in this section. The study is to identify new products with emerging technologies and their market opportunities. To address the forecasting questions, the study required research into two branches of technology forecasting, (1) Technology roadmap and (2) Market Adoption. In this study, TRIZ is used to identify potential future products for technology roadmap, and Bass adoption model is selected to project market growth of the products.

A literature review was conducted in both areas to select the ideal method and technique to apply to each area [12] [13]. In order to select the method, the relevant data available on wearable technology was analyzed along with the specific forecasting focus. Wearable technology is an emerging area, with little historical sales and technology parametric data, but does have analogous products that have been in the market for several years. The technology comprises various sub-components each with its own history in technology, so we need a road-mapping technique that will be able to look at the system holistically.

Planning for technology roadmapping posed a bigger challenge between the various strong candidate techniques such as Technology Forecasting using Data Envelopment Analysis (TFDEA), Regression, Delphi, Hierarchical Decision Making (HDM), Analogy Modeling, Morphology Analysis, Bibliometrics/Patent Analysis and Theory of Inventive Problem Solving (TRIZ). Given that the technology components is complex and highly integrated and there is little historical data; regression and TFDEA techniques were not good choices for this project. TRIZ showed better promise than Delphi and HDM given the complex analytical capability required for sub-components in a short timeframe. TRIZ is an established method, originally developed by the Soviet inventor, Genrich Altshuller, starting in 1946 to analyze technology trends [14] and incorporates aspects of the patent analysis method as well [15] and hence it was chosen.

TRIZ is based upon three basic principles, (1) problems and solutions are repeated across sciences, (2) patterns of solution evolution are repeated across sciences, and, (3) innovations used scientific concepts outside the fields in which they were developed. Altshuller, in his role with the Soviet Navy of initiating invention proposals, came up the finding that inventive solutions were developed in the context of an unresolved contradiction when the situation faced by the inventor meant that improving one parameter negatively impacts another parameter in the system; identified as technical contradictions in his study. He started studying patents and after a study of over 40,000 patent abstracts, developed the concept of ideality and composed a collection of trends of technical evolution for various segments, a contradiction matrix, 40 inventive principles and standard solutions. This collection of information provides an inventor with an algorithmic approach to either invent new systems or refine existing systems to solve the problem that he or she is facing. The trends of technical evolution (aka the laws of technical systems evolution) used to have eight trends, but they have been extended later by many researchers. The original trends include:

- Evolution toward increased Ideality
- Stages of evolution of technology
- Non-uniform development of system elements
- Evolution toward increased dynamism and controllability
- Increased complexity then simplification
- Evolution with matching and mismatching elements
- Evolution toward micro-level and increased use of fields
- Evolution toward decreased human involvement

Darrell Mann was one of the TRIZ experts who studied and extended the original eight trends. He extended the list to over 30 trends and "Space Segmentation" illustrated in Figure 3 is one of them. A summary of the system evolution trends based upon Darrell Mann's work was referenced in this study [18].

TRIZ is fundamentally based upon the concept of ideality as shown in Figure 2, although in actuality, the Ideal Final Result will constantly move ahead over time and not theoretically achievable. The concept of an evolutionary trend using the space segment as an example is shown in Figure 3.

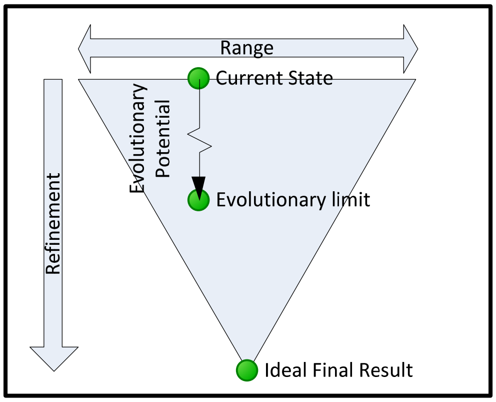

Figure 2. System Evolution and Ideal Final Result

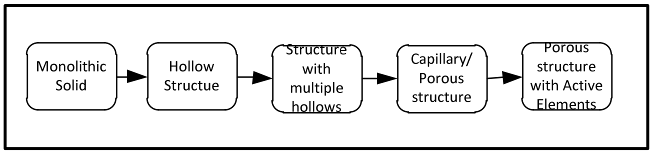

Figure 3. System Evolution Trend for Space Segmentation

There are forty inventive principles derived from Patent Analysis [16]. Solution generation methods are also well documented [17]. An extension of TRIZ and its commonality with the Theory of Constraints with respect to addressing contradictions was researched; this is an area for potential future extension on this research topic [19].

For market adoption forecasting, modeling and leading indicator models such as Growth Curves (Pearl, Gompertz, Fisher-Pry), Lotka-Volterra and Bass Models were considered. Of these, Bass model [20] was chosen based upon two main considerations, (1) innovator and imitator parameters for analogous products are available, and (2) market size is available from studies instituted by reputable organizations such as the US Census [21], CDC and Pew research agencies [22].

The Bass Model is a mathematical derivation for the diffusion of a product or innovation in the market over time. It is based upon three key parameters, (1) the total market size for the product, (2) a probabilistic quantification of innovators in the market and, (3) a probabilistic quantification of imitators in the market. The model was developed by Frank M. Bass, originally in 1963. The innovators in the market tend to hold at a steady level over the years and do not fluctuate much. On the other hand, the imitators in the market grow based upon the word-of-mouth references either through media or based upon references from other users. The imitators play a significant factor in the Technology Adoption life cycle shown in Appendix B.

A good catalog of Bass Model parameters for analogous products is available [23]. Given that the wearable technology has some commonality with a non-intrusive medical monitoring system, the Bass model parameters for ultrasound monitor was added [24]. The Frank Bass methodology applied to a new product into the market place is adopted from a Harvard Business School case study [25].

B. Model Development

Prior to modeling, a high-level assessment of the technology was performed using a Strengths/Weakness/ Opportunities/Threat (SWOT) analysis.

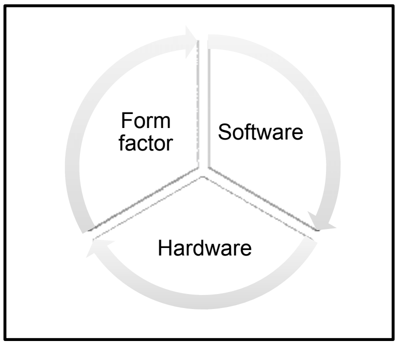

Figure 4. Fitness Tracker System Subsystems

For the TRIZ model application, a close study of the technology of fitness tracker device as summarized in Section

2.1 was conducted to identify the key trends that are relevant to this technology. The fitness tracker system was divided into subsystems as shown in Figure 4.

Of the thirty TRIZ evolution trends, ten were found to be applicable to fitness trackers. The relevant ten critical TRIZ technology trends were mapped into the fitness tracker subsystems. The mapping of the Subsystems and trends are shown in Table 2.

TABLE 2. FITNESS TRACKER SYSTEM SUBSYSTEMS AND

Subsystem	TRIZ System Evolution Trend
Hardware	Reducing Energy conversions
	Mono-Bi-Poly (Various)
	Webs and Fibers
	Dynamization
Software	Market Evolution
	Boundary breakdown
	Mono-Bi-Poly (Increasing differences)
Form Factor	Increased use of color
	Increased use of senses
	Customer Purchase Focus

Each trend segment was then individually scored on a normalized score of 1-10 based upon an assessment of their current position on the trend. The scores were then mapped into radar plot to visualize the maturity level of the technology with respect to the Ideal Final State.

For the Bass market diffusion modeling, the Generic Bass Model equation shown below was used.

$$S(t) = p * [m - N(t-1)] + \left(\frac{q}{m} * N(t-1) * [m - N(t-1)]\right)$$

Where,

S(t) is the new adopters during time period t,
N(t-1) is the cumulative adopters until the previous time period,
m is the total market size,
p is the coefficient of innovators, and,
q is the coefficient of imitators

The total market size was based upon 2013 US population and the percent of individuals who actively track their physical activity using either technical or non-technical systems. Analogous products were identified to obtain the coefficient of innovators and the coefficient of imitators.

IV. DATA COLLECTION AND RESULTS

A. SWOT

The SWOT analysis for fitness tracker technology is shown in Figure 5.

The fabrication methodologies have made size of the device small and flexible and that makes a convincing case for users to wear and adaptable to various designs. The sensor technologies are enabling non-intrusive methods to monitor physical activity thereby again making it easier for users to adopt the system. The rapid advances in Big Data analytics and the Cloud infrastructure are also major strengths. However, the systems in the market today suffer from varying degrees of accuracy. Battery life which is a major user influencing factor also is a challenge and the mean time between charging varies between products. Technologists are not necessarily user design and fashion-savvy for the public and hence the reference designs are still evolving. Given than the technology and industry is in its infancy, the opportunity exists to establish a strong leadership position. Technology developments in the area of polymeric materials are enabling newer sensors to enable better accuracy. We have the opportunity to establish some good integration standards not only between the sensors that could be located at different positions on the body; but also with the cloud infrastructure in terms of security and privacy. As the data collected continues to grow, there will be the opportunity to develop

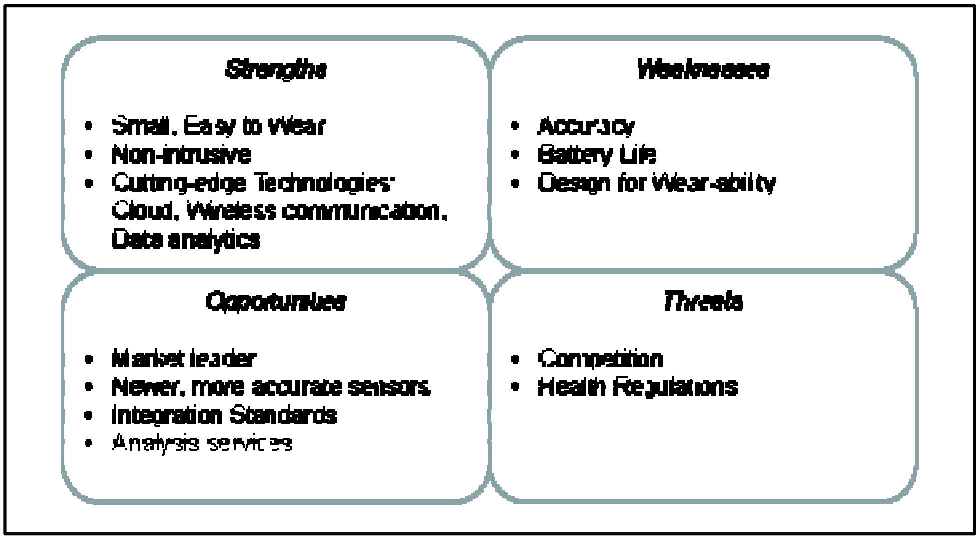

Figure 5. SWOT Analysis for Fitness Tracker

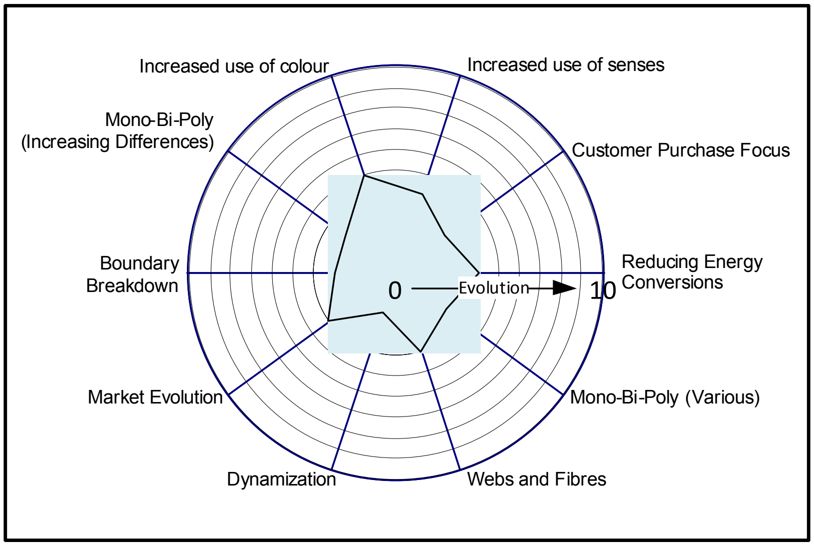

Figure 6. Radar Plot for the TRIZ Analysis of Fitness Tracker Technology

and market healthcare analysis as a service. The main challenge is the competition with over 14 vendors in this market currently. A 2014 litigation case from a Calgary law firm is the first of its kind using data from the Fitbit band in a personal injury case; this brings up the question on the privacy laws applicability to this healthcare data that is traditionally covered by regulations such as Health Insurance Portability and Accountability Act (HIPAA).

B. TRIZ

The information from the SWOT analysis influenced the TRIZ analysis. The quantified results of the TRIZ model application on fitness trackers is shown in Appendix A, Section 1. The radar plot based upon the TRIZ assessment is shown in Figure 6. The average scores, out of a maximum possible value of 10, for the three subsystems are shown in Table 3.

TABLE 3. AVERAGE SCORE FOR FITNESS TRACKER SUB-SYSTEMS

Subsystem	Average Score
Hardware	3.25
Software	3.33
Form Factor	4.00

The key observation from the radar plot results shows that the technology is in an emerging state with quite a bit of growth opportunity ahead. The summarized scores show that hardware is likely the subsystem that will require the closest attention in terms of technology development; followed by software and then form factor.

C. Bass Market Diffusion Model

The analogous products' data was used to derive the coefficients of innovators and imitators for fitness trackers, the details of the calculation are shown in Appendix A, Section 2. The values used in the Bass Model are shown in Table 4 below.

TABLE 4. BASS MODEL PARAMETERS

Parameters	Values
Population (Millions)	316.13
Active trackers	0.69
m (millions)	218.13
p	0.018
q	0.524

The tabular detailed results of the Bass Model is shown in Appendix A, Section .3.The market penetration and adoption rate graphs are shown in Figure 7 with the X-axis being years and Y-axis being the percent of market size.

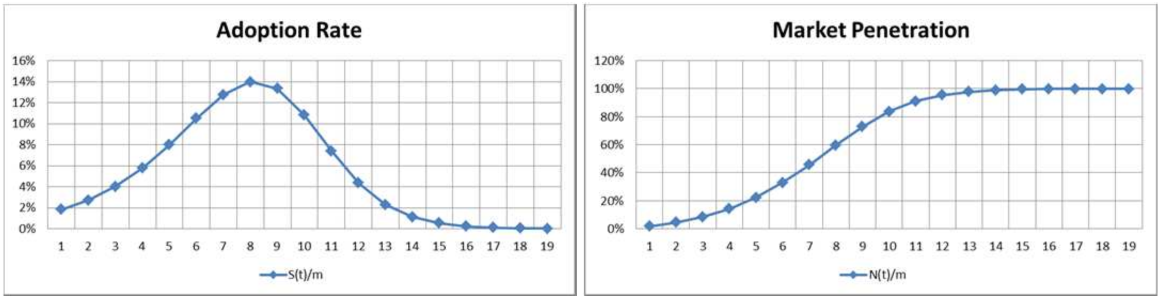

Figure 7. Market Diffusion Model for Fitness Tracker Technology

The results show that the adoption rate peaks at year 8 and the market saturates after year 15.This indicates that the window of opportunity is relatively small for research and development on this technology.

V. CONCLUSION

The TRIZ modeling method provided specific areas of technology and potential solution trends. As a next step, the areas can be prioritized using Delphi methodology which will then drive the specific areas that the technologists can target for further development.

The Bass Diffusion model reflects the high impact of imitators on the adoption model over the innovators, similar to those of cellular phone and ultrasound imaging. The adoption rate peaks quickly and thereby the market saturates in a span of about 15 years.

In summary, the research was a good demonstration of the usefulness of both the TRIZ and Bass forecasting models in developing technology R&D strategy. Putting together the findings from the application of TRIZ and Bass models to fitness trackers indicate that there is significant room for growth in the technology specifically in the areas of hardware and software components. The window of opportunity is relatively small (~8 years). However, these technology advancements are also applicable to adjacent markets in the wearable technology space such as advanced healthcare, vision/augmented reality and perception devices. Hence, the investment will be worth the return. The study was a holistic approach to the technology forecast, providing both the window of market opportunity, and specific technology areas to focus. The SWOT analysis can also be applied when developing the business strategy, another critical area of technology management.

VI. FUTURE WORK

The study can be further extended by applying Regression or TFDEA models to the specific segments of TRIZ model. This will further strengthen the TRIZ modeling technique by adding a time component to the technology evolution and determine realistic targets to achieve the ideal state of evolution of the segments analyzed. This information could be utilized when prioritizing the technology growth focus areas and developing the R&D strategy.

The approach on how a person navigates the system evolution trend in the TRIZ model warrants some attention. There are two aspects to this line of questioning, (1) how will you know the technology selections that you are making are on the right path towards the evolutionary limit and in some cases you may not be able to predict disruptive technologies that would bring about the evolutionary limit, and, (2) would a better approach be to identify a goal along the evolutionary trend and then work backwards towards the current state to identify the ideal evolutionary path.

One of the challenges in the diffusion model is the fact that there is no factoring of the impact of competition in the model perhaps increasing or decreasing the pace of evolution and adoption. The model is assuming the competition mix will remain similar to the analogous products of the past. In reality, however, with increased competition, there is a possibility that the evolution pace will be faster than that predicted in the model. This also reflects why there are also other factors that are applied to the area of technology forecasting, for e.g. scenario analysis.

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APPENDIX A: DATA TABLES

1. TRIZ model data table

Subsytem	Trend	Evolution	Current State	Score (out of 10)	Solution Generation Methods
Hardware	31. Reducing Energy conversions	etc. ==> **Three energy conversions** ==> Two energy conversions ==> One energy conversion ==> Zero energy conversion	* Battery Charging mechanisms generally vary 3-7 days * Needs to be connected to charge	4	(2h) Improve the properties/performance of the system as a whole. E.g. Allow battery charging remotely
	17. Mono-Bi-Poly (Various)	**Mono-system** ==> Bi-system ==> Tri-system ==> Poly-system	* Adding other sensors beyond accelometer are beginning to emerge	3	(1b) Multiply the Object (into 2, 3, ..., infinity) E.g. Add/Replace sensor technologies that can increase accuracy
	6. Webs and Fibres	Homogeneous sheet structure ==> **2D regular mesh structure** ==> 3D fibre, alignment according to load conditions ==> Addition of active elements	* Band that encircles the wrist	4	(2f) Change the phase, utilize the phase change, or change the inner-structure of the Object. E.g. A detachable device, potentially adapts as it is detached
	12. Dynamization	**Immobile system** ==> Jointed system ==> Full flexible system ==> Fluid or pneumatic system ==> Field based system	* Display is limited to device screen	2	(2d) Introduce/enhance a spatial Attribute or distribute/vary in space a harmful/useful Attribute or Attribute's value. E.g. Add projection display
Software	24. Market Evolution	Commodity ==> **Product** ==> Service ==> Experience => Transformation	* Sold as a product	4	(2h) Improve the properties/performance of the system as a whole. E.g. Improve the data analysis of fitness data
	9. Boundary breakdown	**Many boundaries** ==> Few boundaries ==> No boundaries	*Functions as fitness band	3	(2d) Introduce/enhance a spatial Attribute or distribute/vary in space a harmful/useful Attribute or Attribute's value. E.g. Combine notifications, clock, fitness tracking
	18. Mono-Bi-Poly (Increasing differences)	**Similar components** ==> Components with biased characteristics ==> Component plus negative component ==> Different components	* Current focus is limited to localized fitness tracking	3	(1b) Multiply the Object (into 2, 3, ..., infinity). E.g. Enable integration with health records
Form Factor	21. Increased use of colour	No use of colour (monochrome) ==> **Binary use of colour** ==> Use of visible spectrum ==> Full spectrum use of colour	* Most displays are still bi-chromatic	5	(2d) Introduce/enhance a spatial Attribute or distribute/vary in space a harmful/useful Attribute or Attribute's value. (3d) Introduce a new Function to assign to an Object. E.g. Add colors
	20. Increased use of senses	1 sense ==> **2 senses** ==> 3 senses ==> 4 senses ==> 5 senses	* Limited interaction available on existing bands	4	(3g) Realize the detection/measurement Function. (3h) Introduce/enhance the adapting/coordination/control Function. E.g. Add touch/functionality
	23. Customer Purchase Focus	**Performance** ==> Reliability ==> Convenience ==> Price	* Current focus is still performamce	3	(2h) Improve the properties/performance of the system as a whole. E.g. Improve accuracy/reliability

2. Analogous Products

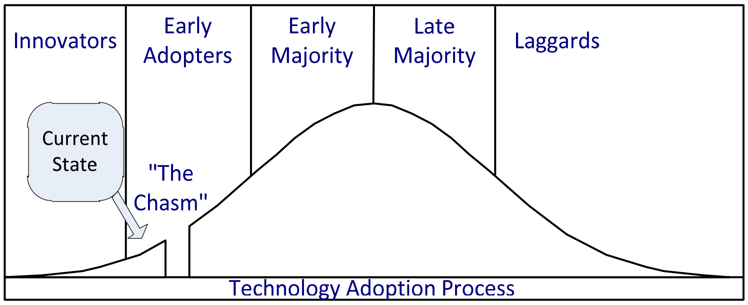
	Coefficient of innovators (p)	***Coefficient of imitators (q)***	Market Structure (W1 = 0.4)	Product Characteristics (W2 = 0.6)	Numerical Score	Weighted Numerical Score
Cellular phone (1986-1996)	0.008	0.421	8	1	3.8	0.267605634
Home PC (1982-1988)	0.121	0.281	3	1	1.8	0.126760563
Ultrasound imaging (1965-1978)	0.0013	0.6196	8	9	8.6	0.605633803
Weighted Average for Fitness Trackers	0.018266197	0.52353239				

3. Bass Model Results

t (years)	N(t)	S(t)	N(t)/m	S(t)/m
1	3.984385	3.984385	2%	2%
2	9.943844	5.959458	5%	3%
3	18.71519	8.771351	9%	4%
4	31.31508	12.59988	14%	6%
5	48.76829	17.45321	22%	8%
6	71.68536	22.91707	33%	11%
7	99.55629	27.87093	46%	13%
8	130.0546	30.49828	60%	14%
9	159.1553	29.10072	73%	13%
10	182.7598	23.60452	84%	11%
11	198.9203	16.16046	91%	7%
12	208.4419	9.521639	96%	4%
13	213.4651	5.023178	98%	2%
14	215.9397	2.474643	99%	1%
15	217.1143	1.174588	100%	1%
16	217.6615	0.547229	100%	0%
17	217.9142	0.252688	100%	0%
18	218.0304	0.116195	100%	0%
19	218.0838	0.053328	100%	0%

APPENDIX B: ADDITIONAL FIGURES

1. Technology Adoption Life Cycle



2. Sample of fitness tracker devices and applications

Jawbone App
Source: Fastcodesign.com

Pebble Steel

Fibit Surge

Nike Fuelband

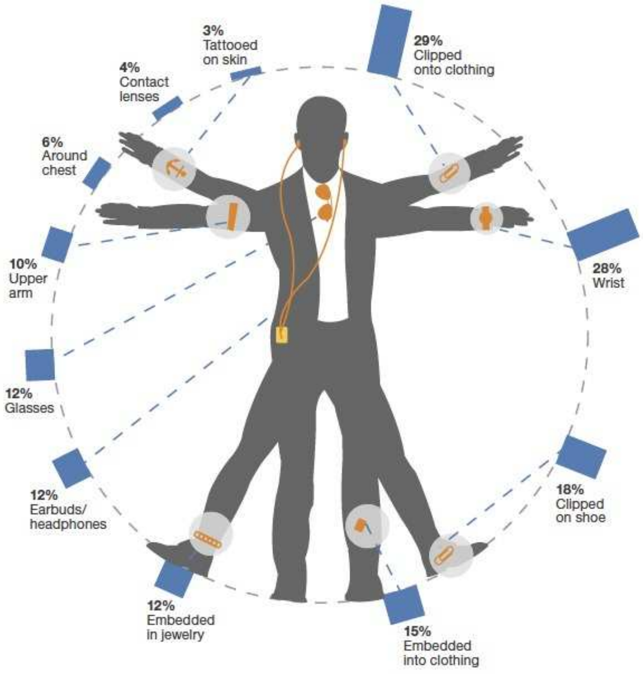
Apple Watch

Basis Peak

Jawbone Up

3. Location for wearable devices

"How would you be interested in wearing/using a sensor device, assuming it was from a brand you trust, offering a service that interests you?"



Base: 4,657 US online adults (18+)
(multiple responses accepted)

Source: North American Technographics® Consumer Technology Survey, 2013