Individual Portfolio

An Analysis of the Pebble Smartwatch as an alternative interface to the Smart Phone

Maria Foo

u5021276

Systems Engineering Analysis

The Australian National University

24 October 2014

Abstract

This paper uses systems analysis techniques as a tool to breakdown the Pebble smartwatch design, and recommends improvements to its design and performance. There are two sections to this paper: quantitative and qualitative analysis, as well as analytical models used to understand the smartwatch industry as whole, followed by more specific applications to investigate the Pebble smartwatch. This is done using the topics of human factors, and time analysis to improve user experience. Energy analysis, and optimisation and reliability are used to improve the performance of the device. Finally, materials and cost analysis are used to understand the impact of the device to their users and the surrounding environment.

Table of Contents

Introduction

Wearable technology has become more relevant due to the miniaturisation of hardware components, the availability of low cost sensors and the existence of widespread Internet access (Swan, 2012). Real-time data can now be delivered autonomously between connected devices to provide users with convenient access to information (Swan, 2012). This growth in the interconnection of devices is known as *The Internet of Things (IoT).*

The smartwatch is a consumer device that has the potential to proliferate the IoT movement in connected wearable devices (Swan, 2012). The current form of the smartwatch acts as a peripheral device to a connected smartphone (Bieber et al., 2013). It is designed to improve user experience by replacing microinteractions between people and their smartphone, such as viewing notifications and controlling music (Patterson, 2013).

The number of smartwatches sold globally has multiplied ten fold from 2012 to 2013 (Smartwatch Group, 2014). By the end of 2014, there will be 200 companies with smartwatch offerings, compared to 40 in 2013 (Smartwatch, 2014). Ultimately, the best smartwatch design will create a right balance between hardware performance, long battery life, and user applications in a stylish manner (Patterson, 2013). This paper investigates the smartwatch, in particular the Pebble watch, as an alternative interface to the smart phone, and recommends improvements to better align the design to the needs of the common user.

1.0 Quantitative Analysis

Knowing the amount of time users spend on their smartwatch can give an initial insight into how the device is used and any areas of potential improvement. There is limited study on the time spent by users interacting with their smartwatch, a Fermi estimate is calculated and compared to the results of a survey to determine this quantity.

1.1 Fermi Estimate

The smartwatch is designed to continuously receive information without direct user interaction (Rhodes, 1997). In this estimation, it is assumed that people purchase smartwatches as a complement to their smart phones. Hence, the length of time a user will directly interact with their watch is a proportion of the number of minutes people use their smart phone per day. A Fermi estimate results in 10 minutes each day. This is likely to be an underestimate because it does not account for GPS and tracking capabilities that may be better suited to the smartwatch. According to Analysis Mason

(2014), consumers spend 195 minutes per day on their smartphone. This would result in an upward adjustment to 20 minutes per day.

A survey on daily smartwatch usage was undertaken, and it was found that usage varies from approximately 30-40 minutes per day. Since smartwatch adoption is still in its early stages, most users are expected to vary from very limited direct interaction, such as solely using the device to check time, to heavy usage involving tracking (Spicer & Rizzoli, 2014).

2.0 Qualitative Analysis

Given the frequency of interaction between users and their smartwatch, a qualitative analysis is completed to understand what features of the device are commonly used, and what features need the most improvement.

2.1 Survey

A 2014 study of smartwatch users across the world by Spicer and Rizzoli found that most users do not use the extended functions available on their smartwatch. These include surfing the web, answering emails, using applications, and health or fitness tracking. The most common use of the device is to monitor the flow of personal information like emails, SMS, messages and twitter updates (Spicer & Rizzoli, 2014). A survey was created to assess smartwatch usage among smartwatch owners. These results aligned with the study, with most users depending on the smartwatch for notifications, and few using the tracking feature. Interaction with the device consists of reading and clearing alerts, changing timer settings, clearing checklists, and synchronising with the smartphone.

Users benefited most from their smartwatch by keeping track of messages without interrupting the flow of social interaction. The ability to check who emails were coming from without needing to open the message was also a valued function. Users agreed that they felt less ‘controlled’ by their smartphone since they no longer needed to locate their phone to check for calls or messages. However, the study found that when users wanted to do anything beyond checking information, they opted for a larger device such as a tablet or a laptop. Those who were most happy with their watch also exhibited the need to compulsively check their wrist for information updates (Spicer & Rizzoli, 2014).

2.2 Comparison to Quantitative Analysis

Qualitative analysis provides some insight into the use cases of the smartwatch, and the accuracy of the estimation in the quantitative analysis. Since the smartwatch is mainly used for notifications, it is reasonable to suppose that users would directly interact with their smartwatch from 10 to 20 minutes a day. This value would rise if smartwatch designers create better user experience in extended functions. The main purpose of the smartwatch at this stage is to act as an alternative interface to checking notifications sent to a smartphone, but does not necessarily replace the functionality of the phone.

3.0 Analytical Models

Future changes to the smartwatch are analysed using diffusion of innovation. Analysing where the market is heading is necessary to produce realistic improvements to the smartwatch design.

3.1 Diffusion of Innovation

In 2013, 1.23 million smartwatches were sold worldwide (MobiHealthNews, 2014). This is only 0.10% of the number of mechanical and digital watches sold in 2013 (Federation of the Swiss Watch Industry, 2013). The smartwatch industry is currently engaging innovators, meaning that the industry is in the middle of the technology development to acceptance phase (Browne, 2014). Challenges in their development are evident when one third of consumers stop using their smartwatch within the first six months of purchase (Ledger, 2014). Reasons that have been attributed to their abandonment include their large size, limited number of useful applications, and limited battery life (Arthur, 2014).

Pebble was the first smartwatch in the market, changes from its first generation are a smaller, but heavier case for aesthetic purposes (Pebble, 2014). Its competitors have incorporated more advanced features such as a complex graphical user interface and operating system at the expense of battery life (Johnson, 2014). However, most watches continue to synchronise their operations to the smart phone, with few maintaining an independent data processing model (Johnson, 2014). According to Patterson (2013), the lack of rapid change in smartwatch hardware growth is due to their dependency on the more powerful smart phone. The next revolution within the smartwatch industry will be to match battery life to the computational requirements of multiple processor cores (Bieber et al., 2013).

4.0 Human Factors

The user interface, and the dimensions of the smartwatch are explored with consideration of human factors to develop an ergonomic design that will better fit the global population.

4.1 Anthropometry

Anthropometric data for the 5^{th}, 50^{th} and 95^{th} percentile Japanese females and American males have been used to derive anthropometric measurements for wrist circumference, shoulder to hand length, and index finger width. This is done to represent the global market that the industry targets. Additionally, the lateral pinch force of females and males has been collected.

Dimensions for the watchband length, case diameter, button size, and button push force have been calculated. These represent exterior features of the smartwatch, which has been compared to the Pebble design. The large variation in measurements for females and males suggest that different watch dimensions are needed to comfortably fit each sex. Recommended lengths are generally higher for males than for females. Trade-offs have been made to determine one size fits all measurements for each sex. This is particularly true for the case diameter, since it has been chosen to be a value that can fit all 5th to 95th percentile wrist circumferences. Choosing such a value has resulted in larger sizing for the 5th percentile, optimal sizing for the 50th percentile, and small sizing for the 95th percentile, as seen in Figure 1 below.

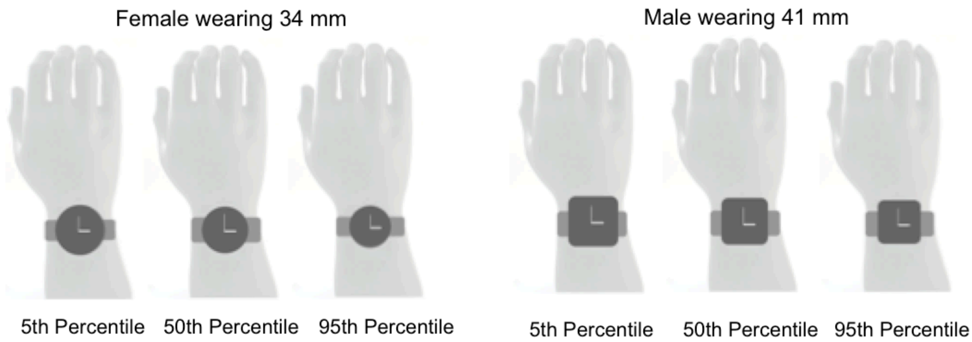


Figure 1 Case diameter sizes compared to wrist circumference

The Pebble watch, having a unisex design does not fall within the recommended anthropometric dimensions. The large case presents issues in comfort for both females and males, and the button size seems small, hindering it accessibility. Honig (2013) has criticised the significant press force of the four side buttons. A recommendation is to have a push force of at most 65N, which should result in a natural pinch force.

The font size has been calculated to determine the readability of characters in the smartwatch. 17pt font has been recommended for the optimal viewing angle of 22 arc minutes at a viewing distance approximately an arm’s length away. The Pebble watch recommends a between 14pt and 28pt font for active reading of texts and numbers (Pebble, 2014). Ensuring that long messages, such as notifications, are displayed at 18pt will improve readability for the user.

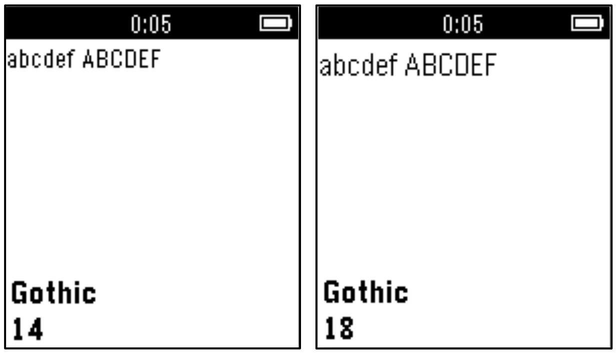


Figure 2 Minimum font size available (14pt) and Reading font size recommendation (18pt)

4.2 Ergonomics and Comfort

Comfort plays a large factor to the adoption of wearable technology (Garvin, 2013). Screen brightness on any electronic display should be greater than 35 cd/m^2, with a luminance higher than 100 cd/m^2 for faster and more accurate reading (Garvin, 2013). The Pebble watch uses a low-resolution black and white e-ink display that reduces glare from the sun (Pebble, 2014). A backlight powered by 3 edge mount LEDs allows the device to be used in dark areas (Pebble, 2014). The display is coupled with sans serif font, which is the recommended font type for lower resolution viewing (Gavin, 2013). This design seems to encourage short bursts of use, such as viewing notifications, rather than lengthy interactions with the device. According to Johnson (2014), better readability is a trade-off with energy usage, which is considered in the embodied energy analysis. Lastly, the Pebble watch does not include a touch interface for navigation. This has implications to the usability of the device, whose main navigation tools are four buttons on the side of the device. Time analysis will relate the usability of these four buttons, with the application program interface of the smartwatch.

Key Outcomes

Using anthropometrics, ergonomics and comfort, the following improvements are recommended for the design of the Pebble smartwatch.

Table 1 Recommended improvements for Pebble smartwatch design

Dimensions		Recommended		Pebble
		Female	*Male*	*Unisex*
Exterior	*Watchband Length*	173 mm	203 mm	178 mm
	Case Diameter	34 mm	41 mm	W: 33 mm, L: 50.8 mm
	Button Size	16 mm	19 mm	11.4 mm, 6.9 mm
	Push Force (Button)	64.84 N	97.02 N	--
	Luminance	> 35 cd/m^2		--
Interior	*Font Size*	17 pt		min:14 pt, max: 28 pt
	Font Type (lower resolution)	Sans Serif		Sans Serif

5.0 Time Analysis

The Pebble watch is a simple interface that operates using a hierarchy. The hierarchy starts with the watch face navigation menu where users can change their watch face design. The second level is the known as the main menu, where applications are stored. From here, the number of branches that expand are dependent on the function of the application, set by the developer who programmed them.

5.2 Queue Theory

Queue theory is used to find a critical path to open applications from the watch face in the Pebble interface. Opening frequently used application can become a repetitive task, and short cuts to this process are likely to increase user satisfaction (Stolze, 2014). The current method to do this takes 3 seconds, requiring 6 button pushes before the application can be used. In contrast, opening any application on a smartphone can take as little as four steps. By knowing that the desired application is not affected by the previous steps to reach the application, it becomes clear that the process can be crashed to a smaller time period.

5.2 PERT Analysis

The current system for navigation requires that all applications are launched from the main menu. According to Stolze (2014), applications are not directly integrated into the first level of the interface because they specify unique functions for the Up and Down navigation buttons. This disrupts the purpose of the navigation buttons for the watch face. The PERT chart for the current interface then requires going from watch face, to main menu, scrolling down the menu to find the application, and launch the application using the select button. The watch face can easily be accessed at any point of this process to go back to the first level.

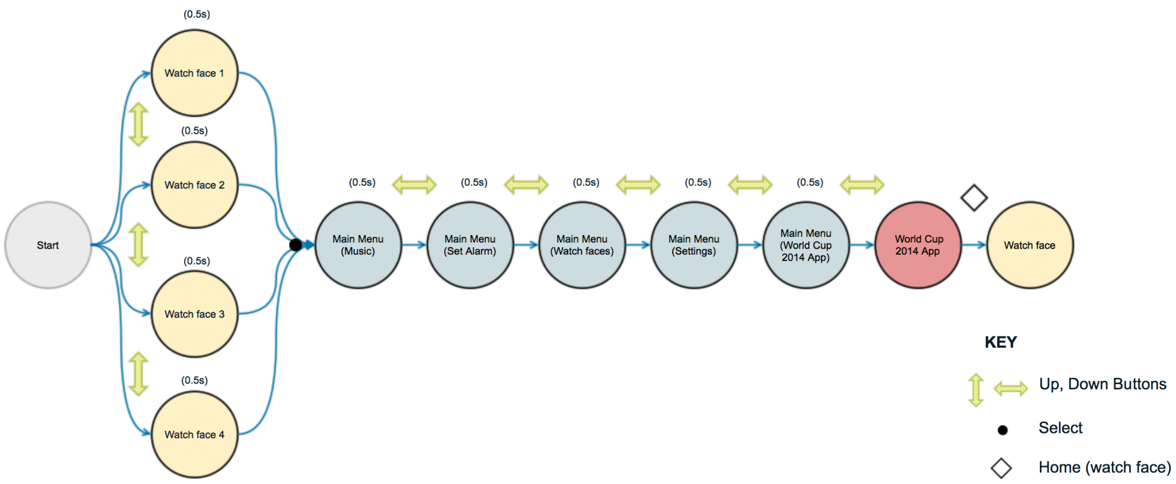


Figure 3 Current PERT chart for the Pebble smartwatch

Stolze (2014) suggests that the application can be placed in the first level by creating a preview-screen of the application that is clearly visually different. The preview-screen would require the user to press the select button in order to run the application. Applications can now have two states, preview and launched, which solves the issue of having different behaviour controls for the Up and Down button in the first level. The watch face navigation menu can be accessed normally until the application is run. The home button takes the user out of the application and back into the watch face navigation menu.

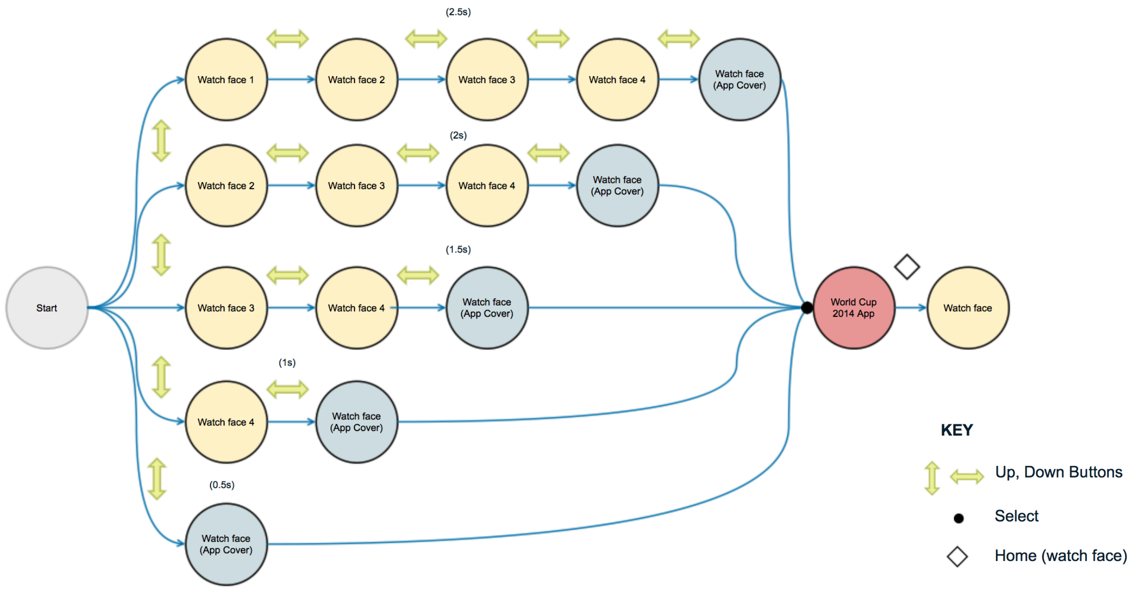


Figure 4 Improved PERT chart for the Pebble smartwatch

Key Outcomes

Placing the application at the start of the hierarchy in the watch face menu, rather than in the main menu removes the need to scroll through the main menu to find the application. The application of queue theory results in a minimum of 0.5 seconds (one button push) to a maximum of 2.5 seconds (five button pushes) before a user can access an application in this setting. The shortened time also reduces the energy expenditure of the system, since the backlight of the smartwatch is used less each time.

6.0 Energy Analysis

An energy breakdown of the smartwatch is undertaken by assessing the emissions produced by the Pebble smartwatch, creating an energy mass balance of the system, and by creating a Sankey diagram to view the largest sources of energy loss in the system. New opportunities to harvest energy are considered to improve the performance of the smartwatch.

6.1 IPAT and Energy Mass Balance

The I=PAT equation is used to investigate the energy emission of the Pebble smartwatch per charge. Equation 1 shows an I=PAT equation that breaks down the energy emission per hour into the number of hours used until the next recharge is required.

$$emissions = hours\ used \times \frac{battery\ consumption}{hour} \times \frac{CO_2\ emissions}{hour}$$

Equation 1 I=PAT equation of the Pebble smartwatch's energy expenditure per charge cycle

CO_2 emissions for every kWh is currently 850g in Australia (McHugh, 2013). The battery consumption of the Pebble watch per hour is 4mW, and the number of hours expected per recharge cycle is 120 hours (Pebble, 2014). This results in an impact of 0.408 g CO_2-e per recharge cycle, and 1.8 kg CO_2-e per year (see Annex E). This is very small, and compared to other smartwatches that require more frequent charges, the Pebble watch seems to be a very energy efficient watch.

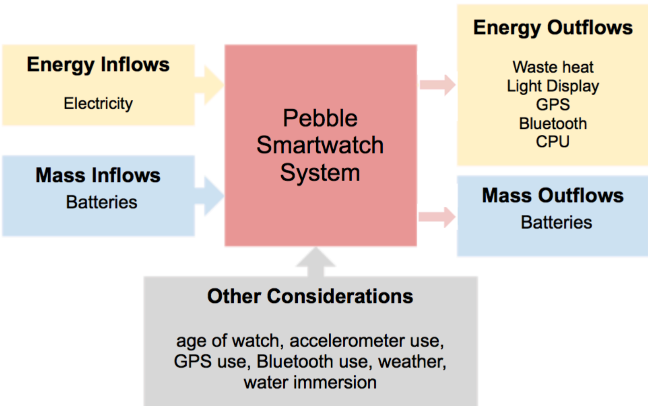


Figure 5 Energy Mass Balance of the Pebble smartwatch system

From the inflows and outflows of the energy mass balance, a Sankey diagram can be created to determine the components that contribute to the most energy loss.

6.2 Sankey Diagram

The Sankey diagram shows that 70% of the energy consumption is attributed to the CPU. Bluetooth connection to the smartphone comes second, consuming 27% of energy. This is followed by the LCD screen, which consumes 1.2% and other functions such as the sensor and backlight consuming 1.8%. According to Bieber et al. (2013), data processing is not done on the Pebble smart watch itself, but sent to the paired mobile phone. This paired system architecture between the smartwatch and smartphone base station allows for the device to be charged once every few days (Bieber et al., 2013). Pebble's low light consumption may be attributed to its monochromatic display, which has an ambient light sensor to regulate the screen brightness depending on lighting conditions (Bieber et al., 2013). A paired system architecture formed by Bluetooth, while beneficial to the smartwatch, decreases the smartphone's battery life heavily (Johnson, 2014).

Key Outcomes

For the smartwatch to succeed in becoming an interface to the smartphone, battery life must increase significantly for both devices, since interaction between the two are dependent on the energy intensive Bluetooth feature. Current mobile computing devices use rechargeable Lithium-ions batteries, which is difficult to scale with increasing computational demands (Hodges, 2013). The Pebble watch has increased battery life by increasing the efficiency of lighting features, such as the LCD screen. Nevertheless, designers must look into new ways of gathering energy than to create a trade-off between features. Carbon-fibre wearable super-capacitors are some of the emerging technologies that can be incorporated into the smartwatch to store energy from natural sources such as body heat, sunlight, body movement and ambient radio frequencies (Jost et al., 2013).

7.0 Materials Analysis

A materials audit is conducted to determine the embodied energy of the product. This gives insights into the efficiency of the product, where recommendations can be made to improve the design to better sustain environmental resources.

7.1 Materials Audit

The design of the Pebble smartwatch consists of a single main circuit board, and a single flexible printed circuit for buttons, shown in Figure 6. The approximate total embodied energy of the watch is calculated in the materials audit, and totals 107MJ. Compared to the iPhone with an embodied energy of 789MJ, this seems to be a reasonable value for an electric product (Synthesis Studios, 2009). The approximate functional life span of the device is the life span of the battery, which is approximately 6 years.

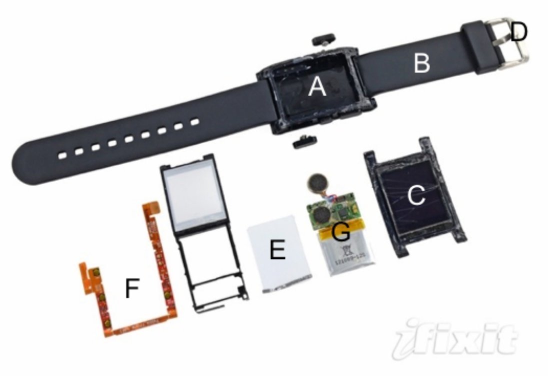


Figure 6 iFixit breakdown of the Pebble watch (Oliver, 2013)

The materials audit table for the Pebble smartwatch is available in Annex G. The table includes the approximate embodied energy for seven components of the smartwatch identified in Figure 6. The embodied energy values have been determined by estimating the proportion of total mass each component contributes to the device. Where values could not be found, such as for the e-paper used in the design, the material was approximated to the closest representative, an LCD display.

7.1 End-of-life Issues

The current model of the Pebble smartwatch breaks upon disassembly, which means individual components that no longer work require a whole new device replacement (Oliver, 2013). There is potential for improvement here, since the watchcase, watchstrap, watch crystal, and watch buckle have the potential to be recycled. The display, circuit board and battery contribute to landfill at the expiration date of the product. For electronic devices, this may be inevitable since continuous improvements in consumer electronics render old circuits redundant for more advanced technology.

Key Outcomes

The materials audit resulted in a total embodied energy of 107MJ for the Pebble smartwatch. The battery contributed to the greatest embodied energy in the system, followed by the circuit board, and the e-paper display. While the electronic components contributed to the most embodied energy of the system, they are also non-recyclable and contribute to landfill. This recyclability of electronic devices is a major issue that should be explored in the design of these devices in the future. The Pebble smartwatch in particular does not have any recyclability feature in its design. Broken components cannot be fixed, as the e-paper display breaks upon disassembly. A recycling program for non-electric components can be created so that there is less material wastage when consumers return broken products for replacements.

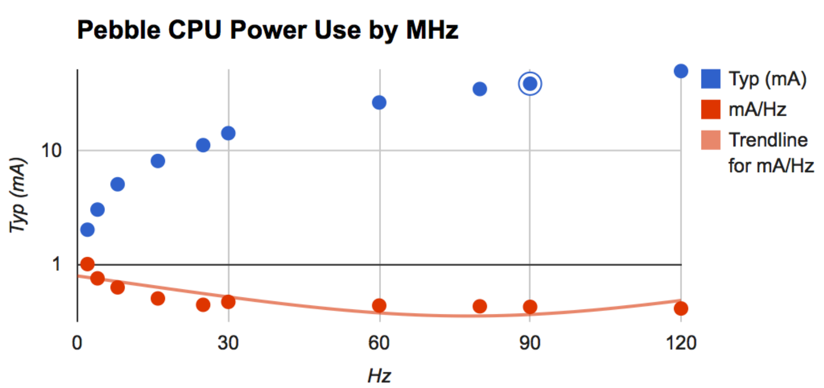
8.0 Optimisation and Reliability

The biggest challenge facing the smartwatch industry is optimising between computer processing power and battery power. There is a trade-off between these variables, and a Pareto analysis is conducted to better understand the trade-offs that can occur in such systems.

8.1 Pareto Analysis

The Pareto principle can be seen within the Sankey diagram, where nearly 80% of energy consumption is attributed to the CPU. Bluetooth and other components of the smartwatch system contribute to the remaining 20% of energy consumption, this follows the 80-20 rule. The current method of power management in the Pebble system is done through modules from STMicrolecetronics (Sangani, 2014). The brain behind the watch is an STM32 microcontroller, which has been optimised to work at very low power levels (Sangani, 2014). This has been relatively easy to achieve, as the Pebble smartwatch has not been designed to require powerful processing. The current design is minimising functionality in order to improve battery life, which is a large factor in the adoption of the device (Johnson, 2014).

The relationship between CPU power use and CPU clock frequency in the Pebble watch is depicted in the graph below. As the clock frequency increases, the CPU power use also increases at a decreasing rate.



MHz	Typ (mA)	mA/Hz
120	49	0.408
90	38	0.422
80	34	0.427
60	26	0.433
30	14	0.467
25	11	0.440
16	8	0.500
8	5	0.625
4	3	0.750
2	2	1.000

Figure 7 Pebble CPU Power against CPU clock frequency (Rajrdajr, 2014)

According to Luculent Systems (2012), the CPU clock frequency and the energy consumed to complete a task exhibits a bathtub curve relationship. The optimal CPU clock frequency can be higher than the lowest frequency. In fact, limiting the frequency to the lowest frequency will actually hinder performance and battery life than improve it (Luculent Systems, 2012).

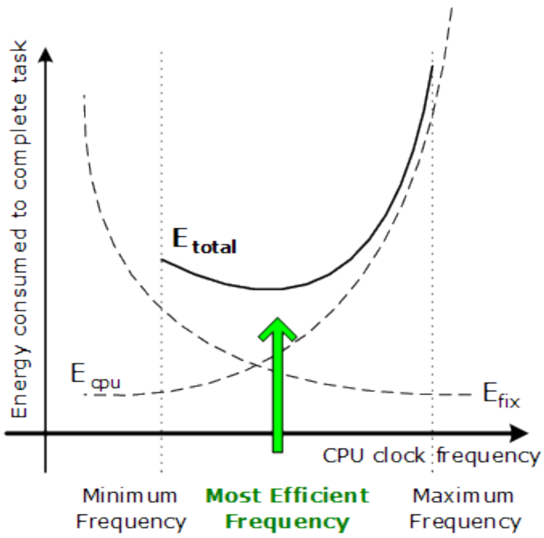


Figure 8 CPU Clock Frequency vs. Energy Consumption (Luculent Systems, 2012)

E_{fix} is the energy required to complete a task. The energy consumed to complete a task while the CPU clock frequency is very low increases due to the time required to complete the task. On the other hand, faster CPU clock frequency means less energy is consumed because the task is completed faster. E_{cpu} increases as the CPU clock frequency increases, and decreases as the frequency decreases. The combination of the two relationships presents an optimal frequency that consumes the least energy to complete a task. This frequency lies between the minimum and maximum clock frequency.

Key Outcomes

The optimal CPU power use and CPU clock frequency can be determined from application of this theory. Looking at Figure 7, the energy consumed per hertz seems to be most when clock frequency is low. It is least when the frequency is high. However, at this point CPU power is at its maximum. A clock frequency of 25Hz is then recommended to achieve the best energy trade-off between CPU power and CPU clock frequency.

9.0 Cost Analysis

Cost analysis provides insight into the financial obligations of owning a smartwatch. This analysis compares the Pebble watch to the Samsung Galaxy Gear 2 smartwatch, by considering acquisition and operation cost. The added cost of owning a Pebble watch to pair with an existing iPhone 5s (16GB) smartphone is then analysed.

9.1 Life Cycle Costing

Acquisition and operational costs are considered for life cycle costing for the purposes of the comparison. Maintenance of both smartwatches are not included, since the Pebble does not have spare parts, and because there is limited information on the maintenance for the Samsung Galaxy Gear 2, considering that it is a relatively new device. Other costs are not directly relevant to a consumer use case.

Calculations for cost of operation are in Annex G. The Samsung Galaxy Gear 2 has a higher operations cost than the Pebble smartwatch due to more power demanding features and lower battery efficiency. Using the Pebble smartwatch adds financial obligations to the user. The running cost of operating an iPhone 5s 16GB model with and without the Pebble is shown in Annex H, Table H2. Using the Pebble smartwatch increases costs to operate the smartphone by $0.1 per year, since pairing using Bluetooth reduces smartphone battery life by 30-40% (Martin, 2013).

9.2 Payback Period

With the fixed and running costs of owning a Pebble smartwatch identified, the total cost for ten years can be plotted against time to determine the financial costs relative to other products in the market, and personal financial costs when using in conjunction with a paired smartphone.

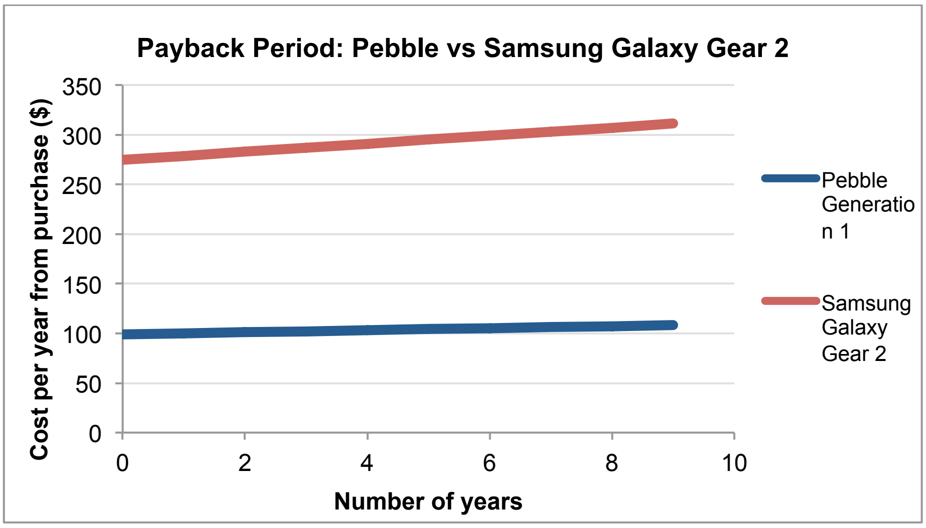


Figure 9 Payback Period for Pebble vs. Samsung Galaxy Gear 2

Key Outcomes

Compared to the Samsung Galaxy Gear 2, the Pebble has a lower acquisition cost and operational cost, due to its more efficient battery. It is one of the cheapest and most cost efficient smartwatches in the market due to its removal of additional functions such as touch screen mobility (Johnson, 2014). For an iPhone user who is also on a monthly plan, the smartwatch introduces a small fixed running cost over the duration of its use. The acquisition and operational cost of the smartwatch does not seem to have a significant financial effect on the original state of the user, although it contributes to more frequent recharging requirements for the smartphone.

Conclusion

Systems engineering analysis of the Pebble watch as an alternative interface to the smartphone has resulted in suggested improvements made to the design and performance of the smartwatch. In human factors, this is mainly to suggest different designs for females and males. In time analysis, the recommendation is to move the application menu to the watch face menu for faster access using less navigational steps. Conducting an energy analysis allowed better understanding of the energy trade-offs in the smartwatch to enhance battery life in optimisation and reliability. Materials analysis has given insights into inefficiencies in the production of the smartwatch. Reducing production costs by recycling can be an initiative to decrease costs associated with the Pebble watch, so it can be even more financially desirable in the cost analysis.

References

Arthur, C 2014, ‘Wearables: one-third of consumers abandoning devices’, *The Guardian,* April 1, viewed 20 October 2014.

Bieber, G, Haescher, M & Vahl, M 2013, ‘Sensor Requirements for Activity Recognition on Smart Watches’, *Proceedings of the 6th International Conference on Pervasive Technologies Related to Assistive Environments,* no. 67, pp. 1-6.

Browne, C 2013, ‘Diffusion of Innovations – ENGN2226 Online Classroom’, viewed 20 October 2014.

Extron Electronics 2014, ‘Font Size and Legibility for Videowall Content’, *Tech Library,* viewed 20 October 2014.

Federation of the Swiss Watch Industry 2013, ‘Wrist Watch Industry Statistics’, Statistic Brain, viewed 20 October 2014.

Forbes 2014, ‘How Much Energy Does Your iPhone (And Other Devices) Really Use?’, viewed 20 October 2014.

Garvin, K, Gonzalez, F, Ruegger, R & Santos, L 2013, ‘Design of small interfaces’, *Universitat Politecnica de Catalunya Barcelona Tech*.

Johnson, K 2014, ‘Literature Review: An investigation into the usefulness of the Smart Watch Interface for university students and the types of data they would require’, *Rhodes University Department of Computer Science,* pp. 1-24.

Ledger, D 2014, ‘Inside Wearables – Part 2’, *Endeavour Partners,* vol. 1, pp. 1-20.

Luculent Systems 2012, ‘Does lowering CPU clock frequency extend battery life?’, *TechBlog,* December 17, viewed 20 October 2014.

Martin, J 2013, ‘3 Reasons the Pebble smartwatch isn’t very small at all’, *CIO,* July 29, viewed 20 October 2014.

McHugh, B 2013, ‘Should Australia consider a nuclear future?’, *ABC Rural,* July 25, viewed 20 October 2014.

Milne, G & Chris, R 2013, ‘Embodied Energy’, *Australian Government Your Home.*

MobiHealthNews 2014, ‘ABI: 90M wearable devices to ship in 2014’, *Statista,* viewed 20 October 2014.

NASA 2008, ‘Man-Systems Integration Standards’, vol. 1, no. 3.

Narayanaswami, C & Raghunath, M.T 2000, ‘Application design for a smart watch with a high resolution display’, *The Fourth International Symposium on Wearable Computers,* pp. 7-14.

Oliver, S 2013, ‘Teardown finds Pebble smart watch unrepairable but built to last’, *appleinsider,* March 13, viewed 20 October 2014.

Patterson, S.M 2013, ‘How smartwatch designers should be designing smartwatches’, *Network World,* 30 October, viewed 20 October 2014.

Pebble 2014, ‘Handling Pebble Font Resources’, viewed 20 October 2014.

Rajrdajr, 2014, ‘Pebble Technical Specs’, *Reddit,* October 21, viewed 21 October 2014.

Rhodes, B 1997, ‘The Wearable Remembrance Agent: A System for Augmented Memory’, *Personal Technologies,* vol. 1, pp. 218-224.

Sangani, K 2014, ‘Is this a wind up?’, *Engineering & Technology,* January, pp. 36-38.

Scott, M & Sale, S 2014, ‘Consumers use smartphones for 195 minutes per day, but spend only 25% of that time on communications’, *Analysis Mason Insight,* May, pp. 1-2.

Smartwatch Group 2014, ‘Top 10 Smartwatch Companies (Sales)’, *Sample Visualisation,* June 14, viewed 20 October 2014.

Spicer, A & Rizzoli, A 2014, ‘Apple delivers smart watch, but you might think twice about getting one’, *The Conversation,* September 10, viewed 20 October 2014.

Stolze, M 2014, 'A Call for a Better Pebble Smartwatch Navigation Model', *Institut fur software,* July 13, viewed 20 October 2014.

Swan, M 2012, 'Senor Mania! The Internet of Things, Wearable Computing, Objective Metrics, and the Quantified Self 2.0', *Journal of Sensor and Actuator Networks,* vol. 1, pp. 217-253.

Appendices

ANNEX A – Fermi Estimation

Number of minutes people use their smart phones per day = 10^2 minutes
Number of minutes people use their smartwatch to interact with their phone = 10% or 1/10 minutes
Fermi Estimate: $10^2 \times 10^{-1} = 10\ minutes\ per\ day$

Number of minutes people use their smart phones per day = 195 minutes
Number of minutes people use their smartwatch to interact with their phone = 10% or 1/10 minutes
Fermi Estimate: $195 \times 10^{-1} = 19.5\ minutes\ per\ day$

ANNEX B – Survey

A survey was completed at two smartwatch forums:

1. forums.getpebble.com/discussion/17827/how-often-do-you-use-your-pebble-watch-per-day#latest
2. smartwatchforum.com/forum/index.php/topic/726-how-often-do-you-directly-interact-with-your-smart-watch-per-day/

The survey question asked how many minutes smartwatch users directly interact with their smartwatch per day, and how many minutes the watch is used for tracking per day. There were a total of 8 respondents. Three descriptive responses are below:

Response 1

During the weekdays when I'm off to my day starting in the morning, I frequently check my Samsung Galaxy Gear smartwatch, as it vibrates often because it's set to alert me about all the activities involving my favorites apps. I would say when I check my watch periodically, I'd spend about a minute on it. If you total it up, likely 30-40 minutes is the time I spend interacting with it throughout the day. As for tracking fitness, I'm not really using that feature from day to day cause I haven't gotten much time daily to exercise. On the weekends, I'm usually home. If there's time to workout, I'll use it for fitness tracking.

Response 2

Analysis wise, 24/7 as I monitor steps and sleep. Interaction is probably a couple of times an hour (during the day), as alerts come in and need reading and then clearing. Then a couple more times for things like timer setting, checklist clearing, sync initiating. And maybe another few seconds for watch-face change, as needs require. (Now I see why my battery doesn't last the 5 days).

Response 3 d

I use mine primarily during the day, and check all notifications probably a few times per hour (every 10 minutes I get at least 1email on average). I do use the step counter daily but have not used the sleep tracking as I do not want to sleep with a watch on. I also use a note pad that I use to remind me of things I need to complete.

ANNEX C – Diffusion of Innovation

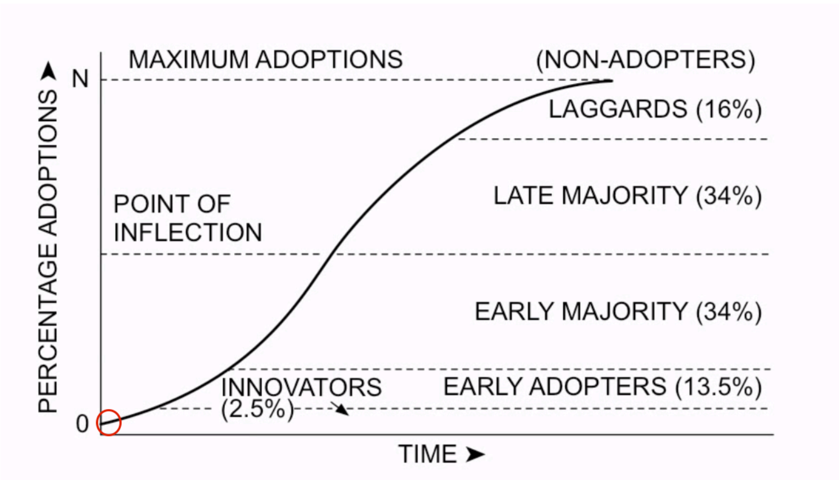


Figure C1 S-Shaped growth innovators represent the current adoption in the smartwatch industry (Browne, 2014)

ANNEX D – Human Factors

Anthropometric Measurements

		Female Percentiles			Male Percentiles		
ID	Dimension	*5th*	*50th*	*95th*	*5th*	*50th*	*95th*
967	*Wrist Circumference (mm)*[1]	137	150	162	162	177	193
751	*Shoulder Elbow Length*[1]	33.7	36.6	39.4	27.2	29.8	32.4
381	*Forearm Hand Length*[2]	44.8	48.3	52.4	37.3	41.7	45.5
	Index Finger Width (mm)[3]	16	18	21	19	21	23
	Lateral Pinch (N)[4]	29.8	64.84	99.88	41.68	97.02	152.36

[1] (NASA, 2008),[2] (United States Marines Corps, 1988), [3] (Bradtmiller et al., 2008), [4] (Astin, 1999)

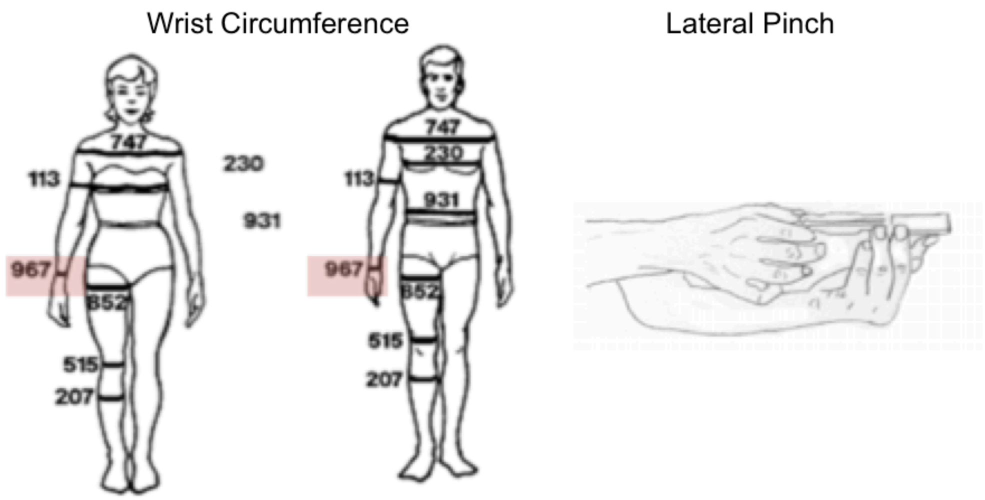


Figure D1 Anthropometric diagrams of wrist circumference and lateral pinch

Calculations

Watchband Length

Recommended: strap length = wrist circumference – watch case diameter + 44.45 mm

	Females (mm)	Males (mm)
5th Percentile	$137 - 34 + 44.45 = 147.45$	$162 - 34 + 44.45 = 172.45$
50th Percentile	$150 - 34 + 44.45 = 160.45$	$177 - 34 + 44.45 = 187.45$
95th Percentile	$162 - 34 + 44.45 = \mathbf{172.45}$	$193 - 34 + 44.45 = \mathbf{203.45}$

Case Diameter

Recommended: wrist circumference to watch diameter ratio of 4.6 (minimum 4.0 and maximum 5.0)

Females

	Minimum (mm)	*Optimal (mm)*	*Maximum (mm)*
5th Percentile	$\frac{137}{5.0} = 27$	$\frac{137}{4.6} = 30$	$\frac{137}{4.0} = \mathbf{34}$
50th Percentile	$\frac{150}{5.0} = 30$	$\frac{150}{4.6} = 33$	$\frac{150}{4.0} = 38$
95th Percentile	$\frac{162}{5.0} = 32$	$\frac{162}{4.6} = 35$	$\frac{162}{4.0} = 41$

Males

	Minimum (mm)	*Optimal (mm)*	*Maximum (mm)*
5th Percentile	$\frac{162}{5.0} = 32$	$\frac{162}{4.6} = 35$	$\frac{162}{4.0} = \mathbf{41}$
50th Percentile	$\frac{177}{5.0} = 35$	$\frac{177}{4.6} = 38$	$\frac{177}{4.0} = 44$
95th Percentile	$\frac{193}{5.0} = 39$	$\frac{193}{4.6} = 42$	$\frac{193}{4.0} = 48$

Button Size

Recommended: approximately equal to finger width

Females: Length = 16-21 mm (between 5th and 95th percentile values)

Males: Length = 19-23 mm (between 5th and 95th percentile values)

Push Force (buttons)

Recommended: approximately equal to natural lateral pinch

Females: Lateral Pinch = 64.84 (using 50th percentile values)

Males: Lateral Pinch = 97.02 (using 50th percentile values)

Font Size

Recommended: 20-22 arc minutes, 918 mm distance (from male shoulder to hand length)

Formula: Arc Minutes = $60 \tan^{-1} \frac{H}{D}$ (Extron Electronics, 2014)

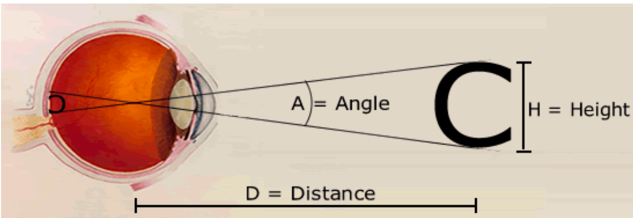


Figure D2 Character and symbol size (Federal Aviation Administration, date unknown)

Where A = 22 arcminutes, D = 918 mm:

$$\angle A = 60 \tan^{-1} \frac{H}{D}$$

$$H = D \tan\left(\frac{\angle A}{60}\right)$$

$$H = 918 \tan\left(\frac{22}{60}\right)$$

$$H = 6\,mm\ (17\,pt)$$

ANNEX E – IPAT Calculation

Where the number of hours used is 120 hours per recharge cycle, the battery consumption per hour is 4mW and the current Australian carbon emission per kilowatt-hour produced is 850g:

$$emissions = hours\ used \times \frac{battery\ consumption}{hour} \times \frac{CO_2\ emissions}{hour}$$

$$emissions = 120\ hours \times 4\times10^{-3}\times10^{-3}\ kW \times \frac{850g}{hours}$$

$$emissions = 0.408\ g\ CO_2\ per\ recharge\ cycle$$

This equates to $\frac{365\times24\times60}{120} = 4380\ recharge\ cycles \times 0.408 = 1787.04\ g\ CO_2\ per\ year = 1.8kg\ CO_2\ per\ year$

ANNEX F – Sankey Diagram

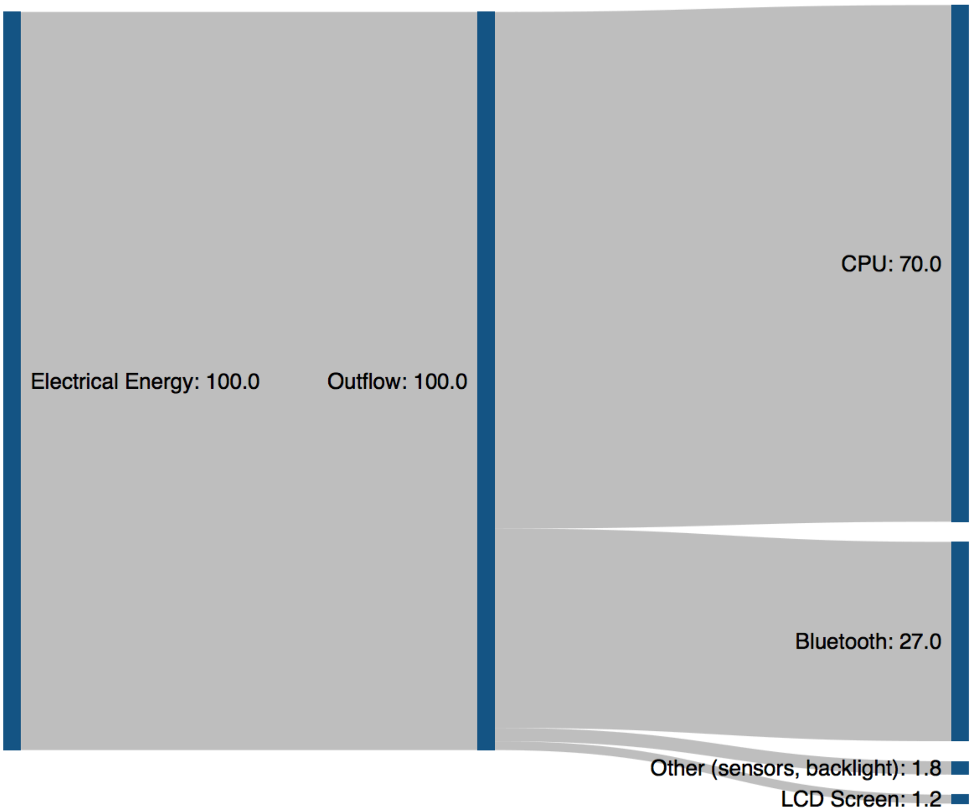


Figure F1 Sankey diagram for Pebble smartwatch

ANNEX G – Materials Audit

Materials Audit of the Pebble smartwatch

ID	Component	Material	Estimated Total Mass (kg)	Specific Embodied Energy (MJ/kg)	Embodied Energy (MJ)	End of life Destination
A	*Watchcase*	Polycarbonate	3×10^{-3}	105	0.315	Recycled
B	*Watchstrap*	Black TPU Rubber	3×10^{-3}	110	0.33	Recycled
C	*Watch Crystal*	Scratch-Resistant Polycarbonate	3×10^{-3}	105	0.315	Recycled
D	*Watch Buckle*	Steel	3×10^{-3}	56.7	0.1701	Recycled

E	*Display*	E-paper	$0.0015\ m^2$	3218 MJ/m_2	4.827	Landfill
F	*Circuit Board*	Circuit Board	1×10^{-3}	11880	11.88	Landfill
G	*Battery*	Lithium-ion Polymer	24×10^{-3}	3707	88.968	Landfill
				Total Embodied Energy	107	

Total weight of Pebble = 37g (including standard band)

ANNEX H – Life-Cycle Analysis

Cost of electricity is 30 cents per kWh (peak), 15 cents per kWh (off-peak)

Pebble battery specifications: 130 mAh, 3.7 V, 481 mWh, 5 days, 120 hours

Samsung battery specifications: 300mAh, 3.7 V, 1110 mWh, 3 days, 72 hours

Recharge cost per year = cost of electricity per kWh × power consumption per kWh × (365×25/battery life in hours)

Table H1 Life Cycle Costing for a Pebble smartwatch compared to Samsung Galaxy Gear 2

		Pebble	Samsung Galaxy Gear 2
Acquisition	Purchase cost	$99	$274.94
Operations	Recharging (peak per year)	$1.05	$4.05

Table H2 Life Cycle Costing for a Pebble smartwatch paired to an iPhone 5s 16GB model

	Pebble	iPhone 5s 16GB	iPhone and Pebble Running	iPhone and Pebble Total
Acquisition	$99	$0	$0	$99
Operations	$1.05	$70	$0.25	$71.3
Added Consumption			$0.1	$0.1

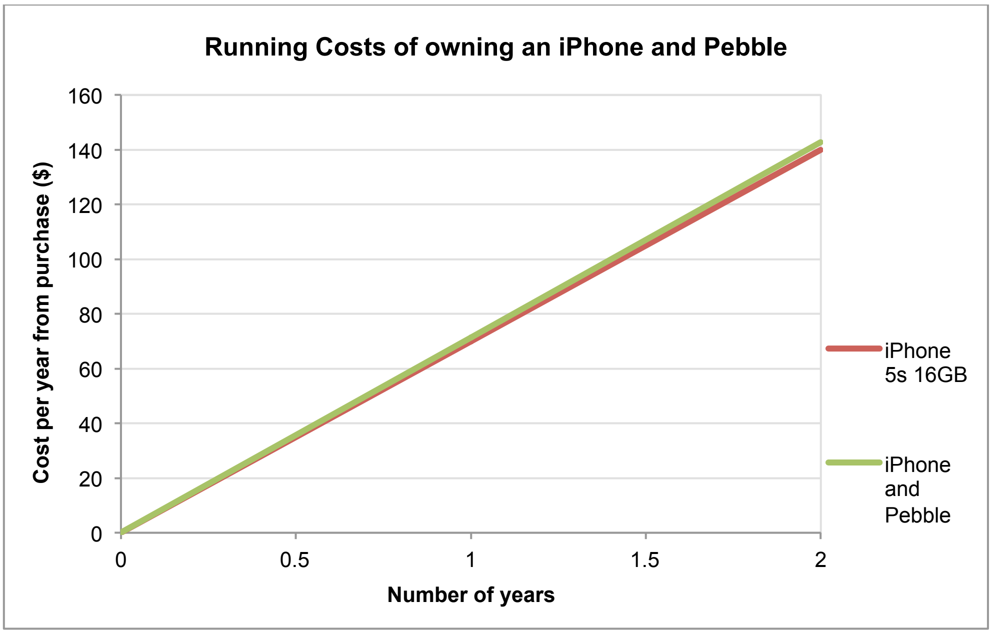


Figure H1 Payback Period Analysis for owning a Pebble watch