Determining the Feasibility of a Modular Smartphone: A Systems Analysis

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Abstract

In a fast paced technology industry, companies are releasing smartphone models annually and consumers are inclined to change smartphones approximately every 2 years. A modular smartphone is a hardware customizable mobile phone made up of separate individual components. This research project aims to determine the feasibility of a modular smartphone using systems analysis methodologies. Problem scoping incorporated a survey-based qualitative analysis along with quantitative data triangulation. The specifics of the system were then examined through anthropometric and ergonomic considerations as well as material and energy factors. As a result, design recommendations included having three models sized 4”, 5”, and 5.5” (diagonal screen length) with suitable lock button positioning, and the option of a synthetic leather backing or metallic finish. Taking an environmental approach comes at a significant monetary cost; a comparative life-cycle cost analysis of a traditional smartphone and an environmental smartphone was used to deduce this. Extended analysis included optimizations in two specific scenarios: a boot-up time optimization and a NFC pay-wave feedback system. The holistic result of this investigation was that the modular smartphone is a feasible venture given that hardware and software developers dedicate separate divisions to this project and communicate comprehensively, along with a marketing strategy aimed at mainstream smartphone consumers.

1.0 Introduction

The smartphone become increasingly evident in society due to its vast range of features reaching far beyond simple voice calling and texting – this includes multimedia (audio/video), internet browsing, instant messaging, widespread application databases and high resolution cameras (Suki, 2013). Since the smartphone has such a high level of convenience, the social need and dependency on smartphones has drastically increased in recent years. Furthermore, those with a strong need of socialization was found to correlate to their increased smartphone usage (Hooi, 2011). In short, there is great demand for smartphones in today’s society, and this trend is expected to continue into the future. Hence from a consumer demand perspective, a smartphone venture has great potential to succeed.

A modular smartphone is a hardware customizable phone made up of separate ‘blocks’ for each individual component such as the camera, battery, processor, GPS, and even the screen itself. These individual components are all connected to the main ‘board’, and the display screen fits the main board size (Yewale, 2015). These components can be easily removed and replaced, and so for instance, it is possible to upgrade the camera when desired, or if the battery performance is decreasing it can simply be replaced with a new unit. This concept reduces the need to dispose old phones for the sole reason of being unsatisfied with one or two components of it. Moreover, many smartphones come with costly hardware that are often of no use to some users, and so a modular smartphone would allow one to create the best device tailored to their specific needs. Several concept versions exist such as the Phonebloks social enterprise (Hakkens, 2013) shown in *Figure 1,* Project ARA led by Google (Gannes, 2014), and the Fairphone (Leonard, 2013).

Figure 1 – Phonebloks modular smartphone (Hakkens, 2013)

This report documents the use of various systems engineering analytical tools and utilizes its outcomes to make a set of recommendations, suggestions, modifications, and other important considerations in designing the modular smartphone and ultimately determining its feasibility. This project is not based on any previous concept models such as those mentioned above, it deals with particular design elements and vital considerations associated with them. *Table 1* below is a summary of the structure of the report, which incorporates a range of systems analysis methods followed by a summary of final outcomes and recommendations

Table 1: Overview of Systems Analysis Methodologies and Final Recommendations

Analysis	Description	Page
	Problem Scoping	
Qualitative Analysis	Qualitative data was obtained in the form of a survey. Using survey results and analysis, various factors were taken into consideration.	3
Quantitative Data Triangulation and Analysis	Quantitative data was analysed to aid the purposes of this research investigation. The inconsistencies and bias linked with the data were analysed.	4
	System Design Specifics	
Human Factors	Human factors such as anthropometry and ergonomics were considered in the design of the modular smartphone to establish a set of design requirements.	6
Material Factors	The smartphone materials were discussed and analysed from the perspective of embodied energy, comparing two different smartphones.	8
Energy Factors	Battery energy usage proportions were analysed through a Sankey diagram, and recommendations for optimizations were made.	9
	Extended Analysis	
Time Factors	Time-related factors such as boot-time were analysed using a PERT chart. Certain changes and modifications were suggested to optimize boot-up times.	11
Dynamics and Control Factors	The NFC Pay-Wave system was analysed as a feedback control loop. Optimizations were recommended after analysing the components of the feedback loop that are within the scope of the project.	11
Costing Analysis	A life-cycle costing was conducted and analysed for two different mobile phones: a traditional iPhone 5 equivalent modular smartphone, and a Fairphone 2 – an environmental and sustainable modular smartphone. Costs and other marketability implications were discussed.	12
	Recommendations And Outcomes	
List of Recommendations	Recommendations, modifications, and suggestions arising from each analysis were listed and discussed in a summary.	14
Conclusion	A summary of the outcomes and answering the research question.	15

2.0 Problem Scoping

At a preliminary stage, it was essential to scope the engineering problem in various ways. The main purpose of *Problem Scoping* was to develop the scope and boundaries of the research project, and to obtain a relatively clear direction of the general objectives of this investigation. The engineering problem was scoped via qualitative means through conducting a survey, and by gathering and analysing key quantitative data. The information obtained was vital to the project at an initial stage, before delving into the various physical and technical details of the modular smartphone itself.

2.1 Qualitative Analysis

A survey was designed with the purpose of obtaining a general understanding on the prevalence of smartphones today, and to receive an indicator of interest towards the idea of a modular smartphone. The survey formed the basis of the qualitative research for this project, and it helped to define introductory questions and points of focus for further analysis techniques (Greenhalgh, 1997). There were a total of 32 respondents for this survey. The survey and its results are shown in full detail in *Appendix 1.*

2.1.1 Smartphone Survey

1. Do you currently use a smartphone? [Yes/No]
2. How many smartphones have you owned, including your current device? [enter a number]
3. What were some reasons as to why you changed your smartphone(s)? [written response]
4. Which operating system(s) (OS) have you used? [Tick box, or written response for multiple]
5. What do you think about the idea of a modular smartphone? – indicate your level of interest in using a phone like this [brief description]
   Options: Not interested at all, Might consider it, Extremely Interested

2.1.2 Survey Outcomes and Analysis

The opening question was intended to be an easy introduction into the survey. Results showed that 100% of respondents currently used smartphones; in today's society, people are dependent on smartphones and this result is indicative of that. The next question is important as it indicates the number of smartphones people have owned and also indicates a level of dependency that people have on smartphones, and how prevalent smartphones are in peoples' lives in general. Also, this question gives a rough estimation as to how long people have been using smartphones for. Results showed that the respondents had owned an average of three smartphones. People tend to change mobile phone every 1.5 to 2 years on average and so the result of three smartphones means that the respondents have had smartphones for 4.5 – 6 years (Kline, 2015). A major contributor to this changeover period is the fact that typical mobile contracts last two years, with an option to change mobile three months before the end of the contract (Kidman, 2013).

The reasoning behind changing smartphones is investigated in Question 3 – this is the most significant question in this survey as it is gives key information for the research project. The top reasons for respondents moving onto new smartphones are summarized below.

- Poor battery life (battery degradation), wanted a phone with a new long-lasting battery
- Slow system speeds, wanted a phone with faster processing
- Features in newer models of phones interested them
- Other people had moved onto newer phones – keeping up with latest technology

The modular smartphone is a design based on individual components that are easy to customize, replace, and upgrade, and so understanding why people move onto brand new smartphones is key qualitative information. A main motivation consumers have when purchasing a modular smartphone, is to have the best qualities of each smartphone, and to have an 'all-in-one' device with high customisability. The question that asks about which operating systems people have used, is important because it indicates the level of familiarity people have with Android OS – modular smartphones are only being designed for Android OS (Yewale, 2015). Results showed that 38% of people had only used iOS, 28% of people had used both Android and iOS, 28% had only used Android, and 6% had used only Windows OS. Hence, 56% of people had some experience with Android.

The final question's purpose was to obtain general response on whether people seem to be interested in the idea of having a modular smartphone; they answered this question after reading a brief overview of the modular smartphone (shown in *Appendix 1 - Question 5*). The level of interest uses a three scale rating as shown above, and this is sufficient qualitative indication of whether people like the idea or not. Results showed that 50% of people 'might consider it', 41% were 'extremely interested', and 9% were 'not interested at all'. These results indicate that many people are be inclined to try out new technologies, and that technology interest levels are quite high.

2.1.1 Survey Demographics and Ethics

Although the survey results obtained indicate a strong positive response towards the implementation of a modular smartphone, it is crucial to note and analyse the demographics of respondents. The majority of respondents were undergraduate students of ANU, particularly those studying engineering. A small percentage were also middle age full-time working adults. Undergraduates are young adults that tend to be more tech-savvy than middle age adults and older population groups, and furthermore, engineering students may be seen as more inclined towards trying new technologies. Due to these factors, there is a certain level of partiality in the qualitative data obtained, and so a broad scale survey covering a larger range of age groups would be required for a better and more realistic perspective (MacNamara, 2014). Ethical considerations were made upon designing the survey. The survey was held on SurveyMonkey and all questions were based around smartphone usage; personal details such as gender or age were not asked as this did not contribute to the purpose of the survey mentioned above. As a result, respondents were not required to input any personal detail and thus the survey upheld ethical standards.

2.2 Quantitative Data Triangulation and Analysis

As part of the scoping of the engineering problem, quantitative data regarding smartphone usage behaviour patterns was gathered. This was done with the purpose of gaining insight into the main functions that people rely on their smartphones for, and the quantitative data associated with this.

2.2.1 Distribution of Time Spent on Smartphones

The following data is from a paper presented at a Mobile Business Conference in 2010, published through the IEEE Computer Society. *Figure 2* below uses face-time application measures to give an overview of how people use their smartphones. This quantitative information was sourced from the MobiTrack Global Smartphone Study conducted during 2008 and 2009 – a project analysing smartphone trends and tendencies. The data was gathered primarily through numerous surveys, targeting adults (Verkasalo, 2010).

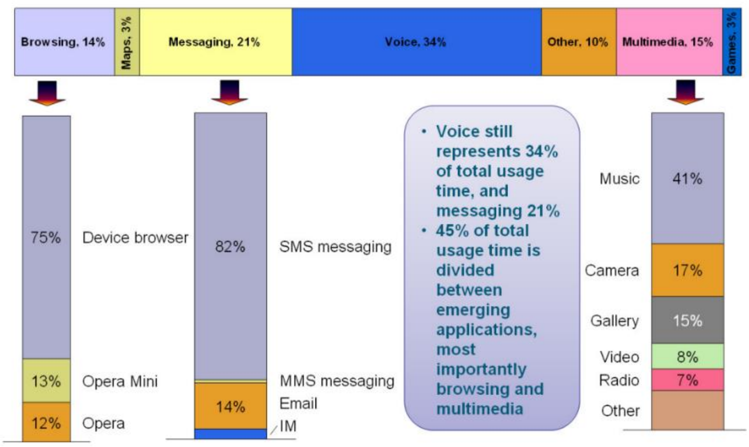

Figure 2 - Overview of smartphone usage – IEEE Computer Society research (Verkasalo, 2010)

Voice functions (primarily calling) and messaging are the two most common uses at 34% and 21% respectively. Multimedia (15%) and browsing (14%) are the next common functions. Multimedia includes music, taking pictures with the camera, viewing photos, videos, and other similar functions.

Error Analysis and Discussion

There are various errors and inconsistencies that should be considered when analysing this data. Firstly, this data does not show which operating system was being used; different operating systems have different capabilities. The data may be biased if a large percentage of people were using a particular OS that had a vast range of multimedia playback options, for example. This would then be somewhat uncharacteristic of the true percentage, since one OS was being favoured in the sample space. The context is important as this data is approximately six years old; smartphones have drastically evolved since then. Although this quantitative data is still useful as it shows general trends in smartphone usage, it is not indicative of the current trends, which are likely to be different to some degree. The significance of social networking in today's society is vastly different to that of 2009, and as a result, smartphones now boast a large range of social networking features. Therefore, it can be correlated that instant messaging percentages would have increased, as well as certain multimedia percentages (that is, the percentage of screen time used by these applications).

2.2.2 Proportion of Consumers Using Particular Smartphone Capabilities

Princeton Survey Research Associates International conducted a series of telephone interviews in USA during 2013 regarding smartphone usage, with a sample of 2,252 adults. The data is presented below in *Table 2*.

Table 2: Smartphone Usage Statistics

Activity	% of people who use their smartphone for this activity
Text Messaging	81
Internet Browsing	60
Email	52
Downloading and using applications	50
Location services (e.g. Maps – GPS)	49
Music	48
Video call/chat	21
Sharing current location	8

Sourced from a Princeton research survey (Duggan, 2013)

Sampling Error and Data Analysis

Using a statistical analysis from a confidence internal perspective, the Princeton research survey claimed to be 95% confident that the sampling error was ± 2.3%. The claimed sampling error for network browsing users was ± 2.5%, for which the sample was 1,895. Furthermore, there were errors were associated with the communication of the questions through telephone conversation. Respondents may have misinterpreted questions, and this would introduce errors in the results obtained (Duggan, 2013). A particular downfall in this quantitative information is that there is no data for simple voice calling; it was assumed that this question was omitted in the survey since voice calling is the main purpose of a mobile phone. Using the previous 2010 data analysis, it can be safely assumed that the vast majority of smartphone users would indeed be making and receiving calls. Similar to the 2010 data from the IEEE survey, this data does not indicate the operating system(s) being used. Also, this is an American survey and therefore it is not representative of the world's usage tendencies. Nevertheless, a relatively large sample was used for this study and hence it provides fairly accurate smartphone usage tendencies.

2.2.3 Quantitative Data Triangulation Outcomes

Although there are various sources of inconsistency within the data sets obtained, the quantitative data still aids the purposes of this research investigation. Calling and texting, internet browsing and emails, and third-party applications (on the Android platform) should be the main internal concerns when designing a new modular smartphone. Secondary considerations would include the camera, multimedia playback, and location services. A main qualitative criteria that was found through the survey was to improve battery performance. If the areas of concern provided by the triangulated quantitative data are enhanced, they may negatively affect battery life and so this is a contradictory factor. Hence, it would be beneficial to improve these internal factors such as internet browsing and applications from a battery conservation point of view.

3.0 System Design Specifics

This section of the systems analysis delves into the specific design elements of the modular smartphone, using a variety of analytical tools such as human considerations, material factors and energy analysis.

3.1 Human Factors

There are numerous human factors within various aspects of the system that need to be considered when designing and building a modular smartphone. The system boundary chart shown below in *Table 3* is a list of human factors and considerations, separated into endogenous factors (within the modular smartphone itself) and exogenous factors (outside of the smartphone - external).

Table 3: System Boundary Chart – Human Factors

Endogenous	*Exogenous*
Smartphone screen size	Hand size, anthropometric ratios
	Population data, demographics,
Smartphone dimensions (size)	Human eyesight ability in relation to brightness, saturation, resolution, etc.
Smartphone weight	Special considerations for vision impaired persons
Positioning of lock/sleep button, home button	Hearing ability
Positioning of secondary hardware/software buttons	Special considerations for hearing impaired persons
Screen resolution, pixel density (PPI), brightness, saturation	Hand grip ability considerations
	Hand preference (left/right)
Back cover material	Hand temperature resistance/comfort level
Loudspeaker positioning	
Font (Android OS based factor)	

Table 3 above is a comprehensive breakdown of human-related factors that must be considered when designing a smartphone. For the considerations presented below, important factors from the *Endogenous* section were analysed: smartphone size (based on screen size), positioning of lock/sleep button, and back cover material.

3.1.1 Anthropometric Considerations and System Recommendations

The size of the modular smartphone, as seen above in *Table 3*, is a crucial anthropometric factor. Various holding styles and positions were analysed. These include one handed use, cradled (secondary hand cupping the phone), and full two handed use – a visual representation can be seen in the *Appendix 2* (Hoober, 2013). This factor of size directly relates to the effectiveness of the smartphone, as a phone size that is well-suited to a particular user's hand will maximise their ease-of-use and also productivity while using the device. The analysis in this research project uses the diagonal length of the touchscreen in inches, as a basis of sizing the phone, as opposed to the physical dimensions of the device. Research has shown that the relationship between hand length and palm width, and required touchscreen size is proportional; the study used error rates and subjective fatigue as appropriate measures to come to this conclusion (Lin, 2013). Incorporating this study into the analysis, the general approach to creating the different sizes for the modular smartphone models was to use the latest prevalent smartphones as a guideline, instead of hand dimensions. It was decided that three different screen sizes must be implemented to cater for different hand sizes – namely 4", 5", and 5.5". The 4" size is comparable to the iPhone 5/5S, the 5" size is comparable to the Samsung Galaxy S6 and iPhone 6/6S, and the 5.5" size is comparable to the Samsung Note series, LG G4, and iPhone 6/6S Plus (GSMArena, 2015). If hand anthropometric data was used for this analysis, it is expected that a similar outcome would have resulted. Additionally, having too many different screen sizes would increase the cost significantly – the acquisition of the display screen is a significant cost itself and this is investigated in *Cost Analysis.*

3.1.2 Ergonomic Considerations and System Recommendations

Lock Button Positioning

Staying within the aspect of smartphone dimensions and hardware design, another significant design element lies in the positioning of hardware buttons, as outlined in *Table 3* above. The button that needs the most consideration is the positioning of the sleep/lock button, as this is the most frequently used button along with the 'home' button. The sleep/lock button must be positioned such that the user has optimal ease-of-use and efficiency. Gathered data indicates that 49% of people use their phone with one hand, 36% use one hand with the second hand as a cradle, and 15% use a completely two-handed style – the data is shown in *Appendix* (Hoober, 2013). Taking this into account, it was decided that the 4" model would have its lock button on the top right of the device, and the 5" and 5.5" model on the right edge – this is seen below in *Figure 3.*

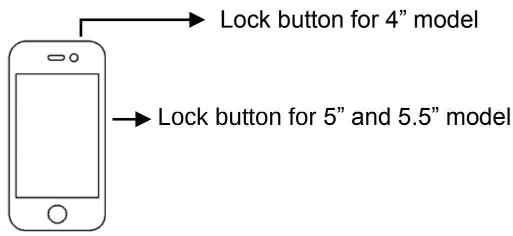

Figure 3 – Lock button positioning for different size models of the modular smartphone

Back Cover Material

Another ergonomic factor lies in back cover material – the surface that smartphone users will be gripping onto. There are a variety of different materials used in smartphones today, such as leather backs as seen on the LG G4, metallic finishes as seen on the iPhone, tempered glass used by the latest Samsung Galaxy, plastic back covers for cheaper models, and others. Although users can personalize their phone through cases, the primary surface material of the phone still remains a crucial design decision. Steering wheel design and manufacturing research determined that leather which was coated in a urethane mixture produced the highest level of grip (Murata, 2011). To improve user ergonomics, leather was decided as a back cover option, for those who are looking for the best grip and feel possible. Recent trends in iPhone and Samsung Galaxy high-end models show that consumers who are after a premium feel prefer metallic material, and so this was decided to be an option for the back cover. It is expected that those who opt for the 5" or 5.5" model of the modular smartphone may intend on a very high-end device.

Synthetic leather is an alternative to natural leather which could be used. The majority of leather is obtained from cows, using on average 473 litres of gasoline and petroleum components for fertiliser, 4.5 ML (megalitres) of water along with many other supplies to harvest the hide from a single 36 kg calf grown to its full size (Burns, 2014). Synthetic leather on the other hand, is made through laminations of a mixture of resins including polyurethane and other PVC based resins (Xia, 2009), and as such the production effort is significantly lower. Hence synthetic leather is a better alternative compared to natural leather, from a production and life-cycle point of view.

Other ergonomic factors that should be considered in the modular smartphone build includes usability functions, and finger-touch areas and layouts that would optimize the touchscreen area (Inostroza, 2012) (Park, 2010). This part of the ergonomic analysis was determined to be out of the scope for this project, as it requires significant communication with touchscreen manufacturers.

3.2 Materials Factors

An embodied energy based materials analysis was carried out. Initially, a materials audit was conducted for two smartphones – HTC Dream (2009) and iPhone 3G (2008) as seen in *Table 4* and *Table 5* below (GSMArena, 2015). As the modular smartphone is fully customizable, it means that many combinations of parts are possible and hence one model is not being repeatedly manufactured. The embodied energy ratio was calculated using EE ratio = EE / (mass × 10^3) which gives units of kilo-joules per gram.

3.2.1 Materials Audit for Two Smartphones

Table 4: Materials Audit - HTC Dream

Material	Quantity/ Mass (g)	Embodied Energy (J)	Embodied Energy/Mass Ratio (kJ/g)
Electronics/Circuits	51	2,550,000,000	50,000
Plastic	44	4,400,000	100
Metal (combined)	58	2,320,000	40
Manganese	2	432,680	216.34
Glass	5	110,000	22
Manufacturing	-	134,992,500	-
Transportation	-	581,253	-
Disposal (Landfill)	-	14,400	-
Total	160	2,692,850,833	-

Table 5: Materials Audit - iPhone 3G

Material	Quantity/ Mass (g)	Embodied Energy (J)	Embodied Energy/Mass Ratio (kJ/g)
Electronics/Circuits	10	326,400,000	32,640
Plastic	27	2,700,000	100
Aluminium	14	2,496,555	178.33
Glass	20	445,500	22.28
Other	74	7,425,000	100.34
Manufacturing	-	450,000,000	-
Transportation	-	502,640	-
Disposal (Landfill)	-	13,014	-
Total	160	789,982,709	-

The data above was gathered from Synthesis Studios: Materials – Embodied Energy Database (Synthesis Studios, 2009). The data presented above assumes that the HTC Dream (released 2009) has an average lifetime of 5 years, while the iPhone 3G's (released 2008) is 2 years (Synthesis Studios, 2009) (GSMArena, 2015). There are certain flaws and inconsistencies of the data displayed in the materials audits. The 'other' material in the iPhone material audit is not clear and therefore cannot be analysed. Also, the 'metal' in the HTC Dream data gathered is very ambiguous, as the type(s) of metal is not specified. The HTC's metal EE Ratio is more optimum than the aluminium in the iPhone, and so this must be investigated further at a later stage in the planning of this modular smartphone project.

The analysis approach was to conduct an embodied energy life-cycle investigation for the option of using a traditional smartphone replaced every two years, and the option of using a modular smartphone and replacing parts when necessary. Firstly, the total embodied energies for the two smartphones above were scaled with respect to their lifetime, to obtain a mean figure of 467 MJ of embodied energy per year – this was an estimated value for the embodied energy of a "traditional smartphone". For the modular smartphone, embodied energies were estimated while considering their replacement period. CPU and RAM embodied energies were assumed from the electronics/circuitry data (200MJ) from the materials audits above, and they would require replacement approximately every two years to keep up with latest processing technologies (Poeter, 2014). The battery is a component that would be replaced yearly to maintain optimal performance, and this embodied energy was estimated to be 100MJ. To keep up with latest camera resolutions, a two year camera replacement period was estimated, and glass embodied energy was used to derive the figures – it was estimated to be 2MJ. A three year period was set for the screen replacement, and glass was used as the embodied energy estimation measure – this figure was 60MJ. Additional replacements of smaller modules were assumed to be approximately 20MJ per two years. The graphical analysis is seen below in *Figure 4*.

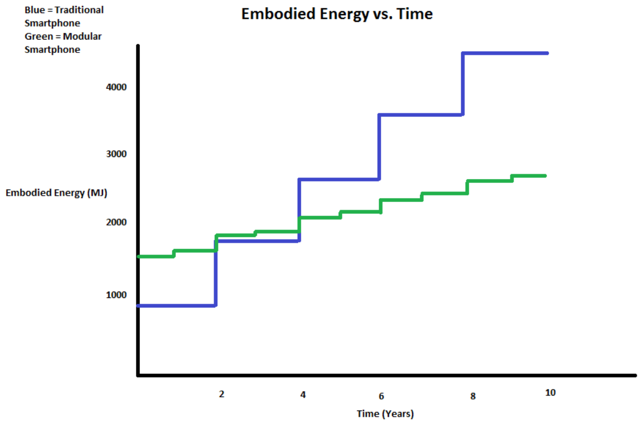

Figure 4 – Embodied Energy vs. Time, blue = traditional smartphone and green = modular smartphone

It can be seen that although the modular smartphone has a higher initial embodied energy (due to its scattered manufacturing from different developers and technical integration), its increase in embodied energy on a yearly basis is much lower than that of the traditional smartphone being replaced every two years. Therefore, in the long run at approximately four years, the modular smartphone is the better option from an embodied energy standpoint.

3.3 Energy Factors

Smartphone energy consumption has been researched for many years in recent times, and has gone through numerous optimizations. For this energy factors analysis, the energy loss flow of a normal smartphone was analysed and this is seen below in the Sankey diagram in *Figure 5*. The figures were obtained from a UNSW published article regarding the power consumption of smartphones (Carroll, 2014).

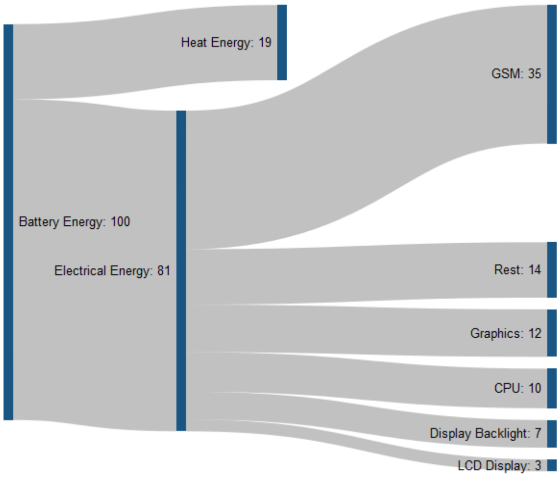

Figure 5 – Sankey Diagram of Energy Flows in a Smartphone

The Sankey diagram above in Figure 1 uses a relative scale of a 100% breakdown for simplicity. Analysing the electrical energy branch, which uses 81% of the total energy, it can be seen that the GSM (Global System for Mobile Communications) is the largest consumer of energy (Carroll, 2014). Using the Pareto principle, this is the first issue to tackle in order to make significant energy optimizations. GSM includes the 3G/4G networking that is built into most smartphones today. The GSM module of the smartphone should be as optimized and efficient as possible. Since the modular smartphone is customizable, if users are not wholly reliant on mobile internet then they can choose to omit a 4G network module which would result in saving much energy and battery life as well as saving costs too. Another area that can be optimized is in graphics – Qualcomm are one of the leaders in the mobile graphics world and so their optimized GPUs could be implemented into the modular smartphone.

There are certain discrepancies in the data gathered for the Sankey analysis above. The 'rest' category is ambiguous and its contents are unknown so they cannot be accounted for in the analysis. It is likely that this 'rest' category relates to the energy consumed by background and standby operations that are ongoing while the phone is in 'sleep' mode. A point to consider is that since the modular smartphone is a system designed for the user, and so the user will most likely care about factors such as battery life compared to energy consumption. This is why it is crucial to implement energy optimizations in new generations of every hardware aspect possible (Navazo, 2014).

4.0 Extended Analysis

This section of the research portfolio consists of investigations that are significantly in-depth and internal within the modular smartphone system, yet still vital aspects to analyse for this project. Firstly, a time-based approach is used to optimize the process of booting up an Android smartphone. Following this is an in-depth look at the implementation of an NFC module from a dynamics and control perspective, which is a modern innovation that many users will be interested in, as users aim to have the latest features on their brand new smartphone. Since the motivation of a modular smartphone is to essentially 'pick and choose' the different components that the user is after, the NFC will be an optional add-on. Lastly, as part of an extended analysis for this modular smartphone project, a cost analysis consisting of a life-cycle costing breakdown was conducted.

4.1 Time-Based Factors: Boot-Up Process

Temporal factors come into play when considering various software and internal aspects of the modular smartphone. A crucial time-related consideration is the time it takes to boot the OS from a powered-off state. Currently, it takes smartphone users approximately 30 to 40 seconds to power on the device. Research was conducted into the optimization of the Android OS boot up time. Different boot methods have been studied, namely a) U-Boot-Fast-Boot, b) Start-up with Suspend Resume, c) U-Boot-Fast-Boot with enhanced read speed, and d) U-Boot-Fast-Boot with enhanced read speed and additional minimal suspend image (Yang, 2014). Method a) was analysed, and this process was contextualized in the form of a PERT chart, as seen below in *Figure 6*.

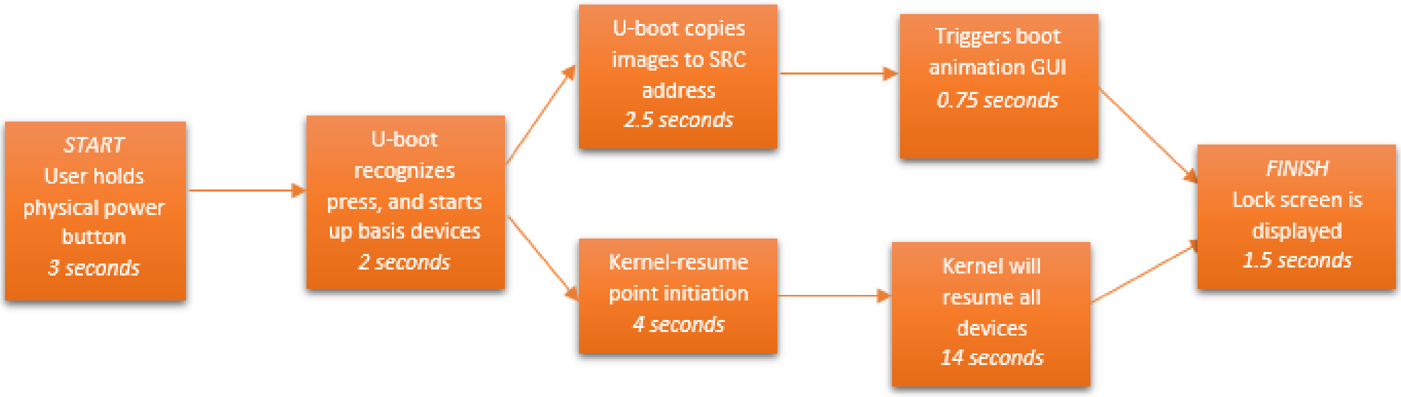

Figure 6 – Android OS Boot-up Process

The situation being analysed here is from the moment the user holds the power button to power the device on, to the point that the lock screen is displayed and fully functional, ready to be unlocked. The total time taken is 24.5 seconds for a typical boot up at a stock system state (no customisation). The second sub-process mentions basis devices which refers to the powering on of hardware components. Now, as with any time related OS function, there is room for improvement and optimization. It was found that the most time consuming element of the booting process was within the kernel-resume phase, particularly “Kernel will resume all devices” which has a duration of 14 seconds. During this phase, the Android OS user space is being initialized which means that applications and services are being started. This optimization would require Android OS developers to work collaboratively with third-party app developers to optimize the initialisation process by minimizing background tasks and other aspects.

Faster boot times provide the benefit of being able to access your smartphone as quick as possible, and is also beneficial for system diagnostics and error related restart times. Staying within this theme, data would also be required for the powering down process as well, and perhaps the boot up and powering off data can be used in conjunction to form an on/off system that is much more efficient and significantly faster. This can be done in future research within Android OS development, but it is out of the scope for this research project.

4.2 Dynamics & Control Analysis: Optimization of the NFC pay-wave system

A new and innovative hardware feature that is on the rise in mobile technology, is Near Field Communication (NFC). This is a technology that allows data to be transferred back and forth in a ‘contactless’ manner, operating in close proximities (≤10cm) and appearing to be a quick hover between two NFC enabled chips. Many smartphones in recent years have incorporated a NFC chip into their design (Security Compass Inc., 2012).

4.2.1 Pay-Wave Feedback Control System

A major function of NFC on smartphones is quick mobile payment. Recent implementations like Samsung Pay and Apple Pay essentially transform the smartphone into an electronic replica of a credit card itself; the new editions of Samsung and Apple Pay allow the user to use NFC payments at virtually any tap-and-pay point of sale (Bohn, 2015). The modular smartphone will include the option of having an additional NFC chip for users who wish to do so. This not only adds to the customisability of the smartphone but also incorporates new technology. Essentially, an extremely thin NFC chip is stuck to the back cover of the mobile phone, and then appropriate circuit wiring is done such that the Android OS can recognize the presence of NFC connectivity (Zeiner, 2013). In particular, the NFC payment system is one that can be controlled, optimized, and represented in a simple feedback diagram as seen below in *Figure 7* (NFC World, 2010).

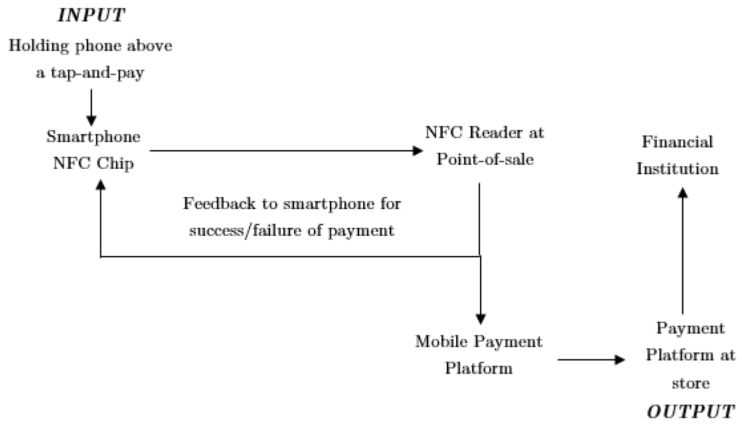

Figure 7 – Control/Feedback Diagram of Mobile Payment System (via NFC)

From *Figure 7* above, it was assumed that the two most important elements were the smartphone NFC chip and the NFC Reader at Point-of-sale. The Mobile Payment Platform forms the ‘controller’ in terms of control/feedback theory and the NFC Reader can be seen as the sensor which works with the mobile payment platform to trigger the feedback of a successful sale or not, going back to the smartphone. Once the payment is confirmed, it appears as a sale on the payment platform at the store, which then communicates with the particular financial institution required. The point of optimization that is within the scope of this project, is the communication of the NFC reader on the modular smartphone and the NFC reader at the point of sale. Latest NFC chips could be implemented and when designing the back cover material, the addition of NFC could be considered in the design so that it allows the NFC to operate at maximum strength and range. This links back to Ergonomic Considerations, when dealing with material choice. Another optimization that is somewhat out of the scope of the project, would be to contact major retailers and advise software updates for their mobile payment platforms to enhance the communication between store payment platforms and NFC enabled smartphones.

4.2 Costing Analysis

A life-cycle costing was carried out for an iPhone 5 equivalent modular smartphone, as seen below in *Table 6*. It must be noted that since the modular smartphone is fully customisable, the costing of a particular device will differ from customer to customer. Next, a Fairphone 2 cost breakdown was analysed – this is a company that takes the environmental approach and has built a somewhat modular smartphone with focus on sustainability.

4.2.1 The Traditional Approach: iPhone 5 Equivalent Modular Smartphone

For this first cost analysis, the modular smartphone was assumed to be a device with similar capabilities to an iPhone 5, with slight variations considered in areas that would differ to the production of the modular smartphone (Sherman, 2013). The cost values gathered for acquisition costs also included operations, which is primarily manufacturing costs. Data gathered was in $USD which was then converted to $AUD at the rate of $1 USD = $1.36 AUD, which is accurate as of 13 October 2015 (XE, 2015).

Table 6: Life-Cycle Costing Analysis

Cost	*Cost Type*	*Amount ($AUD)*
Display screen	Acquisition, Operations	61.20
Memory/RAM	Acquisition, Operations	28.36
CPU	Acquisition, Operations	23.80
Cameras (Front/Back)	Acquisition, Operations	24.48
Cellular Module	Acquisition, Operations	40.80
Wireless Module	Acquisition, Operations	6.80
Battery	Acquisition, Operations	8.16
Power Management	Acquisition, Operations	11.56
Mechanical Parts	Acquisition, Operations	38.08
Packaging, Customer Material	Product Distribution	9.52
Production	Operations	27.20
Operating Expenses	Operations	81.60
R&D	Technical Data	27.20
Software Development	Software	47.60
Customer Service	Maintenance	13.60
Testing Costs	Testing	20.40
Total		470.36

Taking all of the different types of costs shown in *Table 6* into consideration, an iPhone 5 equivalent modular smartphone would cost approximately $470 AUD. This is a rather high-end modular smartphone, and so it should be noted that different customers will have different layouts resulting in very different costs in some aspects. The data collected was for an iPhone 5, and so it would vary with an Android smartphone. Firstly, software and testing costs were assumed to be lower for the Android device, as it is open source rather than Apple's rigid iOS structure. Some hardware parts were assumed to be the same, such as RAM, CPU, display, etc. The display is a significant component of the system costing; it should be noted that this is the cost of a 4" screen and therefore 5" and 5.5" display costs would be even higher.

4.2.2 The Environmental Approach: Fairphone

A recent social enterprise in the mobile phone industry is the Fairphone, which strives to lessen the impact on the environment and ecosystem. The Fairphone does this by incorporating alternative fair-mining practices for gold, tungsten, tin, and other metals. Other initiatives of the social enterprise include responsible e-waste recycling and an innovative self-repair system. A costing breakdown for the newest 'Fairphone 2' was analysed, and this is summarized in *Table 7* below (Fairphone, 2015).

Table 7: Comprehensive Cost Breakdown of Fairphone 2

(All costs are in $AUD, using exhange rate of 1 Pound to $2.10 AUD, accurate as of 13 October 2015)

Product		Tax and Reseller Margin		Investments		Operations	
Materials	483.63	VAT (Value-added tax: 20%)	183.75	Engineering and Development	14.03	Marketing, Communications	13.61
Patents, IP, Royalties	82.11	Reseller Margin	48.24	Software	9.70	Office	10.00
Manufacturing	78.12	Additional Tax	15.75	Design	9.37	Administration, Support	7.50
Warranty Repairs	44.10			Equipment and Tools	6.68	Customer Support	7.46
Handling, Configuration	8.40			Prototyping	3.13	Operations and IT Team	5.48
Welfare Fund for Workers	4.85			Certification	4.10	IT Infrastructure	2.98
E-waste program	4.85			Consulting	2.52	Financing Fees	2.92
Logistics	4.79			Industrial Design	1.09	Sales Team	2.58
Packaging	3.15			Legal Costs	1.09		
				Value Chain/Impact Team	8.59		
				Product Development Team	7.41		
				Creative Team	2.00		
Subtotal	714.00		247.74		69.70		52.52
						Total	1083.96

Fairphone indicated in their documentation that estimations were made in some areas. Also, the cost includes an approximate 20% VAT (value added tax) and so the actual total cost is approximately $903.30 AUD (Fairphone, 2015).

Analysing the two data sets that were gathered, it was deduced that an environmental and sustainability approach to the project has huge positive implications, however at a significant expense. Looking at the cost breakdown of the Fairphone 2, the first costing observation that can be made is that taking an environmental and sustainable approach comes with various additional costs. Elements such as the E-waste program, different manufacturing techniques, additional industrial design costs and similar components increase the cost by a large margin. This is where the motive of the modular smartphone company comes into question.

The Environmental Image and its Implications

Another consideration that should be noted, is that taking an environmental approach to the project could establish a distinctive image for the modular smartphone; mainstream mobile phone users may veer away from such an initiative. It is common for consumers to stick to well-known companies and recognized mobile phones, and so from a marketing perspective, it may be beneficial to advertise the modular smartphone in a similar way to most popular phones such as the iPhone and Samsung Galaxy to attract more consumers.

5.0 Recommendations and Outcomes

This section of the report is comprised of a summary of the final outcomes, recommendations, suggestions, and optimizations that were obtained by carrying out the systems analysis tools in the previous sections. This is followed by a concluding statement that answers the holistic purpose of this research investigation.

5.1 List of Recommendations

Problem Scoping

Qualitative Analysis: Survey

- According to consumers, optimizations must include
  - Battery Life
  - Processing Speed
- Consumers prefer to have latest technologies implemented, e.g. NFC or 4G-LTE

Quantitative Research

- Voice calling and texting still remain as the primary functions
- Internet browsing, emailing, and third-party applications must be optimized to cater for their high usage and user dependency

	• Secondary considerations include the camera, multimedia playback, and location services
System Design Specifics	

Human Factors	• Three different size models (based on screen size): 4", 5", 5.5"
	• Ergonomic Lock Button Positioning
	  o Top right edge for 4" model
	  o Right edge for 5" and 5.5" model
	• Smartphone material choices
	  o Synthetic Leather – maximum grip, sense of feel/touch
	  o Metallic Finish – users who want a 'premium' feel

Material Factors	• After a period of four years, it is beneficial to have a modular smartphone compared to a traditional smartphone, from an embodied energy perspective
Energy Factors	• GSM and other wireless modules consume significant energy o Make 4G-LTE an optional module for the modular smartphone • Optimize graphics by using Qualcomm GPUs
Extended Analysis	

Time Factors	• Booting Up Process Optimization
	  o Android initialization of applications and services must be optimized, as this process is the most time consuming
	  o Done through collaborative work with Android developers
	• Error-related restarts can be optimized as well

Dynamics & Control Analysis	• Feedback system: NFC-based Pay Wave system
	  o Use latest NFC chips within back cover casing
	  o Advise retailers to introduce latest NFC pay-wave technology
	  o Advise software updates to retailers for the mobile payment system

Costing Analysis	• The display is the most significant hardware acquisition cost o Vary between customers for the 4", 5", and 5.5" models • A traditional smartphone has a significantly lower cost compared to an environmental an sustainability-motivated smartphone • Taking the environmental route may establish a 'sustainable' type of image for the device, which may tarnish the consumer base. This can be countered by changing marketing strategies.

5.2 Conclusion

The feasibility of a modular smartphone was gradually determined after the completion of each systems analysis technique seen in this portfolio. At the problem scoping stage, key consumer requirements were defined through the survey and smartphone usage statistics were analysed. Many design elements were established as part of the human factors analysis, and the embodied energy analysis was deduced to be in favour of the modular smartphone when considering a ten year period. However, the optimization of GSM and other wireless modules, as identified to be pertinent in the energy analysis, is relatively difficult as they require strong coordination with specific network hardware developers. In-depth internal optimizations such as the boot-up time and the NFC Pay-Wave system are once again feasible given that modular smartphone developers work collaboratively with specific hardware and software developers. Most importantly, the costing analysis provided a financial perspective into the implementation of an environmental modular smartphone. Given the significantly increased budget, if the developing company's objective is based around sustainability then this remains a feasible project, if it is marketed towards a traditional consumer base.

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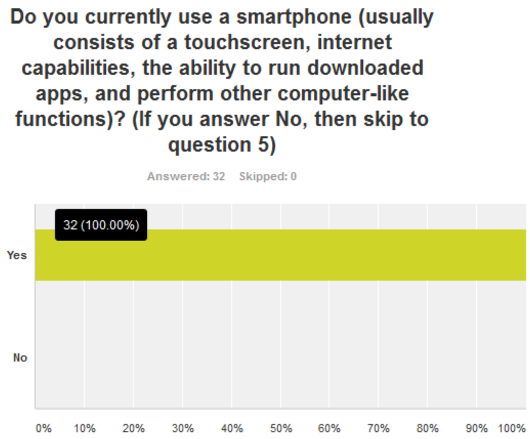
Appendix

1 Survey Results

<u>Question 1</u>



Answer Choices	Responses	
Yes	100.00%	32
No	0.00%	0
Total		32

<u>Question 2</u>

How many smartphones have you owned, including your current device? (enter a number)

Mean number of smartphones owned: 3.095

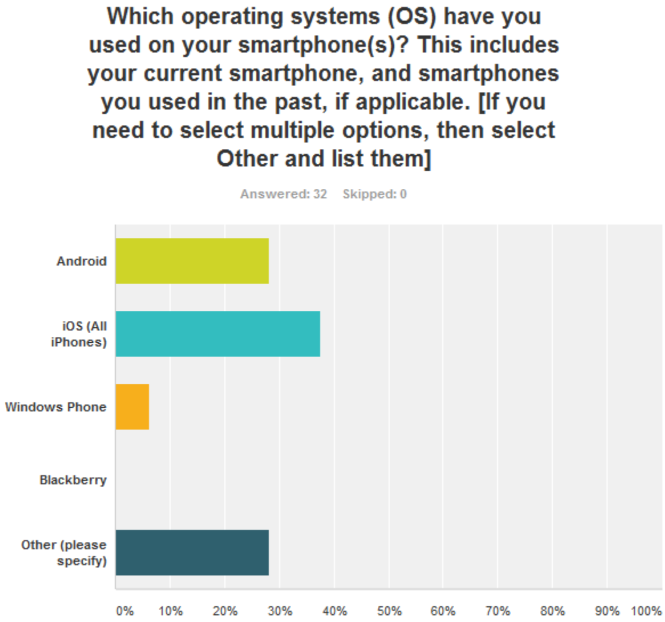
<u>Question 3</u>

What were some reasons as to why you changed your smartphone(s)? Give as much details as you like, and separate reasons/factors with a comma – e.g. “poor battery life, wanted new model”

Top Responses:

- Poor battery life (battery degradation), wanted a phone with a new long-lasting battery
- Slow system speeds, wanted a phone with faster processing
- Features in newer models of phones interested them
- Other people had moved onto newer phones – keeping up with latest technology

Question 4



*Note in "Other (please specify)", All of the text answers were Android and iPhone

Question 5 – Overview of Modular Smartphone

A modular smartphone is a totally customizable phone made up of separate 'blocks' of each individual component such as the camera, battery, processor, GPS, and even the screen itself. These components can be easily removed and replaced, so you can upgrade your camera for example, or if your battery is decreasing in performance, you can simply replace it with a new one. This concept reduces the need to throw away your phone completely, just because you were not satisfied with one component of it. Many smartphones come with expensive features that are often of no use to some people, and so a modular smartphone would allow you to create the perfect device for yourself, tailored to your specific needs, and may therefore save you some money. See http://goo.gl/t3OMhM for a visual graphic. Indicate your level of interest in using a phone like this.

Options: Not interested at all, Might consider it, Extremely interested!

	Not interested at all	Might consider it	Extremely interested!	Total
Level of interest	9.38% 3	50.00% 16	40.63% 13	32

2 Smartphone Holding Preferences

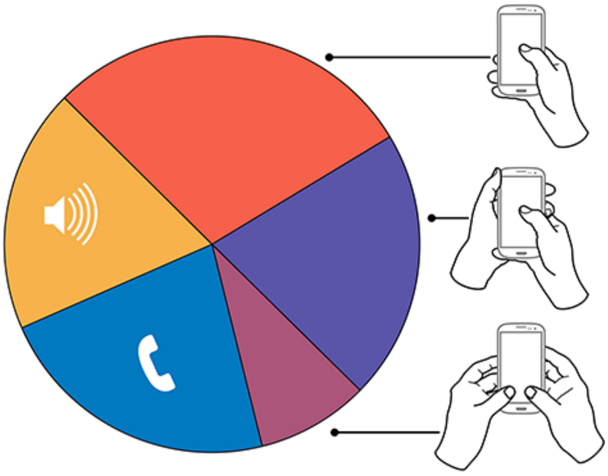


Figure 8 – Holding position preferences (Hoober, 2013)

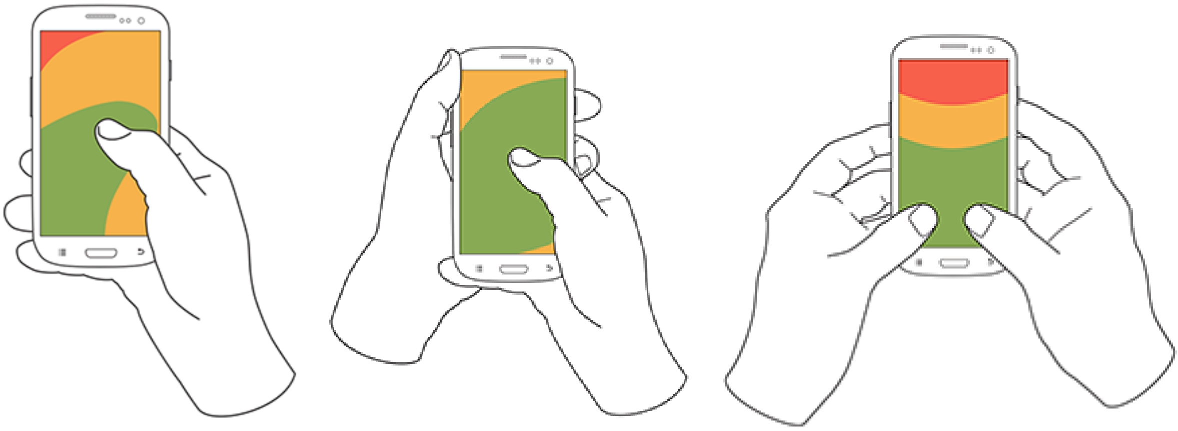


Figure 9 – Holding styles: one-handed, cradled, two-handed (Hoober, 2013)