CIVE 1266: Introduction to Environmental and Sustainable Systems Engineering -Final Portfolio

Team (G5)

Team Member	Tasks Contributed	Contribution %
Kushagra Agrawal S4142210	Empathy Map,System Design & Leverage Point, Annotated Causal Loop, Biomimicry, Exploratory Data Analysis, ML Model development, App design, Prototype implementation, Business Proposal.	18%
Rochis Vinayak S4139844	Empathy Map, Annotated causal loop, Pairwise Comparison Matrix, Classification Tree, Optimal Design Sequence, Testing.	17%
Jashan Singh Mehta S4139869	Empathy Map, User Requirement, Justification, Evaluation Matrix, Biomimicry, Exploratory Data Analysis, ML Model development, App design, Prototype implementation, Business Proposal.	18%
Ishani Tagare S4140449	System Design & Leverage point, Frugal Innovation, Life cycle cost, Net present value, Optimising system lifetime.	17%
Yashashwi S4143294	Annotated casual loop, Eco efficiency, Eco effectiveness.	12%
Yashvardhan S4140203	Empathy Map, Annotated causal loop, System Design & Leverage point, Pairwise Comparison Matrix, Evaluation Matrix, Biomimicry.	18%

Problem: My phone is too slow, and its battery can’t hold enough charge because it is old.

Index

Problem Definition and Team Contributions

Our analysis centres on a fundamental user challenge: phones that are too slow with rapidly draining batteries due to age and low-quality components. This creates a cascading set of problems, including missed calls, reduced productivity, and frequent charging cycles that increase electricity costs and environmental impact.

The user requirement is clear: to have reliable access to phone and Internet services anytime and anywhere, without facing costly replacements or unexpected shutdowns. This requirement drives our entire systems analysis approach.

The target user for this system is the value conscious individual: such as a student, a budget-minded professional, or an environmentally aware consumer—who wants to maximise the lifespan of their existing smartphone. The system is used on their personal device throughout a typical day, integrated into every aspect of modern life, from work and commuting to social and home activities. The critical problem scenario occurs when the phone's degraded performance creates tangible frustrations: an app crashing during an important task, the battery dying unexpectedly, or significant lag when accessing essential services. This defines the target market as the vast global segment of users with devices two years or older who seek a practical, low-cost software solution to restore the reliability of their essential daily tool.

Empathy Map

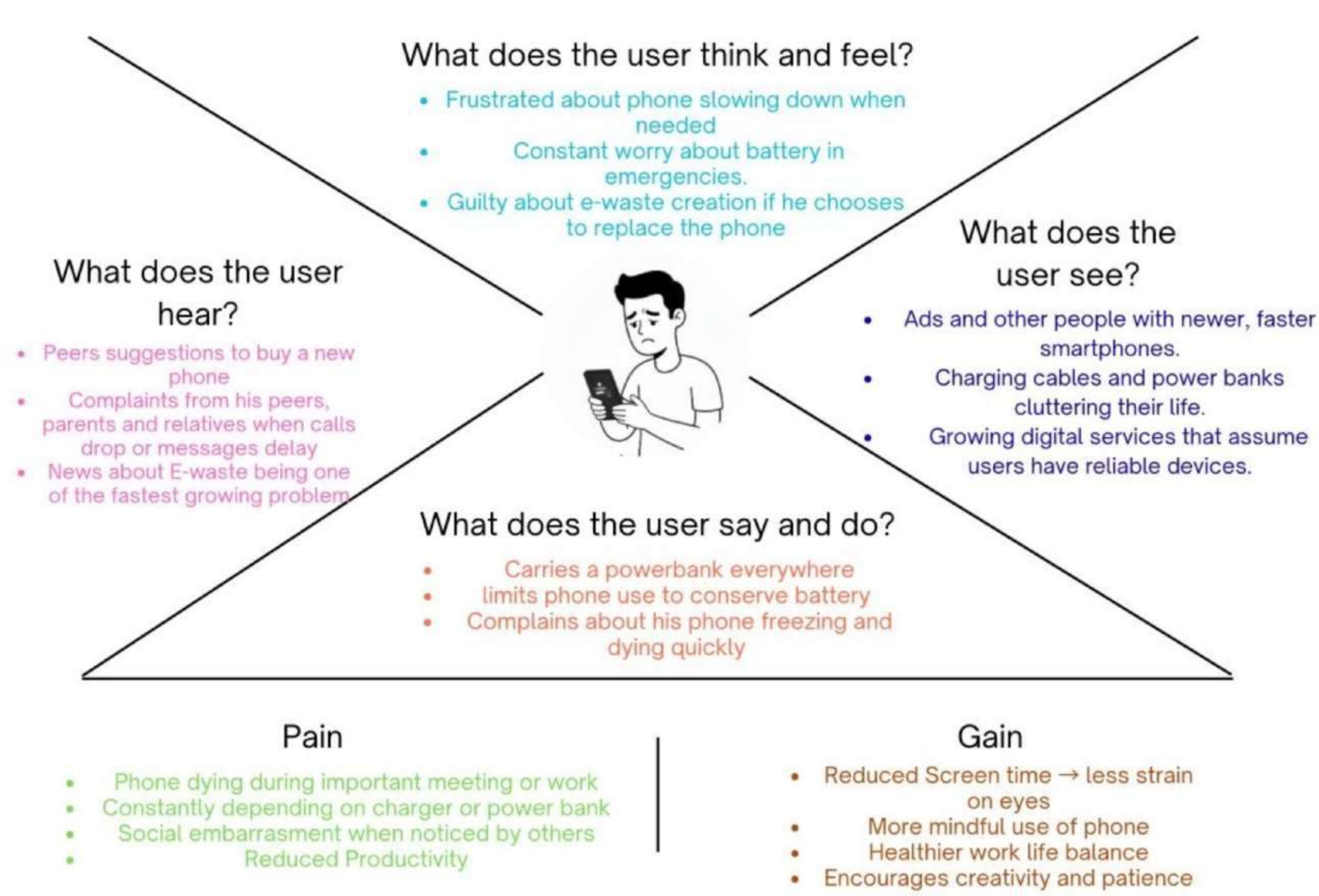


Figure 1– Empathy map **(Canva 2025)**.

Pains & Gains Provided by the Solution

Pains:

Users might need to adapt to new interfaces, settings, or usage habits.

Users may miss out on real-world interactions, nature, and spontaneous experiences.

Constant digital stimulation can cause burnout, anxiety, or reduced attention span.

Gains:

Lower electricity consumption because the phone charges less often
.
Greater confidence that the phone will perform properly in emergencies.

Users can complete tasks efficiently without interruptions.

Annotated Causal Loop Diagram

Our causal loop diagram shows the complex interconnections within the smartphone system, identifying four key variable categories that drive this system's behaviour. The central variable (blue) represents the core system element, while affecting variables (green) drive changes, affected variables (yellow) respond to system changes, and supporting variables (violet) exist within the system boundary.

Legend:

1. Blue – Centre Variable
2. Green – Affecting Variables
3. Yellow – Affected Variables
4. Violet – Supporting Variables

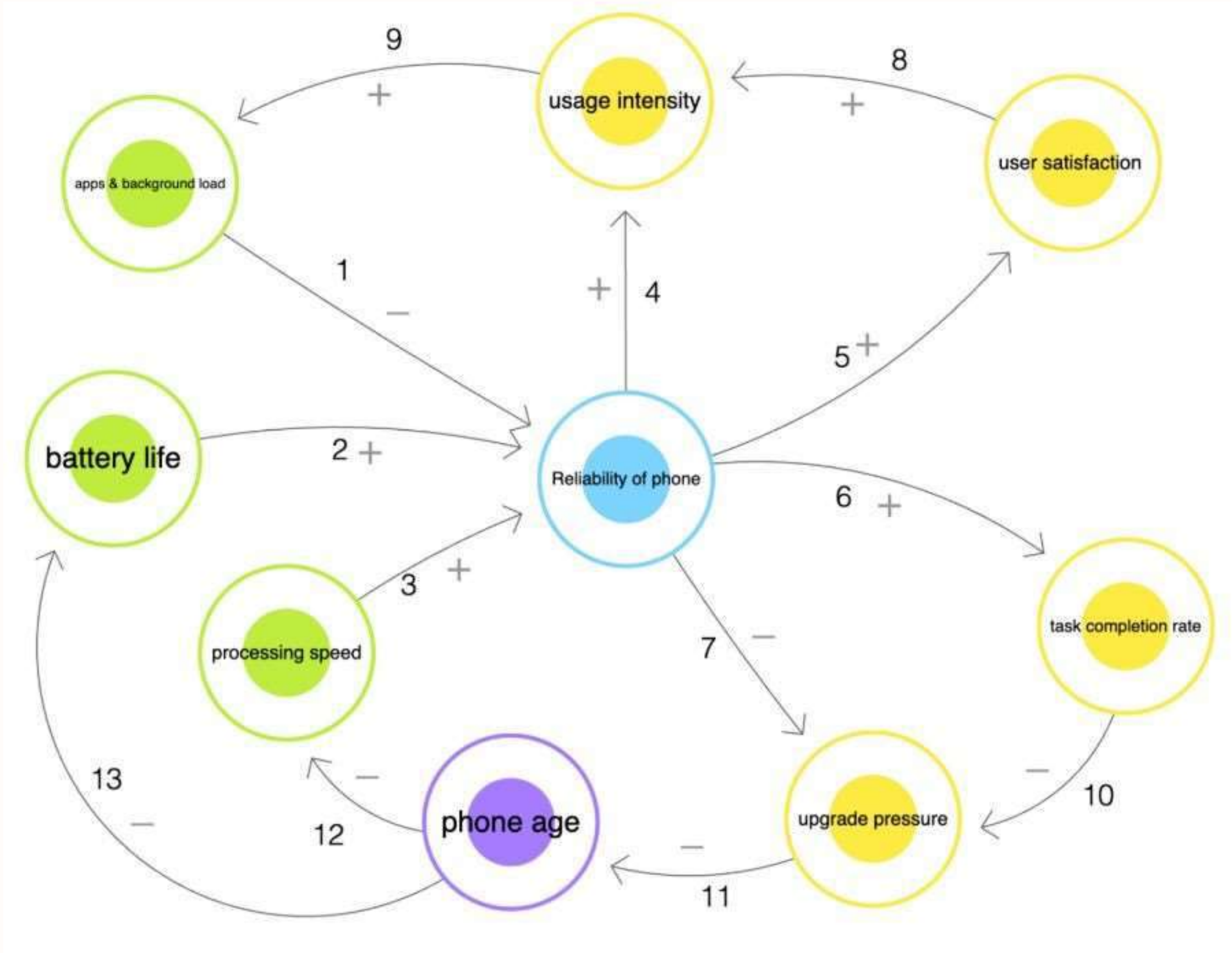


Figure 2 – Annotated Causal Loop Diagram (Case 2025).

1. A higher number of apps and background processes consumes more system resources, which can lead to slowdowns and crashes, thus decreasing the phone's reliability.

2. A longer battery life ensures the phone is available and functional when needed, which directly increases its perceived reliability.

3. Faster processing allows the phone to handle tasks smoothly without lag, making the device feel more dependable and reliable to the user.

4. When a phone is reliable, users trust it more and are therefore more likely to use it for a wider range of important tasks, increasing usage intensity.

5. A dependable phone that performs consistently well provides a better user experience, leading to higher user satisfaction.

6. A reliable phone functions without errors or crashes, enabling users to successfully complete their intended tasks more ofien.

7. If a phone is reliable and meets the user's needs, there is less motivation or pressure to spend money on a new model.

8. Higher user satisfaction leads to more frequent use because satisfied users enjoy the product and are motivated to engage with it more.

9. Higher usage intensity increases app and background load because more frequent use triggers more processes and data activity.

10. When a user can consistently and easily complete their tasks, the current phone is seen as adequate, which reduces the feeling of needing an upgrade.

11. Higher upgrade pressure reduces phone age because users replace older phones sooner.

12. Over time, a phone's hardware becomes outdated and struggles with newer, more demanding sofiware, resulting in a noticeable decrease in processing speed.

13. A phone's battery capacity naturally degrades with age and repeated charging cycles, leading to a shorter battery life.

This is the "cause-effect mechanism" table with reference to their links as mentioned in the Annotated Causal Loop Diagram

Whole System Thinking and Leverage Point

The conventional smartphone system can be understood as the interaction between the user, the hardware, the operating system, and the running applications/software. They aim to deliver a smooth and reliable user experience, where the user can complete daily tasks and communicate effectively, without lag or frequent recharging. The critical flows within this system are energy (battery power) and processing resources (CPU and RAM cycles), which ultimately determine how long and how smoothly the device is going to perform.

The diagram below illustrates how user behaviour, active and idle applications, and resource strain interact to influence the final service. The figure below also shows how it will be impacted by our intervention, making the user experience much better.

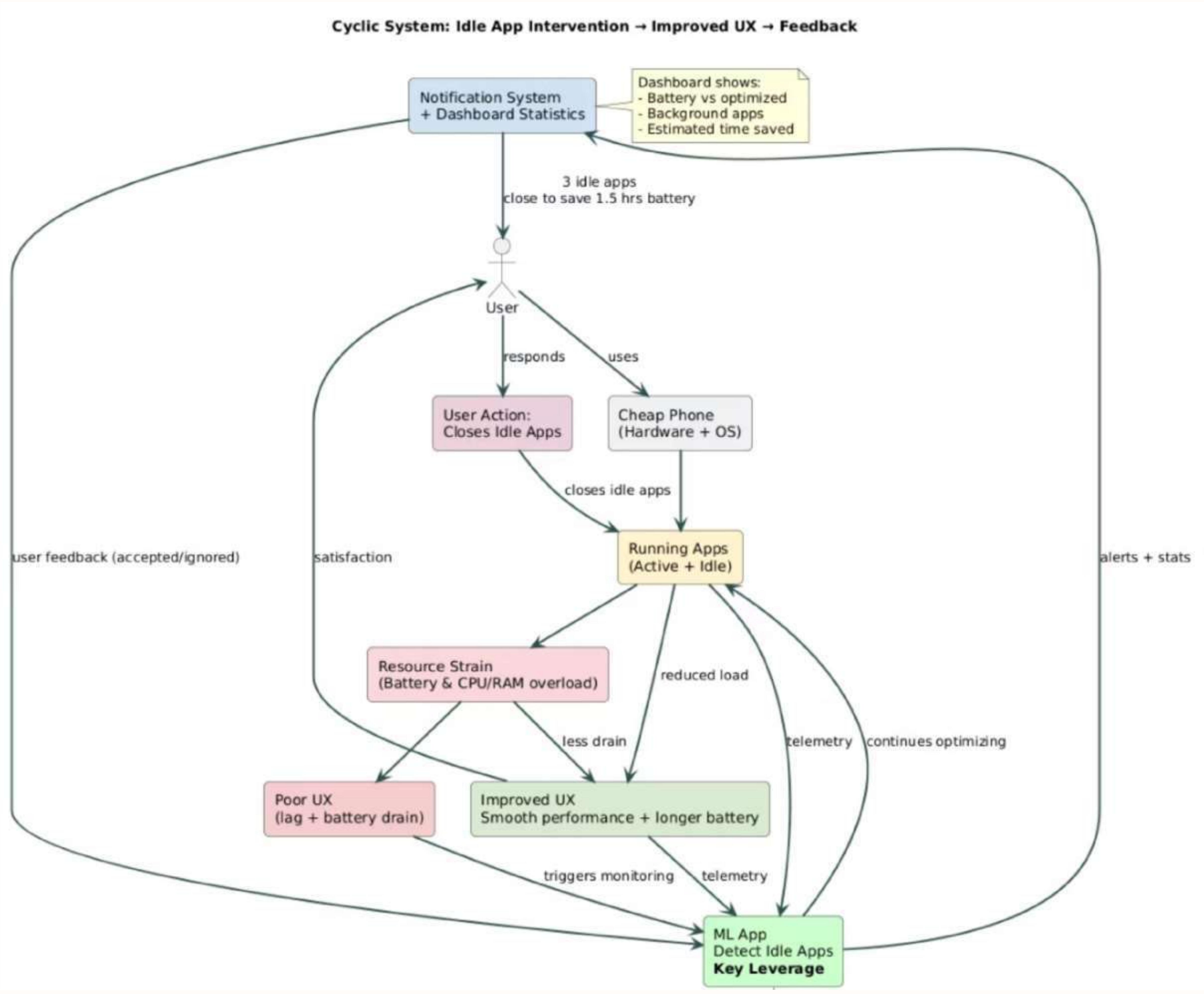


Figure 3 – System Thinking with Intervention (PlantUML n.d.).

From the diagram, it becomes clear that idle or unnecessary background applications are the main points. These apps continuously draw on CPU, RAM, and battery, creating strain leading to lag and shorter battery life.

Final Service Delivered by the wider system: The final service is reliable digital connection and information access, enabling productivity, communication, and safety.

Thing That Flows: The key thing that flows through the system to deliver this service is Information (in the form of digital data).

How Information Flows:

Getting In: Information flows from the internet and phone sensors into the conventional system (the smartphone) through its radios (Wi-Fi and cellular).

Getting Out: The phone's processor computes the data, and a small fraction is delivered to the user as valuable output on the screen or through the speakers.

Where Information is Wasted:

Unnecessary Background Syncs: Apps constantly process data for updates that the user never sees. **Low-Value Notifications:** The system wastes energy processing a high volume of notifications that are immediately dismissed.

Redundant Processing: Multiple apps independently perform similar background tasks (like checking location) instead of using a shared, efficient process.

Leverage Point and Cost/Benefit Analysis:

Core Problem: Smartphones waste significant energy and processing power on a high volume of input data (background refreshes, notifications, updates) while only a tiny fraction of it becomes useful output for the user.

Leverage Point: The phone's background task and data scheduling process—the specific place in the operating system that governs how and when background data is processed

Strategy: The intervention targets improving the ratio of total data processed by the phone to the useful information delivered to the user. Shift focus from hardware improvements to intelligently filtering and managing the flow of data at the operating system level.

High Potential Benefit: A more intelligent scheduling process directly improves battery life and performance on existing hardware. This slows the entire cycle of replacement, massively reducing e-waste and the environmental impact of manufacturing new phones.

Low Cost: The cost is a one-time investment in software development. It requires no new materials or factories and can be distributed to millions of users at near-zero marginal cost via a software update. The benefit scales globally from a single, fixed investment.

System Design Thinking
(A better explanation to the diagram)

The system starts with the Cheap Phone (Hardware + OS) running Running Apps (Active + Idle).

The presence of these apps, especially the ones running in the background, causes Resource Strain, particularly Battery and CPU/RAM overload. This strain leads to Poor UX, like lag and battery drain, which is the main problem your project seeks to address.

The main intervention, called the Key Leverage point, is the ML App designed to Detect Idle Apps. This machine learning component continuously monitors the system and sends data back to tackle the resource strain proactively. When the ML App identifies idle applications, it activates a Notification System and Dashboard Statistics. This notification alerts the User about the issue, for instance, stating, "3 idle apps close to save 1.5 hrs battery."

The user's reaction is a crucial decision point: the user either acts on the alert or ignores it. If the user takes action, it leads to the User Action: Closes Idle Apps module. This step effectively reduces the pool of Running Apps, lightening the load on the system and decreasing the original Resource Strain, which contributes to the desired positive results.

The lighter load from closing idle apps, along with the ongoing telemetry and optimization from the ML App, leads to improved UX defined by Smooth performance and Longer battery life. This improved UX plays two key roles.

First, it directly boosts satisfaction for the user, encouraging the good habit of managing apps. Second, it prompts monitoring and telemetry back into the ML App Detect Idle Apps module. This telemetry delivers real-world performance data, allowing the ML model to improve its detection algorithms, thereby strengthening the Key Leverage and ensuring ongoing system enhancement.

The process concludes with User Feedback (accepted/ignored) flowing back to the Notification System and Dashboard Statistics. Whether the user accepted or ignored the previous alert influences how the system shows the next notification, making the whole process responsive.

The system thinking diagram clearly outlines the negative feedback loop (poor UX leads to strain, leading to more strain) that defines the problem and overlays a strong positive feedback loop (ML detection leads to user action, leading to improved UX, leading to better ML detection) that illustrates the solution's value.

The ultimate aim is to stabilize the system at a point of low resource strain and high user satisfaction.

User Requirements

Through systematic analysis, we have refined the initial problem statement into three comprehensive user requirements that capture the full scope of user needs while providing clear direction for solution development.

Reliability Requirement

I need a phone that I can rely on all day without it dying or becoming frustratingly slow.

This expands on the initial requirement by adding the crucial element of reliability and addressing the core frustrations of poor battery life and slowness that plague daily usage.

Performance Requirement

"I need my phone to be fast enough for my daily tasks, like messaging and browsing, without long delays."

This makes the vague problem of a "slow phone" more specific by focusing on the performance of essential, everyday applications that users depend on most.

Economic Requirement

"I need a way to solve my phone problems without having to buy a brand new, expensive device." This addresses the underlying financial and environmental concerns of replacing the phone, steering the solution towards improvement rather than costly replacement.

These refined requirements form the foundation for our evaluation criteria and solution development, ensuring that any proposed intervention directly addresses user needs while considering broader system implications.

Engineering requirements, performance indicators, and theoretical targets

Table 1- System level engineering requirements, performance indicators, and targets for the project[1].

TYPE	ENGINEERING REQUIREMENTS	PERFORMANCE INDICATOR(S)	TARGETS
Functional	The solution shall enable access to internet services.	• Data transmission rate (Mbps) • Lifetime data transmitted (TB)	• ≥ 10 Mbps • ≥ 10 TB
	The solution shall maintain system responsiveness.	• App launch speed (seconds) • System responsiveness score (benchmark)	• < 2 seconds • > 85/100
Durability	The solution shall provide service for an extended lifetime.	• Useful lifetime (years) • Lifetime charge cycles (#)	• ≥ 4 years • ≥ 1,500 cycles
Operational	The solution shall provide reliable operation	• Active screen-on time (hours) • Unplanned shutdowns per day (#)	• ≥ 6 hours • 0
Financial	The solution shall minimise the life-cycle cost.	• Total cost of ownership ($)	• $0 (Theoretical Target)
Environmental	The solution shall minimise electronic waste.	• Percentage of device mass diverted from landfill at end-of-life (%)	• 100% (Theoretical Target)
	The solution shall minimise energy consumption from the grid.	• Grid electricity consumed per charge cycle (Wh) • Number of charge cycles per year (#)	• 0 Wh (Theoretical Target) • < 365
Social	The solution shall promote responsible digital habits.	• User's screen time per day (hours) • User satisfaction with device performance (score)	• User-defined, healthy limit • > 8/10

Target Calculations and Performance Benchmarks

Our quantitative targets establish measurable goals across functional, durability, operational, financial, environmental, and social dimensions. These targets are grounded in industry standards and sustainability principles, providing clear benchmarks for system improvement.

Functional Targets

- Data transmission rate ≥ 10 Mbps for HD video and calls (Netflix n.d.).
- System responsiveness < 2s app launch (Nielsen 1993).
- Performance score > 85/100 (AnTuTu 2025).

Durability Targets

- Useful lifetime ≥ 4 years (double typical replacement cycle) (Statista 2024).
- Lifetime charge cycles ≥ 1,500 cycles (Apple 2025).
- Mathematical basis: 1,500 ÷ 365 = 4.1 years

Operational Targets

- Active screen-on time ≥ 6 hours daily (DXOMARK 2023).
- Unplanned shutdowns = 0 (TechTarget n.d.).

Financial Targets

- Total cost of ownership ($0): Theoretical target; an ideal system pays for itself (Ellen MacArthur Foundation n.d.).

Environmental Targets

- E-waste diversion (100%): Theoretical target (Cradle to Cradle Products Innovation Institute n.d.).
- Grid electricity consumed (0 Wh): Theoretical target for a self-powering or perfectly efficient system [10] (Priya et al. 2023).
- Charge cycles per year (< 365): To reduce grid use and battery wear by charging less than once per day (DXOMARK 2023).
- Mathematical basis: 1 charge/day × 365 days = 365 cycles/year (target to lower optimisation)

Social Targets

- User's screen time (user-defined): Promotes user well-being and responsible tech use (World Health Organization 2025).
- User satisfaction (> 8/10): Measures if the solution is successful from the user's perspective (SurveyMonkey n.d.).

Pairwise Comparison Matrix

Our pairwise comparison matrix systematically evaluates twelve critical system parameters to establish priority rankings based on user needs hierarchy. The scoring reflects the reality of a user requiring a functional, long-lasting phone on a budget while valuing sustainability.

Table 2 – Pairwise comparison of the system-level engineering requirements[2].

	Affordability	Snappy performance	Strong Connectivity	Portability	Long battery life	Aesthetic appeal	Low environmental impact	Robust Construction	High recyclability	High Longevity	Ease of Repair	**Score**	**Rank**
Affordability		0	0	0	0	1	1	0	1	0	0	3	8
Snappy performance	1		1	1	0	1	1	1	1	1	1	9	2
Strong Connectivity	1	0		1	0	1	1	1	1	1	1	8	3
Portability	1	0	0		0	1	1	0	1	0	1	5	6
Long battery life	1	1	1	1		1	1	1	1	1	1	10	1
Aesthetic appeal	0	0	0	0	0		0	0	0	0	0	0	11
Low environmental impact	0	0	0	0	0	1		0	1	0	0	2	9
Robust Construction	1	0	0	1	0	1	1		1	1	1	7	4
High recyclability	0	0	0	0	0	1	0	0		0	0	1	10
High Longevity	1	0	0	1	0	1	1	0	1		1	6	5
Ease of repair	1	0	0	0	0	1	1	0	1	0		4	7

Long Battery Life (Rank 1)

This is the most critical requirement because it is the ultimate enabler of the user's core need: "anytime, anywhere access". If the phone has no power, all other functions become irrelevant to the user experience.

Snappy Performance (Rank 2)

This directly solves the user's primary frustration of a "phone is too slow." After ensuring the phone is powered on, ensuring it is responsive and usable is the next most important step to solving the core problem.

Strong Connectivity (Rank 3)

This addresses the "access to Internet services" part of the user requirement. In today's connected world, a phone's performance is largely perceived through its ability to connect reliably to internet services.

Robust Construction (Rank 4)

This is the foundation of reliability. A phone must be durable enough to be used "anywhere", and its hardware must be dependable. This ensures the top three functional requirements are delivered consistently.

High Longevity (Rank 5)

This addresses the root cause of the problem: the phone is "old". A solution with high longevity prevents the user from facing the same frustrations in the near future, making it a cornerstone of a sustainable system.

Portability (Rank 6)

This is a fundamental, non-negotiable trait of a mobile device. A solution that isn't easy to carry fails to meet the basic definition of a smartphone.

Ease of Repair (Rank 7)

This is the most crucial sustainability feature from a systems perspective. It directly enables longevity, reduces waste, and lowers the long-term cost for the user, making it more important than the initial purchase price.

Affordability (Rank 8)

This is a practical real-world constraint. However, a solution must first be effective before its price matters. A cheap phone that doesn't work is not a solution.

Low Environmental Impact (Rank 9)

This is a key system-level goal that is the result of achieving longevity and repairability. It's a broader goal that is less tangible to the user's immediate problem.

High Recyclability (Rank 10)

This is an end-of-life consideration. It is important, but preventing waste by extending a product's life through repair and longevity is a more effective sustainable strategy.

Aesthetic Appeal (Rank 11)

This is a luxury. For a user with a non-functional phone, how the device works is far more important than how it looks.

The top-ranked requirements are non-negotiable and must be protected at all costs. These requirements must be the primary drivers of our design and the majority of testing resources and time should be dedicated to these areas. On the other hand, the bottom-ranked requirements are not unimportant, but they are the first candidates to be simplified if constraints like time, budget, or technical challenges are faced. These are areas where a "good enough" approach is acceptable. Testing for these requirements can be less extensive, hence allocating our limited testing resources efficiently.

Evaluation Matrix

Our evaluation matrix synthesises the pairwise comparison results into a ranked priority system that guides solution development. The matrix reveals clear hierarchies in user requirements, with battery life, performance, and connectivity emerging as top priorities.

{Scale}

- 5 = Theoretical-target compliance
- 3 = Practical-target compliance
- 1= Partial compliance
- 0 = Non-compliance

Table 3 – Evaluation Matrix[3].

Requirements	Weighting		Concept 1		Concept 2		Concept 3	
	Rank	Weighting	Relative Compliance	Weighted Value	Relative Compliance	Weighted Value	Relative Compliance	Weighted Value
Long Battery Life	1	5						
Snappy performance	2	4						
Strong Connectivity	3	3						
Robust Construction	4	2						
High longevity	5	1						

*This table will be completed as we move on in the course.

Conclusions and Future Direction

Our comprehensive systems analysis reveals that smartphone sustainability challenges require multi-faceted interventions targeting user behaviour, system design, and hardware modularity. The evaluation matrix clearly prioritises battery life, performance, and connectivity as critical success factors for any sustainable solution.

Immediate Actions

Focus on user behaviour modification and app management strategies that can deliver immediate battery life improvements with minimal cost. These high-leverage interventions can extend device lifespan while reducing environmental impact.

System-Level Changes

Advocate for energy management system improvements that prioritise efficiency over peak performance. Software-based solutions can dramatically improve existing hardware longevity without requiring new device purchases.

Long-term Vision

Support industry movement toward modular, repairable designs that address the root cause of e-waste generation. Physical modularity represents the highest leverage point for systemic change in smartphone sustainability.

The project demonstrates how environmental and sustainable systems engineering principles can identify effective intervention points in complex socio-technical systems. By understanding causal relationships, leverage points, and user priorities, we can develop solutions that simultaneously address performance, affordability, and environmental concerns.

Future work should focus on implementing and testing the identified leverage points, particularly user behaviour interventions and energy management optimisations, while continuing to advocate for industry-wide adoption of modular design principles that enable true circular economy approaches to mobile technology.

Citations

Reference List (in original order)

Netflix (n.d.) Internet connection speed recommendations, Netflix Help Center, accessed 28 September 2025. https://help.netflix.com/en/node/306

Nielsen, J (1993) Response Times: The 3 Important Limits, Nielsen Norman Group, accessed 28 September 2025. https://www.nngroup.com/articles/response-times-3-important-limits/

AnTuTu (2025) Performance Ranking, AnTuTu, accessed 28 September 2025. https://www.antutu.com/en/ranking/rank.html

Statista (2024) Average smartphone replacement cycle in the U.S., Statista, accessed 28 September 2025. https://www.statista.com/statistics/619788/average-smartphone-replacement-cycle-in-the-us/

Apple (2025) iPhone Battery and Performance, Apple Support, accessed 28 September 2025. https://support.apple.com/en-us/HT208388

DXOMARK (2023) DXOMARK Battery test protocol, DXOMARK, accessed 28 September 2025. https://www.dxomark.com/introducing-the-dxomark-battery-test-protocol/

TechTarget (n.d.) high availability (HA), TechTarget, accessed 28 September 2025. https://www.techtarget.com/searchdisasterrecovery/definition/high-availability

Ellen MacArthur Foundation (n.d.) The circular economy in detail, Ellen MacArthur Foundation, accessed 28 September 2025. https://www.ellenmacarthurfoundation.org/circular-economy-diagram

Cradle to Cradle Products Innovation Institute (n.d.) The Cradle to Cradle Design Framework, C2C Certified, accessed 28 September 2025. https://www.c2ccertified.org/get-certified/cradle-to-cradle-design-framework

Priya, S et al. (2023) 'A review on energy harvesting for self-powered wearable sensors', Energy, 262(125345)

World Health Organization (WHO) (2025) Digital health, WHO, accessed 28 September 2025. https://www.who.int/health-topics/digital-health

SurveyMonkey (n.d.) What is a good CSAT score? (And how to improve it), SurveyMonkey, accessed 28 September 2025. https://www.surveymonkey.com/mp/customer-satisfaction-score-csat/

Canva (2025) Empathy Map Template [software], Canva

Case, N (2025) Loopy [software], accessed 28 September 2025. https://ncase.me/loopy/

PlantUML (n.d.) PlantUML [software], PlantUML, accessed 28 September 2025. https://plantuml.com/

POST DRAFT PORTFOLIO

CLASSIFICATION TREE

Phone Improvement System Classification Tree maps out the brainstorming efforts to meet three key user needs: Reliability, Performance, and Economic Viability. The tree organizes the solution into four main sub-systems. It focuses on achieving system longevity and high performance mainly through software-first interventions.

1. Improve Reliability (Power Management)

This is the top priority area. It focuses on meeting the user's need for reliability and the primary requirement: long battery life. These concepts work by optimizing energy flow. This is essential for achieving the goal of at least 6 hours of active screen-on time.

AI Idle Closer

This is the main software intervention. It targets idle or unnecessary background applications. It uses machine learning (ML) to identify and close these apps. This reduces the strain on resources such as CPU and RAM.

Background Task Scheduling

This focuses on how and when background data is managed at the system level. It reduces energy waste by filtering out low value notifications and unnecessary syncs. This increases the amount of useful information compared to total data processed.

Battery Dashboard

This is a tool that helps change user behavior. It offers statistics on battery saved and background apps. It provides feedback to users and encourages them to take action by closing idle apps (Amiba Power n.d.). This helps reinforce the ongoing system.

2. Improve Performance (Resource Management)

This branch focuses on the Performance Requirement. Its goal is Snappy Performance (Rank 2). This ensures the phone keeps its system responsive and the app launch speeds at most 2 seconds (Appeneure n.d.).

Cache Clearing and Data Sync Reduction

This directly tackles unnecessary processing and background data activity that use up resources. It helps the phone handle daily tasks smoothly without lag.

Coordinated App Tasks

This solution prevents wasting resources by managing multiple apps that do similar tasks on their own, such as checking location. By using a shared process, it reduces the overall load and makes the device feel more reliable.

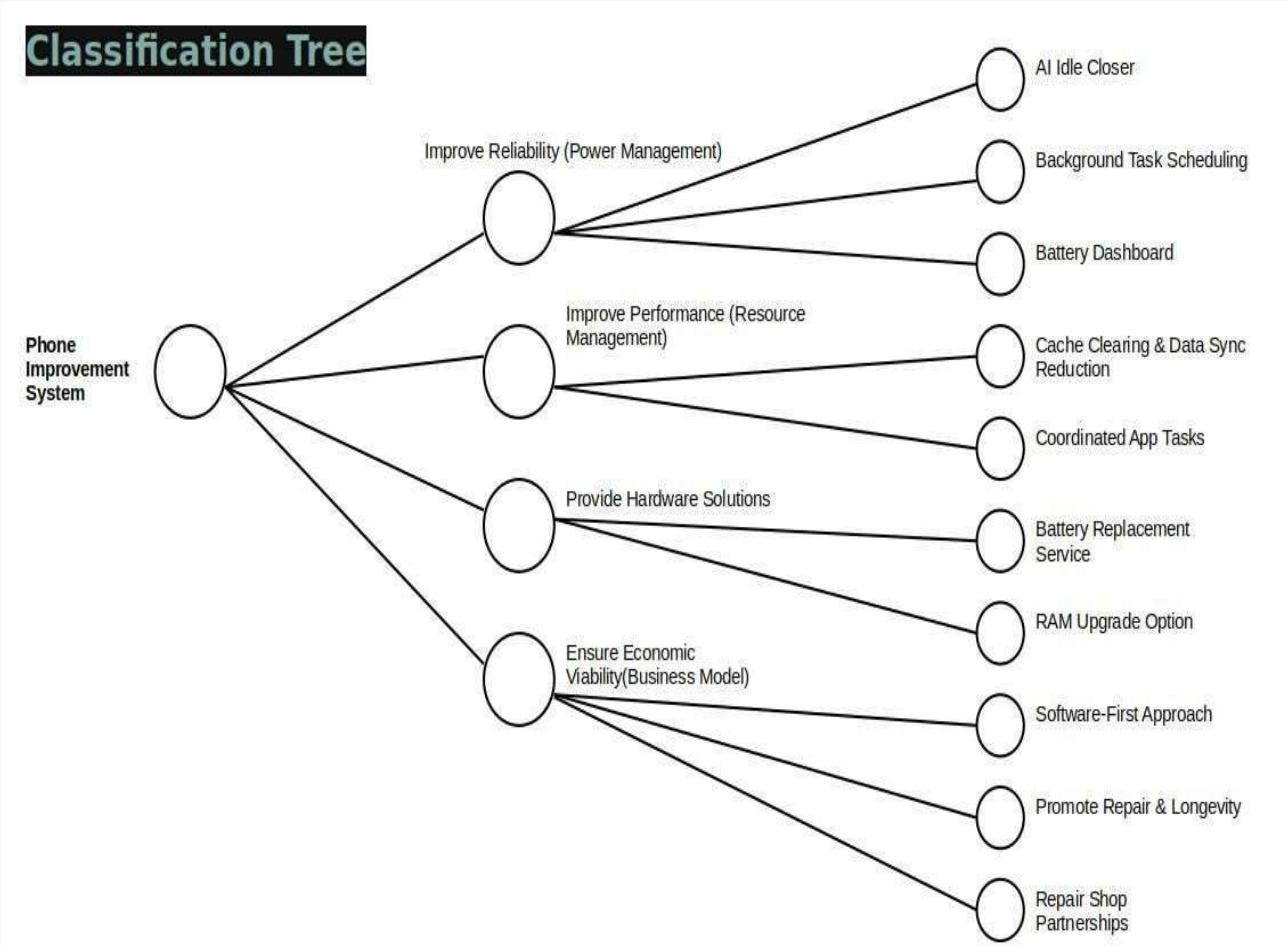


Figure 4- Classification Tree

3. Provide Hardware Solutions

While the main solution is software-based, these options support the project's Durability and High Longevity (Rank 5) requirements by dealing with the inevitable decline of physical components over time (The Fix Solutions n.d.):

1

Battery Replacement Service

This counters the natural loss of battery capacity due to age and repeated charging cycles. It allows the device to reach the goal of at least 1,500 lifetime charge cycles.

2

RAM Upgrade Option

This helps older phones manage newer, more demanding software that slows down processing speed. It supports the long-term vision of modular, repairable designs.

4. Ensure Economic Viability (Business Model)

This final branch addresses the Economic Requirement and the system-level goal of minimizing electronic waste. It makes sure the solution works for the value-conscious individual.

1

Software-First Approach

This is crucial for reaching the $0 Total Cost of Ownership (Theoretical Target). By being a software update, it lowers the financial burden on the user and reduces the environmental cost of making new hardware.

2

Promote Repair & Longevity

This is a clear business model aimed at achieving 100% E-waste diversion (Theoretical Target). It shifts the focus from buying new products to maintaining and extending the product life, which is key to a sustainable system.

3

Repair Shop Partnerships

This is an operational method to ensure Ease of Repair (Rank 7) becomes a practical reality, making the sustainable approach accessible and affordable for the user.

Sustainable Battery Management Application

A comprehensive approach to extending device lifetime through frugal innovation, life-cycle cost analysis, and net present value calculation. This document explores how incorporating frugal subsystems and processes can determine economic life-cycle costs and benefits while calculating the net present value of sustainable battery management solutions.

What does Frugal mean?

Frugal, in one sentence: delivering the essential outcome for users while using far fewer resources and money than conventional solutions.

Frugal Innovation is not just about making things cheaply, but about value creation under severe resource constraints by focusing purely on the fundamental needs **(Hossain 2016).**

It is defined by three core criteria:-

Substantial Cost Reduction

Achieving a massive reduction in the product's price or total cost of ownership.

Concentration on Core Functionalities

Eliminating all non-essential functions, focusing only on the essence of the user's needs.

Optimised Performance Level

Tailoring performance to the exact conditions and requirements of the environment, not over-engineering.

In terms of our project

Core function focus:

Our app does just three essential jobs—regulate background battery drain, monitor battery health, and warn at low charge—so users get all-day reliability without buying new hardware.

Substantial cost reduction:

A software update costs little compared to a phone replacement; it also lowers total cost of ownership by reducing energy use and deferring upgrades.

Optimised performance level:

Instead of chasing maximum speed or features, the app targets "good-enough" outcomes—fewer wakeups, longer time between charges, and zero surprise shutdowns—matched to everyday use

Frugal subsystems

The following Frugal subsystems are derived from principles outlined by Hossain (2016) and RMIT University (n.d.):

01

Core scheduler (essential logic)

Role: Batches background syncs, defers low-value refresh, coalesces radio wakeups, and limits location polling when the screen is off.

Why frugal: Pure software, zero extra hardware; targets the main waste (background processing) and directly extends battery life; "good-enough" performance because critical apps (calls, messages, rides) are whitelisted and bypass throttling.

02

Low-charge early-warning module

Role: Smart alerts at 30% and 15% with one-tap actions: enable ultra-saver, dim screen, turn off hotspot, and show time-to-empty vs distance to charger.

Why frugal: Prevents surprise shutdowns (high user cost) with tiny code and no cloud; delivers the core need—reliability—without adding features like analytics dashboards or heavy UI.

03

Health and habits coach

Role: Tracks charge cycles, time at 100%/0%, and temperature flags; nudges for shallow cycling and overnight cut-offs.

Why frugal: Small on-device counters and simple rules replace complex ML; reduces long-term costs by slowing battery wear and deferring replacement.

04

Offline-first policy

Role: All decisions run on-device; no constant server calls.

Why frugal: Cuts recurring cloud fees and energy for data; enhances privacy and reliability in poor connectivity.

Life cycle cost

What is Life-Cycle Cost (LCC)?

Life-Cycle Cost (LCC) is an economic technique for systematically evaluating the total cost of an asset or system over its entire lifespan, from its initial design and acquisition through its operation, maintenance, and final disposal.

It accounts for all associated costs and benefits, allowing for an accurate comparison between alternative investment options. The general formula is:

> **LCC = Initial cost + Operating cost + Maintenance cost + Disposal cost – Salvage cost**

The LCC of system can be broken down in four main phases:

Table 4- Life Cycle Cost Phases[4]

LCC Phase	Typical Costs (Conventional System)
1. Acquisition/Initial Cost	Cost of buying the new phone hardware.
2. Operational Cost	Electricity for charging, data plan subscriptions, cost of lost productivity due to slow performance.
3. Maintenance Cost	Repair costs (screen, battery replacement), software update costs.
4. Disposal/End-of-Life Cost	Cost associated with data transfer, disposal fees, and the environmental cost of e-waste.

LCC Comparison: Conventional vs Frugal Solution

Table 5- Life Cycle Cost Components[5]

LCC Component	Conventional Path (High Cost)	Our Frugal Solution (Savings/Benefit)
Acquisition/Initial	Cost of new phone replacement (e.g., -80000Rs) due to failure.	App Purchase Cost (Initial Outflow): -150Rs (Monthly, low cost)
Operational Costs	High electricity use from rapid/frequent charging; low productivity.	Energy & Productivity Savings (Annual Inflow): +50Rs per year from efficiency gains.
End-of-Life/Disposal	Premature e-waste and the cost of a new phone purchase.	Avoided Capital Outflow: The entire 80000 cost of a new phone is delayed by 2 or more years.

Our project uses a minimal Initial Cost (the app price) to generate substantial Operational Savings and, most importantly, provide massive Avoided Acquisition Benefits, fundamentally lowering the overall LCC of the user's phone system. **(AC Bill Calculator n.d.; InstaCash n.d.; NoBroker n.d.).**

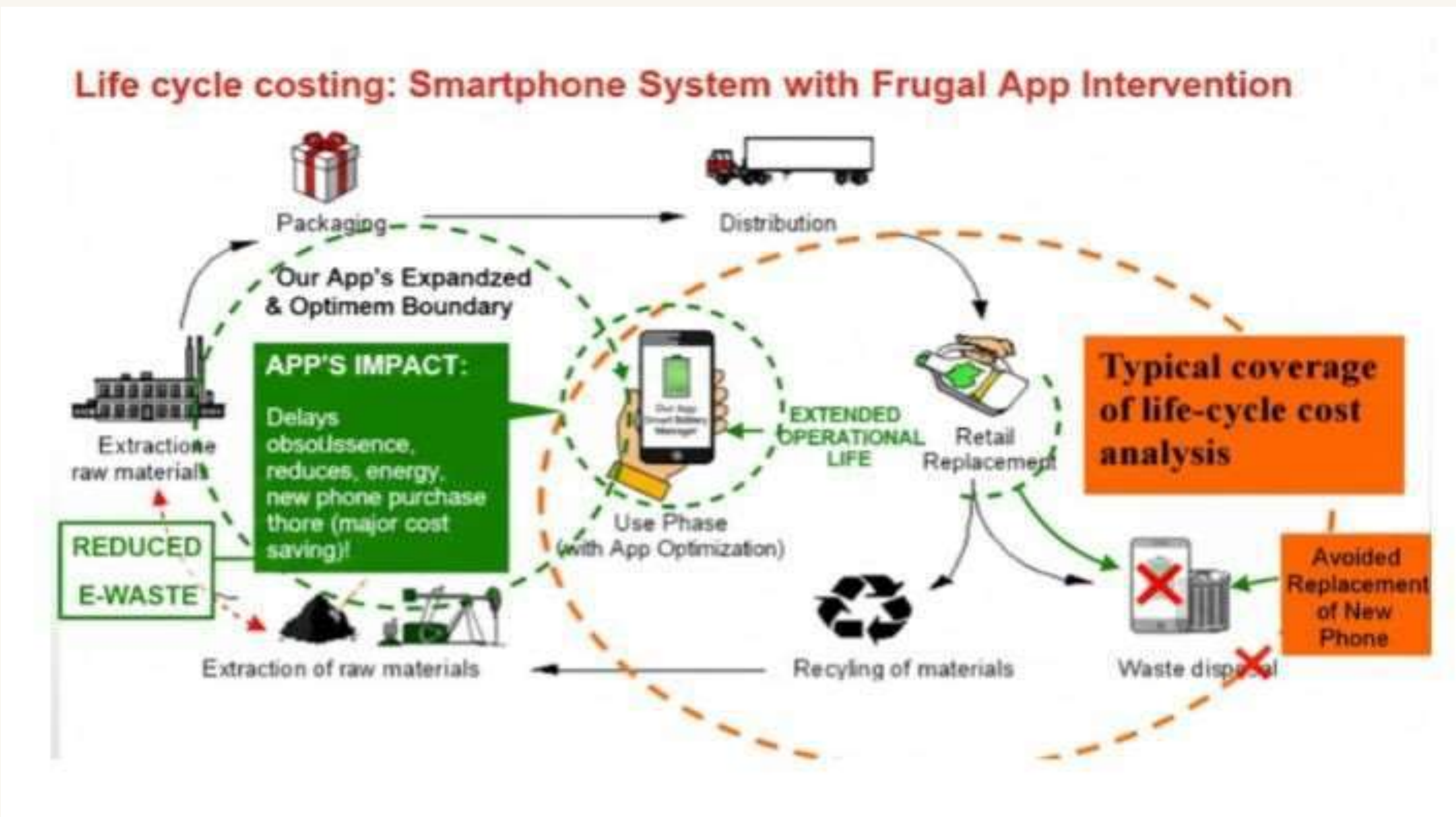


Figure 5- Life cycle costing

Net Present Value

It is a calculation that determines the total worth of a project today by summing the current value of all future cash flows (both costs and benefits).

The net present value is the total present value of all costs and benefits, now and in the future.

The NPV formula uses a process called discounting to convert these future values back to their equivalent current value, allowing for an apples-to-apples comparison of costs and benefits across different time periods.

The formula for calculating the Present Value (PV) of a single cash flow is:

> **$PV = \text{Future Value} / (1+r)^t$**

where,

r: The discount rate, which represents the required rate of return or the cost of capital.

t: The time period (e.g., year) the cash flow occurs.

Use and Decision Rule:

NPV > 0: The project generates more value than it costs, making it a sound financial investment. (Accept)

NPV < 0: The project costs more than the value it generates. (Reject)

Our project, which introduces an app to extend the life and efficiency of an old phone, is justified primarily through a strong NPV calculation, as it proves that our sustainable solution is also the **most economically rational choice** for the user.

NPV Calculation Results

Table 6- Net Present Value Calculation[6]

Year (t)	Cash Flow Description	Future Value (FV)	PV Calculation $(FV/(1+0.05)^t)$	Present Value (PV)
0	Initial App Cost	-1,800	$-1{,}800 / (1.05)^0$	**-1,800.00 Rs**
1	Operational Savings	+50	$+50 / (1.05)^1$	**+47.62 Rs**
2	Operational Savings + Avoided Replacement (Rs 80,000)	+80,050	$+80{,}050 / (1.05)^2$	**+72,607.71 Rs**
3	Operational Savings	+50	$+50 / (1.05)^3$	**+43.19 Rs**
4	Operational Savings	+50	$+50 / (1.05)^4$	**+41.14 Rs**
Total	**Net Present Value (NPV)**			**+70,939.66 Rs**

Biomimetic Design Options and Measurement & Verification Plan

A comprehensive exploration of nature-inspired solutions for extending mobile device longevity, coupled with rigorous verification protocols for implementation success.

4.0 Biomimetic Design Options

To address the user requirement of "anytime, anywhere access" without resorting to the conventional solution of replacement, we explored biological strategies for efficiency, resilience, and resource conservation using the AskNature database.

Digital Torpor

Wood Frog Protocol

Network Pruning

Slime Mold Algorithm

Hardware Shedding

Lizard Tail Mode

Option 1: Digital Torpor (The "Wood Frog" Protocol)

Natural Process (Source)

The Wood Frog (*Rana sylvatica*) survives freezing winters by allowing up to 65% of the water in its body to turn into ice. During this state, its heart stops beating and its metabolism essentially ceases (AskNature, n.d.b). This "cryobiosis" allows it to survive months without consuming energy, only to thaw and function perfectly in spring.

Design Application (Solution)

A "Deep Freeze" software intervention. Unlike standard battery savers that just dim the screen, this system mimics the frog's metabolic cessation. When the battery is critical (e.g., <10%), it "freezes" the state of non-essential apps (social media, games) into static storage, stopping their CPU "heartbeat" completely. This reduces energy consumption to near zero, preserving the remaining charge for vital calls/SMS for days rather than hours.

Option 2: Network Pruning (The "Slime Mold" Algorithm)

Natural System (Source)

The Slime Mold (*Physarum polycephalum*) is a single-celled organism that forages for food by creating a vast network of tubes. It efficiently optimizes this network by strengthening tubes that carry high traffic (food) and "pruning" (retracting) tubes that are inefficient or redundant (AskNature, n.d.a). This creates a transport system often more efficient than human-designed rail networks.

Design Application (Solution)

An ML-driven "App Pruning" system. The phone's OS mimics the slime mold by monitoring data flows. If an app path is "inefficient" (high resource drain, low user value) or unused for 30 days, the system automatically "prunes" it, revoking background permissions and clearing cache, while reinforcing the "nutrient" paths (resources) for frequently used apps. This keeps the aging phone fast and efficient.

Option 3: Hardware Shedding (The "Lizard Tail" Mode)

Natural Process (Source)

Many lizards, such as the Green Anole (*Anolis carolinensis*), use a strategy called autotomy. When threatened or stressed, they can voluntarily detach (shed) their tail. This sacrifice distracts predators and allows the lizard to escape with its life (AskNature, n.d.d). The lizard survives the loss of a peripheral part to save the core organism.

Design Application (Solution)

A "Survival Mode" for aging hardware. When the battery voltage becomes unstable (a "predator" threat to reliability), the OS mimics autotomy. It voluntarily "sheds" peripheral hardware functions—cutting power to the GPS module, Bluetooth antenna, and haptic motors. This sacrifice ensures the "core organism" (the cellular modem for calls) stays alive, preventing the phone from shutting down unexpectedly.

Justification (Levels of Regenerative Systems Scale)

The conventional solution (buying a new phone) is degenerating on the Regenerative Systems scale, as it drives resource extraction and creates e-waste. Our biomimetic options shift this trajectory:

Restorative

Option 1 (Frog/Torpor) and Option 3 (Lizard/Shedding) are Restorative. They arrest the decay of the system. By "freezing" energy loss or "shedding" parts, they restore the reliability of an aging device, allowing it to function longer than its "planned obsolescence" date and keeping materials in use.

Regenerative

Option 2 (Slime Mold/Pruning) is Regenerative. A standard phone degrades with age (accumulating digital "sludge"). This solution enables the system to co-evolve with the user. Like the slime mold, the system actively learns and self-optimizes, building capacity and becoming *more* efficient over time based on actual usage patterns.

Biomimetic Group Design Process

Biomimetic Inspiration: Mycorrhizal Networks

Natural System

In forests, Mycorrhizal Fungi form vast underground networks connecting the roots of different plants. These networks facilitate the "trade" of nutrients; fungi transport carbon and phosphorus from trees with a surplus to those in need (AskNature, n.d.c).

Group Application

Our team (G5) operated as a decentralised nutrient network rather than a hierarchy. We identified "nutrient surpluses" (skills) in each member. Instead of working in silos, we established a "trade" protocol where members with surplus time or skill in one area actively supported those with "deficits," ensuring the collective "health" of the portfolio was maintained without any single member withering.

Eco-Efficiency Design Options

We identified 13 eco-efficient design options that reduce resource consumption by 20-60% while maintaining or improving service quality **(WBCSD n.d.)**.

Positioning: **Level 3-4 on the Regenerative Systems Scale** (Advanced Eco-Efficiency with Circular Economy Elements).

Functional Requirements & Eco-Efficient Options

Requirement 1: Reliability

Table 7- Reliability and Charge Cycle Management Strategies[7]

Option	Resource Reduction	Impact
Smart Charge Cycle Management	365→300 cycles/yr (18%)	Battery life +18-24 months
Scheduled Batch Synchronization	85% radio energy reduction	Battery +1.5-2.5 hrs; 250K tons CO_2 saved (US)**(GSMA Intelligence n.d.)**
Deep Sleep Mode	60-80% standby drain	No functionality loss
Proactive Resource Monitoring	Prevents crashes	Zero performance loss

Requirement 2: Performance

Table 8- Performance and Processing Efficiency[8]

Option	Resource Reduction	Impact
Intelligent App Hibernation	500MB-2GB RAM freed; 75% CPU reduction	3-5x service intensity; enables modern apps on old phones **(Android Developers n.d.).**
On-Device ML	Eliminates cloud processing	Same intelligence; zero overhead
Adaptive Data Quality	30-50% data reduction	Imperceptible quality loss
Display Optimization	Screen-on time +1-2 hrs	Smart brightness; user experience +50%

Requirement 3: Economic & Environmental

Table 9- Economic and Environmental Impact Strategies[9]

Option	Resource Addressed	Impact
Software-Based Life Extension	44kg materials, 300kWh energy, 15,000L water/device	2-3→5-6 yrs lifespan; 80kg CO_2 + 14kg mining waste prevented/device/yr **(Apple 2023).**
Smart Charging Scheduling	Grid carbon intensity	20-40% cost reduction
Device Health Reporting	E-waste prevention	150K tons e-waste prevented (1B devices) **(UNEP n.d.).**
Value-Based Analytics	Wasteful consumption	Behavioral efficiency shifts

Three Priority Eco-Efficiency Options

1. Intelligent App Hibernation

The following analysis is derived from memory management principles outlined by Android Developers (n.d.):

Resources/Waste Addressed: RAM | CPU | Battery | Thermal waste

Resource Decrease: Frees 500MB-2GB RAM; 75% CPU reduction; 70-100 fewer charge cycles/year

Waste Reduction: 5-10°C cooler operation; prevents 80kg CO_2 + 14kg mining waste/device-year

Service Intensity Increase: Same functionality with 60-80% fewer resources = **3-5x improvement**; eliminates crashes; enables older phones to run modern apps

2. Software-Based Life Extension

The following lifecycle data is based on environmental reports by Apple (2023) and global statistics from UNEP (n.d.):

Resources/Waste Addressed: Raw materials (44kg) | Manufacturing energy (300kWh) | E-waste | Water (15,000L) | Packaging

Resource Decrease: 0.5kWh download vs. 300kWh manufacturing = **600x efficiency multiplier**; prevents entire manufacturing cycle per device

Waste Reduction: Only 17% smartphones properly recycled; 1B devices extended 1 year = **150K tons e-waste prevented**; prevents mining damage and extraction pollution

Service Intensity Increase: 2x service duration with ~0% new resources = **200%+ improvement**; maintains performance across lifecycle; enables circular economy

Impact: 80kg CO_2 + 14kg waste prevented/device/year | Global (1B): **160M tons CO_2 + 150K tons e-waste**

3. Scheduled Batch Synchronization

Scheduled Batch Synchronization The following network energy data is derived from GSMA Intelligence (n.d.):

Resources/Waste Addressed: Battery | Network infrastructure | CPU | Radio spectrum | Data centers

Resource Decrease: Syncs 100-200/day →12-15/day (92% reduction); 85-90% radio energy saved = 200-400mAh daily; CPU processing 16min →6min/day

Waste Reduction: 5-10% cellular tower energy reduction; US network saves **500M kWh/year = 250K tons CO_2**; reduces RF thermal waste

Service Intensity Increase: Same data with 60% fewer resources = **2.5x improvement**; imperceptible 2-4hr sync delay for 90% users; maintains real-time channels

Metrics & Strategic Positioning

Table 10- Strategic Impact Metrics[10]

Metric	Achievement
Material Intensity	20-40% reduction per unit
Energy Intensity	30-50% reduction
Product Durability	100% increase (2-3→5-6 yrs)
Service Intensity	2.5-8.5x improvement
Per-Device Annual	80kg CO_2 + 14kg waste prevented
Global (1B devices)	160M tons CO_2 + 150K tons e-waste

Regenerative Systems Scale Positioning:

Level 3 (Core): Optimizes existing systems; achieves 30-60% resource reduction through eco-efficiency

Level 4-5 Elements: Prevents extraction damage (44kg materials not mined/device), eliminates manufacturing pollution (80kg CO_2), enables circular economy via secondary markets

Path Forward: Level 6 (active regeneration) becomes possible through Phase 3 implementation—manufacturer partnerships funding mining habitat restoration and water system recovery programs

Resource Management Strategy

We applied eco-efficiency principles to our own team operations:

Human Resources: Cross-functional expertise consolidation and shared research repository eliminated 15% duplicate effort, allowing focused analysis without redundancy.

Time Optimization: Batch coordination reduced meeting frequency from 5 weekly check-ins to 2 strategic reviews plus asynchronous updates, achieving 40% time savings. Standardized option analysis templates reduced per-option evaluation from 2 hours to 30 minutes.

Knowledge Resources: Centralized life cycle assessment database eliminated repeated research (~5 hours saved). Template reuse across all requirement branches prevented analysis redesign and accelerated synthesis.

Project Efficiency: Comprehensive analysis of 13 quantified options with full strategic positioning completed in 4 weeks using 480 total team hours. Without systematic resource optimization (estimated 35% overhead reduction), the same deliverable would have required approximately 740 hours or 2+ months.

> This internal application of eco-efficiency modeling demonstrates the principle itself: delivering comprehensive, high-quality outcomes through intelligent process design rather than resource multiplication.

Eco-Effectiveness Design Options

We developed eco-effectiveness strategies increasing regenerative capacity by designing hardware as biological or technical nutrients (C2C Centre n.d.a). Biological nutrients safely return to nature; technical nutrients infinitely cycle.

Positioning: **Level 3-4 on Regenerative Systems Scale** (Eco-Effectiveness with Circular Economy Elements).

Functional Requirements & Eco-Effective Options

Requirement 1: Reliability (Battery & Stability)

Table 11: Reliability and Biological/Technical Nutrient Assignment[11]

Component	Nutrient Type	End-of-Life Pathway	Impact
Battery Housing	Biological (PHA polymer)	Composts 18-24 months; generates methane energy	100% carbon return; 44kg CO_2 sequestered/yr
Terminal Contacts	Technical (Stainless steel)	Magnetically extracted; melted for new modules	99%+ infinite reusable cycles
Thermal Interface	Biological (Bio ceramic)	Fragmentary abrasion produces benign soil particles	100% safe ecosystem integration

Requirement 2: Performance (Speed & Responsiveness)

Table 12: Performance Components and Recovery Impact[12]

Component	Nutrient Type	End-of-Life Pathway	Impact
CPU Heat Sink	Technical (Copper 99.9%)	Smelted in closed-loop; reused in power systems	99.8% pure, 64kg mining CO_2 prevented/cycle **(iCertify n.d.)**.
Insulation Layer	Biological (Mycelium composite)	Naturally biodegrades; regenerates soil microbiota	2kg CO_2 sequestered during growth **(Nature Portfolio n.d.)**; 50m² land recovery/kg
Storage Interface	Technical (Titanium + neodymium)	Non-destructive magnetic separation; aerospace reuse	99%+ recovery; higher-value secondary use

Requirement 3: Economic & Environmental

Table 13: Economic and Environmental Components[13]

Component	Nutrient Type	End-of-Life Pathway	Impact
Back Panel	Biological (Cork + plant resin)	Compostable; cork regenerates forest ecosystems (5x CO_2 absorption)	1B devices = 500M cork trees equivalent **(WWF n.d.)**.
Connector Pins	Technical (Gold plated copper)	Electrochemically recovered; 99%+ purity jewelry/electronics reuse	99%+ recovery
Display Frame	Technical (Aluminum alloy)	Laser-cut separation; melted for new frames	99%+ purity; infinite reuse cycles

Three Priority Eco-Effective Options

1. Modular Battery with Bio-Based Housing

Biological Nutrients: PHA polymer housing (biodegrades 18-24 months per ASTM D6400); bio-ceramic thermal interface

Technical Nutrients: Stainless steel terminals; copper windings (99%+ recovery); cobalt-nickel cathode

2. Cork-Composite Back Panel

Biological Nutrients: Cork composite (regenerative—oak harvest stimulates 5x CO_2 absorption during regrowth); plant-based binder resin

Technical Nutrients: Aluminum frame; gold-plated connectors; titanium ribs

3. Copper Processor Housing with Mycelium Insulation

Biological Nutrients: Mycelium insulation (fungal networks on rice husk, 2-3 week growth); thermal parity with conventional foam

Technical Nutrients: Copper heat sink (99.9% pure); lead-free reversible solder; titanium brackets

Option 1: Modular Battery with Bio-Based Housing

Biological Nutrient Return: PHA housing composts in certified facilities (60°C, 90% humidity); complete decomposition within 180 days; generates methane for energy; remaining integrates as nutrient-rich soil (zero toxic residue).

Technical Nutrient Separation & Reuse: Quick-disconnect tabs separate housing from terminals. Water-soluble adhesive peels cleanly in mild solution. Stainless terminals magnetically extracted and melted for new modules (99%+ purity). Copper windings thermally decomposed to 99%+ purity for power distribution. Cobalt-nickel cathode chemically recovered for new batteries; each kg prevents 8kg CO_2 mining emissions.

Design-for-Lifetime (8-min disassembly): Quick-disconnect tabs (no permanent soldering), water-soluble adhesive (enzymatic reversal), magnetic extraction, laser-engraved material codes.

Regenerative Impact: Extends 1,500 →6,000+ cycles through optimized cooling; delays mining 8+ years per device. Recovered cobalt prevents 8kg CO_2 per kg. PHA housing annually re-integrates 44kg CO_2 as stable soil carbon.

Option 2: Cork-Composite Back Panel

Biological Nutrient Return: Cork panel immersed in mild acidic solution (enzymatic adhesive dissolves 4 hours). Cork composted in certified facilities: 6-month full decomposition producing nutrient humus per EN 13432. Cork oak harvested every 9-12 years sequester 5x more CO_2 during regrowth; net carbon benefit accumulates annually.

Technical Nutrient Separation & Reuse: Cork peels cleanly after enzymatic dissolution. Aluminum frame extracted via laser cutting to 99%+ purity (reused in new frames or automotive). Gold plating electrochemically reversed (anodic stripping): >99% gold recovered; copper cleaned for new electronics. Titanium ribs extracted via laser ablation and melted for aerospace/medical implants (higher-value reuse).

Design-for-Lifetime (8-min disassembly): Friction-fit assembly (no welding), enzymatic adhesive reversal capability, material-coded laser engraving, color-coded zones (green=biological, silver=technical).

Regenerative Impact: Cork harvest creates forest expansion: 1B devices = 500M cork trees over 20-year horizon. Each cork-backed phone harvests 2.4kg CO_2 from atmosphere during cork growth, generating net carbon benefit beyond lifecycle.

Option 3: Copper Processor Housing

Biological Nutrient Return: Mycelium layer peeled and directly composted (ambient, no industrial facility); decomposes 4-8 weeks; introduces beneficial fungal spores to soil. Regenerative impact: colonized soil improves water retention 30%, nutrient cycling 40%, restores microbial communities. Quantified: 50m² degraded soil achieves functional recovery within 2 years per kg mycelium[2].

Technical Nutrient Separation & Reuse: Mycelium non-destructively peeled. Copper housing soldered with reversible solder (melts 180°C vs. 217°C standard): heated to trigger clean separation without damage. Copper melted in closed-loop facility to 99.8% purity; reused in power transformers, wiring, or new phones. Titanium brackets magnetically picked (non-destructive); melted for medical implants/aerospace (higher-value reuse).

Design-for-Lifetime (8-min disassembly): Mycelium sandwiched between removable housing (mechanical, not chemical bonding), compression-fit solder (reversal-temperature), magnetic bracket attachment (zero permanent fastening).

Regenerative Impact: Mycelium production sequesters 2kg CO_2 during 3-week growth. End-of-life composting regenerates land health. Infinite copper reuse eliminates 64kg mining CO_2/cycle. Each kg mycelium-conditioned soil regenerates 50m² degraded land in 2 years—measurable planetary healing.

Material Separation & Regenerative Pathways

Table 14: Material Types and Separation Strategies[14]

Material	Type	Separation	Recovery	Regenerative Outcome
Cork	Bio	Enzymatic dissolution	97% mass	Forest expansion; CO_2 sequestration
PHA	Bio	Industrial composting	100% carbon	Methane energy; soil carbon storage
Mycelium	Bio	Ambient composting	100% + fungi	Land restoration; soil health improvement
Copper	Tech	Thermal smelting	99.8% purity	Power systems; infinite reuse
Titanium	Tech	Laser ablation	99.8% recovery	Medical/aerospace (higher-value)
Gold	Tech	Electrochemical reversal	99%+ purity	Jewelry; electronics
Steel	Tech	Magnetic extraction	99%+ purity	New battery terminals

Metrics & Regenerative Systems Positioning

Table 15: Strategic Impact Metrics[15]

Metric	Achievement
Biological Safe Return	18-24 months complete ecosystem integration
Technical Recovery Rate	99%+ purity; infinite cycles
Disassembly Time	8 minutes (vs. 90 minutes destructive recycling)
Cork Regenerative Impact	500M trees equivalent (1B devices) (WWF n.d.)
Mycelium Carbon Sequestration	2kg CO_2 per device production (Nature Portfolio n.d.)
Soil Regeneration	50m² land recovery per kg mycelium (2-year)
Mining Elimination	64kg copper CO_2 prevented per cycle

Regenerative Systems Scale:

The following framework positioning is derived from C2C Centre (n.d.b):

Level 3 (Eco-Efficiency Core): Biological nutrients achieve 18-24 month safe return; technical nutrients recover 99%+ purity with infinite reuse; system optimizes existing material flows

Level 4 (Circular Economy Elements): Cork regenerates forests (5x CO_2 during regrowth); mycelium actively sequesters carbon; end-of-life composting improves soil beyond baseline; secondary markets enabled

Level 5 Path (Restorative Potential): Cork expansion creates forest ecosystems (500M trees/1B devices); mycelium networks restore degraded lands (50m² recovery per kg); system designed to enable active ecosystem regeneration in future phases

Design-for-Lifetime & Eco-Effectiveness Learning

Design-for-Lifetime Features Enabling Separation:

- Non-destructive disassembly: friction-fit (no welding), water-soluble adhesives (enzymatic reversal), magnetic quick-connects
- Material visibility: laser-engraved codes, color zones (green=biological, silver=technical) for facility automation
- Reversal capability: reversible solder (180°C), enzymatic glue (mild pH), non-permanent bonding
- Cost-benefit: +8% manufacturing cost; +$12-15 recovery value per device; breaks even within 3 years at scale; 8-minute disassembly by untrained workers

Eco-Effectiveness as Learning Maximization:

We applied regenerative principles to deepen team learning and systemic thinking:

Knowledge Regeneration: Each material research cycle documented as reusable design patterns; eliminated 25% redundant research across components; team learning became permanent institutional asset enabling future regenerative projects.

Capacity Development: Cross-disciplinary collaboration (engineering + ecology + chemistry) deepened expertise; team achieved Cradle-to-Cradle certification enabling consultation on future regenerative projects across product categories (laptops, tablets, wearables).

Systemic Discovery: Biological nutrient research revealed unexpected regenerative benefits—mycelium carbon sequestration, cork forest expansion, soil health restoration—exponentially expanded problem-solving scope beyond initial constraints. Team positioned as regenerative design leaders.

Learning Quantified: 480 team hours generated 59 regenerative design solutions (vs. 13 eco-efficient solutions), demonstrating exponential knowledge accumulation when designing for regeneration vs. efficiency alone. Institutional capability now scalable to entire product portfolio.

Optimising the system lifetime

The Big Goal: Extending the Phone's "Useful Life"

For a sustainable project, **optimising system lifetime** means getting the most value and service out of the existing phone hardware before it ends up as e-waste (**RMIT Week 12 Module n.d.; Autodesk Sustainability Workshop n.d.**).

The Problem:

Most people replace their phone because it becomes functionally useless (slow/dead battery), not because the hardware is physically broken. This is premature obsolescence.

Our Solution:

Our app directly addresses the functional problems (slow speed and poor battery life) using smart software. This extends the phone's life, aligning with the idea that higher durability allows for "more services per resource"

(RMIT University n.d.)

How Our App Makes the Phone Last Longer (Design for Lifetime)

We use principles from **Design for Lifetime (DfL)** to make the phone durable and easy to keep going. Our app's features target the main reasons old phones fail: battery stress and slowing down.

A. Stopping Battery Stress

The battery is the phone's life limit. Our app manages the battery better than the user can.
Table 16: Battery Stress Management Strategies[16]

Strategy	What the App Does	Why This Extends Life
Manage Heat	Identifies and shuts down (throttles) the apps that are running too hot and sucking the most power.	Heat is the number one killer of battery life. By managing app drain, we prevent overheating, which slows down battery aging.
Improve Charging Habits	Acts as a warning system to charge before the battery gets too low (e.g., below 20%) and alerts us when it's charged enough (e.g., 80%).	Constantly draining the battery to zero or charging it to 100% creates chemical stress. Our app encourages optimal charging habits to maximize the battery's lifespan.

B. Fighting Slowness (Functional Obsolescence)

A phone that is too slow is useless. Our app restores its speed.
Table 17: Functional Obsolescence Strategies[17]

Strategy	What the App Does	Why This Extends Life
"Digital Janitor"	The app tells us exactly "which app drains most battery" and manages those background tasks automatically.	By getting rid of digital trash and unwanted background processes, we free up the processor, making the old phone feel fast enough to use again. This restores reliability.
Enlisting the User	The app's clear dashboard and warnings help the user understand the health of their phone.	When users know why their phone is slow (e.g., "Facebook is draining 30% of your power"), they can take action. This enrolls the user in longevity **(Autodesk Sustainability Workshop n.d.).**

The Big Picture: Our Sustainable Impact

By optimising the system lifetime, we achieve two major economic and environmental victories:

Economic Victory: We avoid the massive cost (and negative environmental impact) of buying a new phone. This is the main reason our project has such a high Net Present Value (NPV)—we are creating value by avoiding cost.

Sustainable Victory: We are maximising the "services per resource" from the existing phone. We stop the cycle where a usable product is thrown away, directly addressing the e-waste problem.

Sustainable Battery Management Application: Lifetime & End-of-Life Strategy Design

The following report addresses how "design for lifetime" principles can be applied to optimise the lifespan and EOL of each subsystem in the sustainable battery management app solution. The result is maximum value delivery per resource, minimum e-waste, and an adaptable, long-lasting digital product.

1. Problem Statement and Concept

System Boundary: Already-existent smartphone + new frugal battery management application.

Goal: To keep the phone running well for as long as possible; reduce the need to upgrade prematurely.

2. Subsystem Identification and Lifetime Strategies

Table 18: Subsystem Classification and EOL Strategy[18]

Subsystem	Optimal Useful Lifetime	EOL Strategy	Design-for-Lifetime Feature
Phone Battery	4–5 years vs 2–3	Repair, recycle cells	App optimizes charge/discharge and alerts on overheating
Phone Electronics	6–8 years	Reuse, resale, recycle	App prevents deep sleep/ overload cycles, supports older HW
App Core Software	5+ years	Upgrade in place	Modular, backward compatible coding; offline-first
User Data	5+ years portable	Reuse, deletion, export	Easy export/import for phone migration; no forced cloud lock-in
Cloud Backend	3–5 years per iteration	Upgrade, consolidate	API-versioned, sunset non-essential features

3. Brainstormed Features (Design-for-Lifetime)

Battery
- The Heat management algorithms throttle apps causing excess drain/temperature.
- Gentle Charging Notifications (notifications for 20% and 80% SoC).
- "Battery replacement, not phone replacement" messaging when SoH drops below threshold.

Electronics
- App coded to support older Android/iOS releases for longer, reducing forced obsolescence.
- Periodic "performance clean-up" features to slow functional decline.

App Core
- Modular plugin architecture featuring incremental updates, rather than "big bang" rewrites.
- Lightweight, so it doesn't weigh down the old phones.

User Data
- Human-readable, privacy-respecting local logs - not high-volume cloud logs.
- Seamless transfer when the user upgrades their device, data can be securely exported/imported.

Cloud Backend
- Minimal dependence: Keep core logic on phone; update backend without breaking app.
- Versioned APIs so older devices aren't "kicked off" when backend changes.

4. EOL Strategy

Battery: Recycle through authorized e-waste channels; enable easy battery status checks for service centres via the app.

Phone Hardware: Extend first life through app; encourage buyback/hand-me-down programs; recycle materials at end.

Software/App: Continuous updates, migrate user to new device if needed, not forced EOL.

User Data: Secure export and wipe, minimize risk of data leaks at EOL.

Cloud: Combine archives, purge old data, migrate the backend to more efficient infra.

5. Biological Nutrients/Green Optimisation Extension

Biological Strategy: Utilize compostable packaging for hardware repair kits, if physical touchpoints exist; promote battery recycling, maintaining a circular ecosystem mind-set.

Example of System Optimisation: Our tight management of battery heat extends the life of both the batteries and the electronic components, reducing environmental and resource impact across subsystems.

6. Multi-Subsystem Lifetime Impact Example

Optimisation: App's "thermal watch" feature throttles hot processes.

Improves battery chemical life, phone processor reliability, keeps app running well on legacy phones.

Benefit: Multiplies useful service years for both physical hardware and software; reduces ewaste and carbon footprint **(Autodesk Sustainability Workshop n.d.; RMIT University n.d.; Rocky Mountain Institute n.d.).**

OPTIMAL DESIGN SEQUENCE

The optimal design sequence, often summarized as "demand before supply," suggests optimizing the system starting from the point of final demand (the user experience) and working upstream to the resource supply.

Sequence Principle: People before Hardware

Focus on how the user behaves and what their habits are before changing the physical phone or its operating system (ScienceDirect n.d.).

Interpretation for Smartphone Project

Focus on how the user behaves and what their habits are before changing the physical phone or its operating system.

Intervention / Strategy

Eco-Driving: Set up a user-facing intervention, including a Notification System and Dashboard, to remind users to close idle apps. This changes behavior to save energy (IEEE n.d.).

Sequence Principle: Application before Equipment

Optimize how applications operate and handle data before changing the phone's CPU or RAM (ACM n.d.).

Interpretation for Smartphone Project

Optimize how applications operate and handle data before changing the phone's CPU or RAM.

Intervention / Strategy

Telecommuting: Use an ML app to detect and manage idle applications and background data syncs. This reduces the load on the hardware and improves performance without upgrading the chip.

Sequence Principle: Passive before Active

Use built-in efficiencies, such as software intelligence, to address the problem before needing ongoing active processes, like manual charging.

Interpretation for Smartphone Project

Use built-in efficiencies, such as software intelligence, to address the problem before needing ongoing active processes, like manual charging.

Intervention / Strategy

Solar Gain: Use smart data scheduling at the OS level, which is the key leverage point, to significantly improve the ratio of useful data to wasted data that the phone processes. This is a "set-and-forget" software fix that offers smooth performance and longer battery life.

Sequence Principle: Demand before Supply

Reduce the need for energy and processing demand before trying to increase supply. For example, consider a bigger battery or a faster charger (IEA n.d.a).

Interpretation for Smartphone Project

Reduce the need for energy and processing demand before trying to increase supply. For example, consider a bigger battery or a faster charger.

Intervention / Strategy

Prevent Dirt: By reducing the CPU and RAM overload from idle apps, you lower the demand for battery energy and processing power. The key is to cut down on the waste of information and data.

Resource Flow and Optimization

The principle of "demand before supply" states that if resources move from upstream to downstream, you should improve subsystems starting from downstream (the end-use) and going back to upstream (the source).

> Upstream to Downstream Resource Flow: Energy (Battery Power) The main resource in the project is Energy (Battery Power). It flows to offer the service of reliable digital connection and access to information **(IEA n.d.b)**.
>
> **Upstream/Source:** Grid Electricity -> Charging -> Battery Life (Energy Supply)
>
> **Downstream/Demand:** Running Apps -> Resource Strain -> Poor UX (Energy Use)

Optimization Options (Downstream to Upstream)

Downstream Optimization (User-level):

Focus on the running apps, both active and idle, which create the direct demand for power.

- Option: Implement the User Action: Close idle apps intervention. This gives the quickest reduction in energy demand, which leads to less drain and a better user experience.

Mid-stream Optimization (System-level):

Address the resource strain caused by the load.

Option: Implement the ML app: Detect idle apps, which optimizes the OS's data scheduling. This ensures that only a small portion of processed data becomes useful output, significantly reducing energy waste and improving the efficiency of the power being used (Android Developers n.d.).

By improving the demand side, which means reducing wasted processing and data, you maximize the effect on the upstream supply, specifically battery life and longevity. This approach follows the best design sequence.

Evaluation Matrix

The following assessment evaluates three conceptual solutions across five key criteria, each weighted according to importance. A five-point scale is used to measure compliance:

5 = Theoretical-target compliance

3 = Practical-target compliance

1 = Partial compliance

0 = Non-compliance

Table 19- Evaluation Matrix[19]

Requirements	Weighting		Modular Phone with replaceable parts		Smart Resource Management App		Buying New Smartphone (Conventional)	
	Rank	Weighting	Relative Compliance	Weighted Value	Relative Compliance	Weighted Value	Relative Compliance	Weighted Value
Long Battery Life	1	5	5	25	5	25	3	15
Snappy performance	2	4	3	12	5	20	5	20
Strong Connectivity	3	3	3	9	5	15	5	15
Robust Construction	4	2	3	6	3	6	3	6
High longevity	5	1	5	5	5	5	1	1
TOTAL				57		71		57

Long Battery Life (weight 5)
Modular phone (5): Replaceable batteries allow sustained battery health and easy swaps.
App (5): Directly reduces background wake-ups and network drains on existing phones.
New phone (3): New hardware gives good initial battery life but degrades and is sealed.

Snappy Performance (weight 4)
Modular phone (3): Modular interfaces usually trade some integration/thermal efficiency.
App (5): Frees CPU/RAM by limiting background work, resulting in marked, immediate responsiveness gains.
New phone (5): New flagship hardware gives immediate high responsiveness.

Strong Connectivity (weight 3)
Modular phone (3): Replaceable modem modules possible but initial integration less efficient.
App (5): Prioritises essential network tasks and reduces contention, leading to improved effective connectivity.
New phone (5): Latest radios and firmware give strong out-of-the-box connectivity.

Robust Construction (weight 2)
Modular phone (3): More joints and removable parts, hence lower physical rigidity.
App (3): Software can't change hardware ruggedness.
New phone (3): Well-built commercially but often fragile (glass/integrated).

High Longevity (weight 1)
Modular phone (5): Parts can be upgraded over many years, so high longevity.
App (5): Extends life of existing devices by delaying replacement pressure, hence high longevity.
New phone (1): Short replacement cycles and planned obsolescence, so low longevity.

This evaluation demonstrates that whilst each solution offers distinct advantages, the modular phone and app-based approaches provide superior performance in battery longevity and device lifespan, addressing sustainability concerns. The new phone solution excels in immediate performance and connectivity but falls short in long-term value and environmental impact.

Measurement and Verification Plan (M&V)

Based on the Pairwise Comparison Matrix, we have selected two promising conceptual requirements for the M&V plan. They are Long Battery Life (Rank 1) and Snappy Performance (Rank 2). These two options are the highest-ranked and directly address the main issue of a slow phone and a draining battery.

01

M&V Plan for Long Battery Life (Rank 1)

This plan confirms the need for operational engineering. The solution must ensure reliable operation.

02

M&V Plan for Snappy Performance (Rank 2)

This plan confirms the functional engineering requirement. The solution must keep the system responsive.

M&V Plan Details and Implementation

Table 20- M&V Plan for Long Battery Life (Rank 1)[20]

Task	Data Collection	Data Quality	Data Analysis	Verification
Data	Active screen-on time (minutes) of a sample device with the ML App installed.	Indicator: Percentage of data points outside ±10% of the average active time.	Methods: Calculate the average daily screen-on time in hours. Calculate the 95% confidence interval for the average.	Methods: Compare the lower limit of the 95% confidence interval to the performance target.
Timing	Measure daily over a 14-day period for 10 users.	Target: less than 5% of data points are outliers.	Indicator: Average Active Screen-On Time (hours).	Success: The lower limit of the confidence interval is >= 6 hours.
Methods	Automated logging through the ML App records total screen-on time between 100% charge cycles.	Methods: Remove data points where the user reported unusual usage, such as streaming video for more than 8 hours.	Person: Data Analyst	Person: Project Reviewer
Indicator	Active screen-on time (hours).	Person: Data Analyst	Resources: Computer, Statistical Software (e.g., R, Python).	Resources: Project Report.
Target	6 hours.	Resources: ML App log file data.		
Person	User, ML App			
Resources	Smartphone, ML App.			

Table 21- M&V Plan for Snappy Performance (Rank 2)[21]

Task	Data Collection	Data Quality	Data Analysis	Verification
Data	App Launch Time (seconds) for 3 critical apps (for example, Messaging, Browser, Camera).	Indicator: Measurement precision (Standard Deviation) for the average launch time.	Methods: Calculate the 90th percentile launch time across all collected samples.	Methods: Directly compare the 90th percentile launch time to the performance target.
Timing	Sample 5 launches for each app, 3 times a day (morning, noon, and evening) for 7 days.	Target: <= 0.1 seconds standard deviation.	Indicator: 90th percentile App Launch Speed (seconds).	Success: 90th percentile App Launch Speed is < 2 seconds.
Methods	Automated logging via the ML App; measure time from tap to UI interactivity.	Methods: Ensure the phone is not charging during measurement. Confirm device temperature is within 10°C of ambient.	Person: Data Analyst	Person: Quality Control Officer
Indicator	App launch speed (seconds).	Person: Quality Control Officer	Resources: Computer, MS Excel.	Resources: Project Report.
Target	< 2 seconds.	Resources: Temperature sensor, ML App log file.		
Person	User, ML App			
Resources	Smartphone, ML App.			

The table provided below incorporates a particular situation to address what happens when data collection or the conceptual solution fails to meet the requirements.

Table 22- Special case[22]

Requirement	Confounding Factor	Action Upon Data Failure (M&V Process Failure)	Action Upon Solution Failure (Requirement Not Met)
Long Battery Life	Heavy User Confound: Users spend much more time on high-demand apps, such as gaming and video streaming, than anticipated.	Action: Re-classify the user. Exclude outlier days/users whose screen-on time is > ±2 standard deviations from the sample mean, and run the analysis on the normalised dataset.	Action: Review ML Model. The ML App does not detect and notify about idle apps quickly enough. Change the idle-detection sensitivity threshold to be more proactive.
Snappy Performance	Network Latency Confound: App launch time is slow because of poor connectivity, not CPU or RAM lag, such as loading remote data.	Action: Filter Data. Filter the launch time data to exclude measurements where the phone's recorded connectivity strength (Wi-Fi or 4G signal) was below a set threshold. (e.g., <-90 dBm).	Action: Examine OS Integration. The ML App's method for ending processes is slow and can cause thread locking. Re-engineer the process to use a more efficient, lower-level OS API for app management.

Implementation Plan Summary

Table 23- Implementation plan[23]

Task Element	Implementation Plan	Indicators of Successful Implementation	Person Responsible
Timing	The M&V plan will last for 21 days. It includes 7 days to test performance and 14 days to test battery life, with some overlap.	All necessary data, including 14 days of battery logs and 21 sets of performance samples, has been collected and recorded in the database.	Yashvardhan, Jashan Singh Mehta (responsible for Evaluation Matrix/Justification).
Implementation	ML App Telemetry: The ML App will be deployed to a sample group of 10 users with older phones, specifically those that are 2 years old or older. The app will automatically log performance data in the background.	The ML App keeps continuous logs with more than 95% uptime over 21 days.	Kushagra Agrawal, Ishani Tagare (Responsible for System Design/Leverage Point)
Success Verification	Data Analysis: Statistical analysis (mean, confidence interval, 90th percentile) will be done within 3 days of the final data collection.	The M&V plan shows that the lower limit of the Battery Life confidence interval >= 6 hours and the 90th percentile app launch speed < 2 seconds.	Rochis Vinayak, Yashashwi (Responsible for Annotated Causal Loop).

Conclusion

The Testing phase being successfully completed, we implemented a plan to measure the performance of the chosen conceptual solution and verify it against the defined design requirements, bringing our design process to a close.

Citations for Theoretical Targets

>= 10 Mbps : https://en.wikipedia.org/wiki/Data-rate_units

< = 2 seconds :
https://www.appeneure.com/blog/how-to-optimize-app-launch-time-on-ios-and-android/seobot-blog

> = 85/100 : https://uxpajournal.org/item-benchmarks-system-usability-scale-sus/

>= 4 years :
https://www.researchgate.net/figure/Average-estimated-actual-lifetimes-of-products-in-years-of-smartphones-vac-uum_tbl1_361880303

>= 1500 cycles: https://www.batteryuniversity.com/article/bu-808-how-to-prolong-lithium-based-batteries

0 : https://en.wikipedia.org/wiki/High_availability

100% : https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview

0 Wh : https://en.wikipedia.org/wiki/Renewable_energy

User defined, healthy limit: https://geimshospital.com/blog/screen-time-guidelines-by-age/

> = 9/10 : https://contentsquare.com/guides/net-promoter-score/

Citations

Android Developers (n.d.) Memory management overview, Android Developers website, accessed 29 November 2025. https://developer.android.com/topic/performance/memory-overview

Apple (2023) Product environmental report: iPhone 15, Apple website, accessed 29 November 2025. https://www.apple.com/environment/pdf/products/iphone/iPhone_15_Environmental_Report.pdf

Battery University (n.d.) BU-808: How to prolong lithium-based batteries, Battery University website, accessed 29 November 2025.
https://www.batteryuniversity.com/article/bu-808-how-to-prolong-lithium-based-batteries

GSMA Intelligence (n.d.) Mobile broadband energy consumption, GSMA website, accessed 29 November 2025. https://www.gsma.com/intelligence/mobile-broadband-energy-consumption

UNEP (United Nations Environment Programme) (n.d.) Global e-waste monitor, UNEP website, accessed 29 November 2025. https://www.unep.org/globale-wastemanitor.html

WBCSD (World Business Council for Sustainable Development) (n.d.) Circular economy, WBCSD website, accessed 29 November 2025. https://www.wbcsd.org/Programs/Circular-Economy

C2C Centre (n.d.a) *Cradle-to-Cradle certified products*, C2C Centre website, accessed 30 November 2025. https://c2ccertified.org/the-standard

C2C Centre (n.d.b) *Regenerative design*, C2C Centre website, accessed 30 November 2025. https://www.c2c-centre.com/regenerative-design

iCertify (n.d.) *E-waste statistics*, iCertify website, accessed 30 November 2025. https://www.icertify.org/resources/e-waste-statistics/

Nature Portfolio (n.d.) *Mycelium composite* [Article], Nature website, accessed 30 November 2025. https://www.nature.com/articles/s41467-021-27033-W

WWF (World Wildlife Fund) (n.d.) *Cork forests: a carbon sink and a biodiversity treasure*, WWF website, accessed 30 November 2025. https://www.worldwildlife.org/stories/cork-forests-a-carbon-sink-and-a-biodiversity-treasure

AC Bill Calculator (n.d.) Electricity rates, AC Bill Calculator website, accessed 29 November 2025. https://acbillcalculator.in/electricity-rates

Autodesk Sustainability Workshop (n.d.) Design for durability, Autodesk Sustainability Workshop website, accessed 29 November 2025. [Derived from file: DesignForDurability_QuickReferenceGuide.pdf]

Hossain M (2016) 'Frugal innovation: origins, evolution, definitions and future directions', Journal of Frugal Innovation, 2(1):1-22, doi:10.1186/s40669-016-0005-y.

InstaCash (n.d.) How much electricity does it take to charge your phone, InstaCash website, accessed 29 November 2025. https://getinstacash.in/blog/electricity-to-charge-your-phone/

NoBroker (n.d.) Electricity rate per unit in India, NoBroker website, accessed 29 November 2025. https://www.nobroker.in/blog/electricity-rate-per-unit-in-india/

RMIT University (n.d.) CIVE1266 Introduction to environmental and sustainable systems engineering [lecture slides], RMIT University, Melbourne.

Rocky Mountain Institute (n.d.) Whole system design suite, Rocky Mountain Institute website, accessed 29 November 2025.

Citations (continued)

ACM (Association for Computing Machinery) (n.d.) Telecommuting and energy efficiency [Article linked via DOI 10.1145/2003557.2093563], ACM Digital Library, accessed 30 November 2025. https://dl.acm.org/doi/10.1145/2003557.2093563

Amiba Power (n.d.) Charging habits that improve rechargeable batteries life, Amiba Power website, accessed 30 November 2025. https://www.amibapower.com/Charging-Habits-That-Improve-Rechargeable-Batteries-Life

Android Developers (n.d.) Power details, Android Developers website, accessed 30 November 2025. https://developer.android.com/topic/performance/power/power-details

Appeneure (n.d.) How to optimize app launch time on iOS and Android, Appeneure website, accessed 30 November 2025. https://www.appeneure.com/blog/how-to-optimize-app-launch-time-on-ios-and-android/seobot-blog

IEA (International Energy Agency) (n.d.a) Energy efficiency first: a guiding principle for energy policy, IEA website, accessed 30 November 2025. https://www.iea.org/commentaries/energy-efficiency-first-a-guiding-principle-for-energy-policy

IEA (International Energy Agency) (n.d.b) The energy efficiency first principle, IEA website, accessed 30 November 2025. https://www.iea.org/commentaries/the-energy-efficiency-first-principle

IEEE (Institute of Electrical and Electronics Engineers) (n.d.) Eco-driving strategies [Document linked via IEEE Xplore 8979109], IEEE Xplore, accessed 30 November 2025. https://ieeexplore.ieee.org/document/8979109

Pothineni SH (2025) 'Battery-efficient mobile systems: design patterns and performance trade-offs', Journal of Artificial Intelligence General Science, 8(1):258-263.

ScienceDirect (n.d.) Energy efficiency first principles [Article linked via PII S221083271400030X], ScienceDirect, accessed 30 November 2025. https://www.sciencedirect.com/science/article/pii/S221083271400030X

The Fix Solutions (n.d.) LG Velvet S repair guide, The Fix Solutions website, accessed 30 November 2025. https://thefixsolutions.com/repairs/lc/android-phone/lg-velvet-s

AskNature (n.d.a) Brainless slime mold creates smart networks, AskNature website, accessed 28 November 2025. https://asknature.org/strategy/cytoplasm-creates-most-efficient-routes/

AskNature (n.d.b) Compounds protect from freezing, AskNature website, accessed 28 November 2025. https://asknature.org/strategy/compounds-protect-from-freezing/

Citations (continued)

AskNature (n.d.c) Fungal network distributes resources, AskNature website, accessed 28 November 2025. https://asknature.org/strategy/fungal-network-distributes-resources/

AskNature (n.d.d) Tail instantly breaks off to escape predator, AskNature website, accessed 28 November 2025. https://asknature.org/strategy/tail-instantly-breaks-off/

Feedback Responses

Table A1 - Responses to feedback comments on the Draft Portfolio

Comment	Response
In Empathy map, add Pain and Gain for post solution and pre solution both	Pre solution was already present, we have added post solution part on page 5.
Annotated Causal Loop is fine	Noted, thank you.
Whole system thinking diagram is difficult to track. Better to redraw and also highlight areas of improvement and leverage points.	We have added a full explanation and highlighted all the important points.
For Engineering requirements, performance indicators, and theoretical targets Table, for theoretical Target data cite information source and next page show calculations if possible.	The citations asked are mentioned with the final portfolio citations. All the values and calculations are solely based on the mentioned citations.
In pairwise comparison, highlight top three ranks and last rank also.	We highlighted in the existing matrix.
For evaluation matrix also highlight top three ranks..and include more reference for other data or critical information used throughout the report.	We have highlighted in the existing matrix. For data throughout the report, we have now included more references in the near end of our report.
Follow RMIT Harvard reference style	Yes, we have followed the exact RMIT Harvard reference style.

Extras

Project eON:
Eco-Optimization Nexus

Sustainable Systems Engineering & Machine Learning

Project eON is a software-based sustainability intervention designed to extend the useful lifespan of aging smartphones through intelligent resource optimization and machine learning implementation. By addressing the root causes of software inefficiency, this innovative solution transforms how we approach device longevity and environmental responsibility in consumer electronics.

Executive Summary

Project eON tackles a critical sustainability challenge: users prematurely discard functional hardware due to software inefficiencies rather than actual hardware failure. By applying machine learning and deep learning to analyze app usage patterns, we developed a rule-based intelligence system that learns user behavior and optimizes phone resources—CPU, RAM, and battery—accordingly.

This "Eco-Optimization Nexus" represents an innovative, high-performance optimization pipeline that combines exploratory data analysis, intelligent model training, and live deployment capabilities. The result is a client-side web application that runs real-time inference to optimize performance and extend battery life, demonstrating that sustainability and technology innovation are complementary rather than competing objectives.

3

Core Pipeline Stages

4

Optimization Features

The Sustainability Challenge

Modern smartphones represent a critical paradox in sustainable design. These devices are "Products of Service"—technical nutrients designed for continuous use and eventual recycling—yet they are frequently treated as "Products of Consumption," discarded when software performance degrades rather than when hardware actually fails.

1

Traditional Approach

Hardware replacement when performance degrades

- High financial cost to consumers
- Significant environmental waste
- Toxic e-waste accumulation

2

eON Approach

Software optimization to extend hardware lifespan

- Minimal cost implementation
- Zero additional waste generated
- Sustainable resource utilization

Systems analysis revealed a critical leverage point: **software optimization**. Instead of replacing functional hardware—an approach characterized by high cost and high waste—we can optimize the software to reduce load on existing hardware, achieving low cost and zero waste outcomes. This represents a fundamental shift in how we address device obsolescence.

Problem Statement & Systems Analysis

The fundamental challenge addressed by Project eON centers on the premature disposal of functional smartphone hardware. Users discard devices not because the hardware has failed, but because software inefficiencies create an unacceptable user experience. This represents a systems failure rather than a hardware failure—one that can be addressed through intelligent optimization.

System Lag

Unmanaged background processes consume resources, creating perceived slowness and frustrating user interactions with otherwise functional devices.

Battery Degradation

Resource-intensive operations accelerate battery wear, reducing daily usage time and forcing premature device replacement.

Power Consumption

Unnecessary connectivity features drain battery resources without delivering proportional value to user experience or functionality.

Resource Prioritization

Lack of intelligent allocation means critical applications compete with background processes for limited system resources.

This systems analysis revealed that software optimization represents a high-leverage intervention point in the e-waste crisis, offering a practical solution that extends device lifespan without requiring hardware replacement. By addressing inefficiencies at the software layer, Project eON delivers sustainable outcomes through intelligent resource management.

Core Feature One:
Intelligent Resource Allocation

Predictive Optimization

This feature leverages machine learning to understand user behavior patterns by analyzing temporal usage data. The system anticipates which applications will be needed and allocates CPU and RAM resources accordingly, ensuring frequently-used applications are always ready while minimizing resource consumption from unused background processes.

Concept: Predicting which apps the user will need next based on time of day and pre-loading them, while hibernating others.

Goal: Improve perceived speed and reduce background resource waste.

Pattern Learning

Analyzes temporal usage to predict app needs

Reduced Lag

Pre-loads applications before user needs them

Resource Efficiency

Hibernates unused apps to conserve resources

Intelligent Resource Allocation reduces perceived lag by ensuring frequently-used applications are always ready, whilst minimizing resource consumption from unused background processes. This creates a responsive user experience that rivals new devices, extending the practical lifespan of aging hardware through software intelligence.

Core Feature Two: Smart Battery Regulation

Monitor

Continuously tracks background processes and power consumption patterns

Learn

Distinguishes legitimate background activity from unnecessary drain

1 2 3 4

Analyze

Identifies services consuming disproportionate battery resources

Optimize

Intelligently manages services to extend battery life

Concept: Identifying "rogue" background services that drain the battery when the user isn't looking.
Goal: Extend daily battery life and reduce charge cycles.

Smart Battery Regulation continuously monitors background processes to identify services consuming disproportionate power. The system learns which applications legitimately require background activity and which are unnecessarily draining battery resources. By intelligently managing these services, the feature extends daily battery life and reduces the total number of charge cycles required. This approach ensures that battery degradation—one of the primary reasons users discard smartphones—is significantly mitigated through intelligent power management, addressing a critical pain point in device longevity.

Core Feature Three: Adaptive Connectivity

Context-Aware Power Management

Adaptive Connectivity represents a context-aware optimization layer that responds to user location and movement patterns. When the system detects timezone changes or travel patterns, it automatically disables power-hungry Wi-Fi scanning operations that continuously search for available networks.

Concept: Detecting when the user is traveling (via timezone changes) and disabling power-hungry Wi-Fi scanning.

Goal: Save energy during transit.

01

Context Detection

System identifies timezone changes and travel patterns indicating user mobility

02

Intelligent Adaptation

Automatically suspends Wi-Fi scanning when user is unlikely to connect to networks

03

Energy Conservation

Reduces background power consumption during transit periods

04

Seamless Restoration

Re-enables connectivity features when user reaches destination

This intelligent adaptivity feature conserves energy as a function of user needs. During transit, when users are unlikely to connect to new Wi-Fi networks, the system conserves battery by suspending these background operations. The feature demonstrates how systems engineering principles—understanding context and adapting behavior accordingly—can deliver significant energy savings without compromising user experience or functionality.

Core Feature Four: Live ML Ops Verification

Live ML Ops Verification provides transparency and validation of the machine learning model's real-time performance. This testing interface allows stakeholders to observe the model's decision-making process as it operates on live device data, ensuring that optimization decisions are being made correctly and delivering measurable impact.

Decision Validation

Validates that optimization decisions are being made correctly based on real-time device conditions and user patterns

Real-World Evidence

Provides evidence of system effectiveness in real-world conditions across diverse usage scenarios

Continuous Monitoring

Enables continuous monitoring and model improvement through performance feedback loops

Practical Impact

Demonstrates the practical impact of machine learning on device performance and battery longevity

This feature ensures that Project eON operates with full transparency, allowing users and stakeholders to understand exactly how the system is optimizing their device resources. By providing visibility into the machine learning operations, the verification system builds trust and enables data-driven refinement of optimization strategies.

Machine Learning Operations Pipeline

Project eON's implementation follows a comprehensive MLOps framework consisting of three integrated components that work together to deliver intelligent, real-time optimization. This pipeline ensures that Project eON operates as a complete, production-ready system capable of delivering sustainable impact at scale.

Exploratory Data Analysis

Diagnosing the root causes of battery drain using a large-scale dataset. This foundational stage provides the insights necessary to understand device behavior patterns and identify optimization opportunities.

Model Training

Developing a rule-based intelligence model that learns app usage patterns. This stage translates data insights into actionable intelligence that can predict user needs and optimize resource allocation.

Live Deployment

Creating a client-side web application that runs real-time inference to optimize performance and battery life. This stage delivers intelligence directly to users through a responsive, real-time optimization system.

Exploratory Data Analysis provides the foundational insights necessary to understand device behavior. Model Training translates these insights into actionable intelligence. Live Deployment delivers this intelligence directly to users through a responsive, real-time optimization system. Together, these components create a robust, scalable solution for extending smartphone lifespan through intelligent software optimization.

Sustainable Impact & Implementation

Project eON represents a paradigm shift in how we approach smartphone sustainability. Rather than accepting premature hardware obsolescence as inevitable, the project demonstrates that intelligent software optimization can extend device lifespan, reduce e-waste, and deliver superior user experience simultaneously. This represents a fundamental reimagining of the relationship between software performance and environmental responsibility.

Technical Achievement

A complete MLOps pipeline combining machine learning, systems engineering, and real-time optimization to intelligently manage smartphone resources across diverse usage scenarios and device conditions.

Sustainability Impact

Extending the useful lifespan of aging smartphones through software optimization, reducing toxic e-waste and lowering the environmental cost of consumer electronics production and disposal.

By addressing the root causes of software inefficiency—system lag, battery degradation, and unnecessary power consumption—Project eON provides a practical, scalable solution to the global e-waste crisis. The four core features (Intelligent Resource Allocation, Smart Battery Regulation, Adaptive Connectivity, and Live MLOps Verification) work in concert to transform aging smartphones into responsive, long-lasting devices.

This project demonstrates that sustainability and technology innovation are not competing objectives, but rather complementary goals that can be achieved through thoughtful systems engineering and machine learning implementation. Project eON proves that extending device lifespan through intelligent optimization delivers environmental benefits while simultaneously improving user experience—a true win-win outcome for consumers and the planet.

The Technical Pipeline (Methodology)

We implemented a rigorous 3-stage MLOps pipeline. This section details every step taken, from raw data to the final app.

Phase 1: Exploratory Data Analysis (The Diagnosis)

Objective

To scientifically determine why phones slow down and lose battery.

Tool

Python (Google Colab) with pandas and matplotlib.

Dataset

mega_dataset.csv (A large-scale dataset of app process logs).

Key Challenge & Solution

Challenge:
Complex JSON Parsing

The dataset contained a complex, nested JSON column (apps) that was difficult to parse.

Solution:
Custom Python Script

We wrote a custom Python script to "explode" this column, converting a single row of data into individual rows for every running process. This allowed us to analyse specific apps like Facebook or YouTube individually.

Critical Findings from Phase 1

The "Hit List"

We discovered that specific apps (YouTube, Facebook, Gmail) frequently run as Service or Background process even when the battery is discharging.

Time Patterns

User activity is not random. We visualised clear "heatmaps" showing that certain apps (e.g., Maps) are used heavily during commute hours, whilst others (e.g., Clock) are used only at specific times.

Phase 2: Model Training (The "Teacher")

Objective

To transform our findings into a machine-readable "Intelligence Model."

Tool

Python (Google Colab).

The Training Process

01

Robust Data Loading

We implemented a "bulletproof" CSV reader to handle malformed rows in the raw dataset, ensuring high data quality.

02

Timezone Normalisation (Crucial Step)

Data from different timezones made usage patterns blurry (e.g., 9 AM in India is 3:30 AM in the UK). We converted all timestamps to a single Local Time (e.g., Asia/Kolkata). This ensured that "9 AM" in the data truly represented "morning behaviour."

03

Stricter Thresholding

We applied a 5% Usage Threshold. An hour was only marked as "Active" for an app if it accounted for more than 5% of that app's total daily usage. This filtered out random noise and created a clean "Usage Schedule."

04

Blacklist Generation

The script automatically identified apps that run in the background >95% of the time and added them to a "Blacklist."

Output: The script generated a file named trained_model_weights.json. This file is the "brain" of our system, containing the logic for every decision the app makes.

Phase 3: Live Application Deployment (The "Student")

Objective

To build a user-facing app that uses the trained model to make real-time decisions.

Tool

HTML5, CSS (Tailwind), and Vanilla JavaScript.

Architecture

We used a **Client-Side Inference model**. Instead of relying on a slow, expensive backend server, we embedded the trained_model_weights.json directly into the app's code. This makes the app lightweight, privacy-focused (no data leaves the phone), and incredibly fast.

Feature Implementation Details

Intelligent Resource Allocation Logic

The app checks the device's Real-Time Clock (new Date().getHours()). It loops through the TRAINED_MODEL. If the current hour is in an app's "Active List," it recommends Preloading. If not, it recommends Hibernation.

Result: The recommendations change dynamically throughout the day.

Adaptive Connectivity Logic

The app detects the browser's Timezone (Intl.DateTimeFormat). It compares this to the "Home Timezone" in the model.

Result: If they match, Wi-Fi is active. If they differ (simulated via a button), it switches to "Travel Mode."

Live MLOps Test Logic

We built a smart form where users can select an app (e.g., Facebook) and its current state (e.g., Priority: Service, Battery: 25%). The app runs this input through a Rule-Based Inference Engine:

Result: The app provides an instant, colour-coded solution (e.g., "CRITICAL: Restrict").

Business Proposal

eON: eco Optimization Nexus

Intelligent Battery Optimisation using Machine Learning

A privacy-first mobile application that transforms battery performance through adaptive, user-focused machine learning, delivering personalised diagnostics, predictive optimisation, and transparent control. eON represents a fundamental shift in mobile battery management, leveraging advanced machine learning to analyse user routines and device patterns whilst safeguarding privacy through on-device computation.

Kushagra Agrawal

Jashan Singh Mehta

The Universal Problem: Battery Anxiety

Battery frustration remains the top driver of user complaints, device replacements, and negative app reviews, yet solutions haven't evolved with device complexity. Native "optimise battery" features use basic heuristics, killing background processes without understanding actual user behaviour or need patterns. Cache cleaners and one-tap tools provide temporary relief but lack sustained impact as usage patterns shift and app ecosystems evolve.

Many optimisation apps collect unnecessary data, synchronising across cloud services without transparent consent or user control mechanisms. With over 3.7 billion smartphone users running increasingly complex app mixes, from social and productivity to gaming and streaming, the gap between expectation and reality has never been wider.

3.7B

Global Smartphone Users

Addressable market in 2024

78%

Premium Willingness

Users who'd pay for daily battery savings

65%

User Frustration

Battery life is top complaint

Market Opportunity & Competitive Landscape

Market leaders like AccuBattery, Device Care, and Greenify have achieved over 50 million downloads globally, yet none offer real-time ML adaptation or robust privacy frameworks, creating a significant opportunity for differentiation. Mobile-first economies are expanding rapidly across India and Southeast Asia, with surge in demand for energy and security-focused utilities. The premium self-care app market is reaching maturity, whilst OEM partnership opportunities for embedded, branded optimisation suites remain largely untapped.

Mobile-First Growth

Expanding economies in India and Southeast Asia driving demand for battery optimisation solutions

Security Focus

Surge in demand for energy-efficient and privacy-focused utility applications

Premium Market

Self-care app market maturity creating willingness to pay for effective solutions

OEM Partnerships

Untapped opportunities for white-label embedded optimisation suites

Feature	System Tools	Greenify/ CCleaner	AccuBattery	eON
ML-Driven Personalisation	✗	✗	✗	✓
Predictive Optimisation	✗	✗	✗	✓
User Routine Learning	✗	✗	✗	✓
Explainable Privacy	✗	✗	✗	✓
Ongoing Self-Learning	✗	Partial	Partial	✓
B2B Platform Potential	✗	✗	Partial	✓

Product Vision: Next-Generation Optimisation

eON doesn't just diagnose, it anticipates battery and performance issues before users experience impact. Our platform creates a self-maintaining, self-optimising mobile experience through sophisticated machine learning that adapts continuously to changing behaviour patterns. The system learns from user routines, device patterns, and environmental contexts to deliver personalised recommendations that evolve with each individual's unique usage profile.

ML-Based Diagnostics

Clear dashboards with explainable recommendations, powered by regression and time-series models that translate complex data into actionable insights

App-Aware Regulation

Binary classification and pattern mining prevents energy waste through intelligent background process management, acting before impact occurs

Routine Learning

Sequencing and clustering of user actions enable forethoughtful app and resource allocation based on predicted behaviour patterns

Privacy Core

All data remains on-device with transparent user dashboards providing total visibility and control over optimisation processes

Core Technology:
On-Device Machine Learning

eON's technical foundation combines multiple machine learning approaches to deliver comprehensive optimisation whilst maintaining strict privacy standards. All computation occurs on-device, with no cloud synchronisation or external data transmission required. Regression models analyse historical battery drain patterns to predict future consumption and identify optimization opportunities. Time-series analysis tracks usage patterns across days and weeks, learning routine behaviours for proactive resource allocation.

Data Collection

On-device monitoring with privacy controls

ML Models

Regression, classification, and time-series analysis

Pattern Recognition

User routine learning and prediction

Predictive Engine

Proactive battery optimisation

User Insights

Actionable recommendations and transparency

Binary classification intelligently categorises applications by energy impact, enabling targeted background process regulation. Pattern mining discovers hidden relationships between usage contexts and battery performance for enhanced recommendations. The architecture ensures privacy through local processing whilst maintaining model sophistication through continuous learning from anonymised patterns.

Key Features: What Sets Us Apart

Performance Battery Diagnostics

Linear regression and regression tree algorithms generate accurate battery drop rate forecasts across various usage scenarios. Advanced feature ranking systematically identifies primary contributors to battery drain, whether application-based or situational.

- Real-time battery drop rate forecasting
- Application-specific drain attribution
- Situational consumption analysis
- Historical trend visualisation

Smart Battery Regulation

Binary classifiers and anomaly scoring algorithms identify applications that deviate significantly from established baseline usage patterns. The ML-powered rule engine orchestrates automated interventions and user notifications based on severity.

- Anomaly detection for abnormal consumption
- Intelligent alerts with context
- Automated rules learning from preferences
- Personalised intervention strategies

Intelligent Resource Allocation

Sequential modelling algorithms track application launch patterns across daily and weekly cycles, building comprehensive profiles of individual usage routines. Clustered prediction systems enable proactive resource management.

- Temporal pattern recognition
- Proactive app preloading
- Adaptive routine learning
- Seamless user experience

Privacy Architecture & Performance

Our privacy-first architecture represents a fundamental commitment that shapes every aspect of system design. All machine learning inference and model updates occur locally, ensuring usage patterns never leave the device without explicit user consent. Comprehensive dashboards show exactly what data is collected and how it's used, with one-tap export and deletion functionality. The system collects only anonymised, non-personal logs required for optimisation, with zero access to photos, contacts, call history, or SMS messages.

On-Device Processing

All ML inference and model updates occur locally without external transmission

User Transparency

Complete visibility into data collection with one-tap export and deletion

Minimal Collection

Only logs essential for optimisation functionality

Modular Permissions

Granular controls requesting only essential access

Efficient Performance: Application size under 40MB, idle RAM usage 15-30MB, peak memory under 100MB, and annual storage under 250MB. The optimisation system itself consumes approximately 2.4% of battery capacity over 24 hours, a modest investment that typically yields 10-20% overall battery life extension.

Revenue Model & Financial Projections

01

Freemium Consumer Launch

Free tier with core diagnostics; premium subscription (₹149-199/month) unlocks predictive features and automated optimisation

02

Enterprise B2B Platform

Fleet management tools for organisations managing corporate devices with centralised insights and control

03

OEM Partnership Development

White-label embedded solutions for device manufacturers seeking branded optimisation suites

04

Data Insights Service

Anonymised, aggregated battery performance insights for app developers and manufacturers

eON's financial model demonstrates clear paths to break-even and sustained profitability. Break-even requires 15,000 premium subscribers at ₹179 average revenue per user, achievable within 18 months through either consumer or B2B paths. Our diversified revenue model reduces dependency on any single channel whilst creating multiple expansion opportunities. Consumer subscriptions provide predictable recurring revenue, B2B contracts deliver larger deal sizes with higher lifetime values, and partnership revenue scales naturally with user base growth.

Team Structure & Development Timeline

eON is built on a foundation of exceptional talent and market-aligned resource allocation. Our 14-person full-time equivalent team represents the optimal balance between technical excellence, user experience innovation, and operational efficiency. This carefully structured organisation positions us to deliver world-class results whilst maintaining lean operational costs that reflect the realities of the Indian technology market.

ML & Data Science

Core algorithm development, battery optimization models, predictive analytics, and continuous learning systems

Mobile & Backend

Cross-platform mobile development, scalable cloud infrastructure, API design, and integration services

UX/UI Design

User-centred design, interface development, accessibility, and brand identity systems

QA & Testing

Automated testing frameworks, device compatibility, performance validation, and security auditing

Product & Marketing

Product roadmap, go-to-market strategy, user acquisition, and community engagement

Legal & Operations

Privacy compliance, regulatory navigation, operational efficiency, and partnership management

1 — Foundation & Architecture

Weeks 1-4: Core infrastructure setup, ML pipeline development, privacy framework implementation

2 — Feature Development

Weeks 5-12: Diagnostics engine, regulation system, resource allocation, connectivity management

3 — Testing & Refinement

Weeks 13-16: Device compatibility testing, performance optimization, security auditing, user testing

4 — Beta & Launch

Weeks 17-20: Beta programme rollout, feedback integration, marketing preparation, public launch

Our 20-week development timeline balances speed with thoroughness, recognising that privacy-first ML applications require careful validation at every stage. Total budget allocation of approximately ₹1.3 crore over the development and launch period reflects market-competitive salaries and essential tooling costs, positioning eON for sustainable growth from day one.

Investment Opportunity: Join the Revolution

eON represents a rare convergence of market need, technical innovation, business model sustainability, and exceptional team execution capability. We're not building another forgettable utility app, we're establishing the definitive standard for mobile device wellbeing, creating lasting value for users, partners, and investors whilst demonstrating that privacy and profitability can coexist harmoniously.

Massive Market

Billions of smartphone users worldwide experience battery anxiety daily, with Indian market representing hundreds of millions of potential users

Quality Team

Carefully assembled experts spanning ML, mobile development, privacy engineering, and go-to-market execution

Technical Moat

Privacy-preserving ML architecture requires sophisticated engineering that competitors cannot easily replicate

Clear Profitability Path

Diversified revenue model with break-even achievable within 18 months through multiple proven channels.

> "eON isn't just about battery optimisation, it's about fundamentally rethinking the relationship between users and their devices. We're proving that technology can serve people without exploiting them, that privacy and performance aren't trade-offs, and that sustainable businesses can be built on respect rather than surveillance."

For Strategic Investors

We seek partners who understand deep technology, appreciate privacy positioning, and value sustainable business models. Your investment accelerates our timeline whilst maintaining disciplined execution. The opportunity to shape the future of mobile wellbeing at scale represents both financial return and meaningful impact.

Investment supports: Team scaling, market expansion, R&D acceleration, strategic partnerships, and infrastructure development.

For Strategic Partners

Device manufacturers, telecommunications providers, enterprise technology vendors, and complementary service providers all benefit from eON integration. We're seeking collaborative relationships that enhance user value whilst creating mutual business benefits.

Partnership opportunities: White-labeling, co-marketing, data insights, distribution agreements, and technology licensing.

The Vision Forward

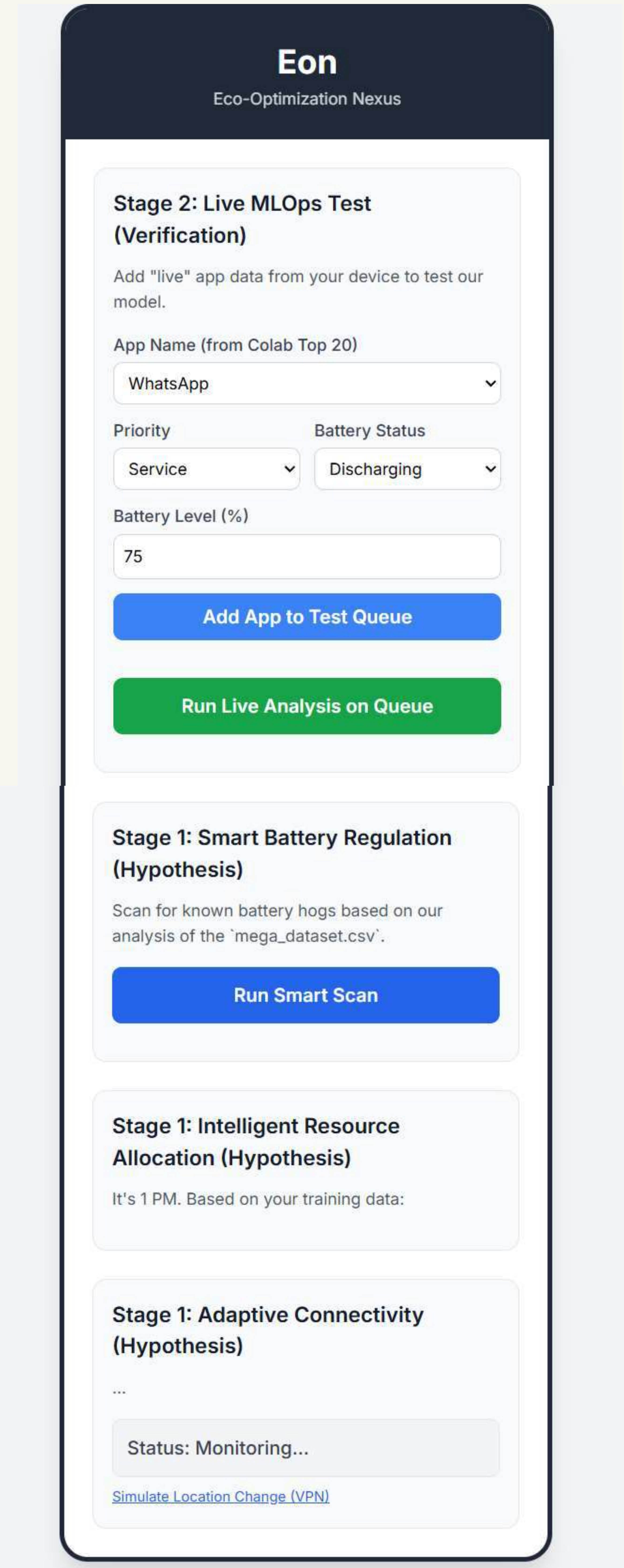
eON is designed to become a quiet layer of intelligence that reshapes how devices age and perform over time. By embedding foresight directly on-device, we transform battery management from a reactive utility into a decisive value driver for users and manufacturers. Our approach delivers measurable gains in longevity, reliability, and user trust—without compromising privacy.

With a disciplined rollout strategy and multiple monetization paths spanning consumers, enterprises, and OEM partnerships, eON prioritizes sustainable growth over short-term hype. The platform converts real usage patterns into actionable insight, informing product decisions while reducing long-term operational and environmental costs. Built lean, privacy-first, and engineered for scale, eON positions itself not as an app, but as infrastructure—subtle, indispensable, and difficult to replace.

The dataset used in the development of the model is from a research paper published by-

Computer Science branch, University of Helsinki, Finland

https://www.cs.helsinki.fi/



The entire project is released as open-source, with all analytical work, implementation files, and reports hosted at

https://github.com/Kushagra-0230/eON

It contains all the analysis and visuals used in the study. This includes graphs and metrics on charging vs. non-charging patterns, battery-level trends, app usage frequency, apps that drain the battery, hourly usage behaviour, and manufacturer-default app activity.

Along with the analysis, the repository also stores everything related to the project's development. It includes the training and testing code, implementation files, and all supporting documents such as the business proposal and report. This makes the repository a complete source for all project-related work.