The Future of Respiratory Health

Team 4

Sarthak Das: 01897538
Tanya Ahmed: 01896617
Lauren Chong: 01856351
Jiayi Chen: 01883225
Anusha Narayan: 01895792

Supervisor

Professor Thrishantha Nanayakkara

0 Abstract

Respiratory diseases in the United Kingdom are likely to get considerably worse by 2042, due to: an increasing number of e-cigarette users and smokers between the ages of 18 and 34, rising air pollution in urban places caused by the high levels of vehicular transport and trends towards a sedentary lifestyle. This is going to increase the pressure on the already over-burdened National Health Service. Current diagnoses are only administered after a patient recognizes symptoms themselves. This fact, combined with the extended waitlists of the NHS, mean that respiratory issues become serious before they can be treated, and require more advanced care. The aim of this project is to propose a novel method of detecting respiratory conditions early, and reduce pressure on the NHS.

This report details the design process behind uncovering a method of detecting respiratory diseases in 2042. This included extensive future contextual studies, to understand the future of the NHS, as well as a thorough literature review, which shed light on technological enablers that could be used in the final product. These enablers fuelled the concept development process.

The final outcome of the report is a wearable chest patch consisting of a variety of sensors to detect different datapoints and generate a comprehensive view of the user's lung health. The data is stored, and analysed to detect inconsistencies. This will enable easier identification of key data aspects and insights, allowing for the doctor to quickly refer to the most relevant data, speeding up the diagnosis pipeline and reducing workload.

Contents

1 Introduction

The National Health Service (NHS) is the greatest asset that the United Kingdom has with regards to taking care of the population's health. The basic goals of the system have not changed in the seven decades since its inception – to provide a comprehensive service to all, regardless of financial status [1]. It has grown from having a staff of 144,000 in 1948 [2], to being one of the biggest employers in the world, with the head count done in January 2022 reaching nearly 1.4 million [3].

Unfortunately, the system is no longer able to keep up with the demand on its services. Workforce projections suggest that an extra 475,000 posts will need to be filled within the healthcare industry by the start of the next decade [4], in order to keep up with the population needs. This is a target that is unlikely to be met. Respiratory health, mental health and musculoskeletal conditions are contributing significantly to the burden on the NHS [5], with management of respiratory health conditions alone costing the NHS £11 billion annually [6]. Serious, long-term interventions are required to reduce the burden of healthcare professionals.

In conjunction with a decline in the services offered by the NHS, there has been an increase in self-monitoring wellness devices. Devices such as Fitbits have seen an extremely high rate of adoption, with 25% of adults around the UK now owning an exercise tracker [7]. The NHS, however, has been remarkably slow incorporating this technology in its workflow, due to an outdated care model. There is little provision for healthcare outside the hospital or surgery. The NHS plans to increase the use of wearables and more self-monitoring devices, thus allowing patients to be cared for in the comfort of their own home. This project focuses on using the trend of self-monitoring wearables to reduce the burden that respiratory conditions place on the NHS.

2 Future Contextual Studies

2.1 Sense Making

2.1.1 STEEPV Wheel

To help define a future scenario, a STEEPV Wheel was created. Under the theme "The Future of Healthcare", the overarching drivers, trends and enablers that will drive the project were identified. Key themes included the rise of telemedicine, development of personalised point-of-care healthcare solutions, the shift towards preventative models and the reduction of workload on healthcare workers through the integration of data-driven systems and partial privatisation of the NHS.

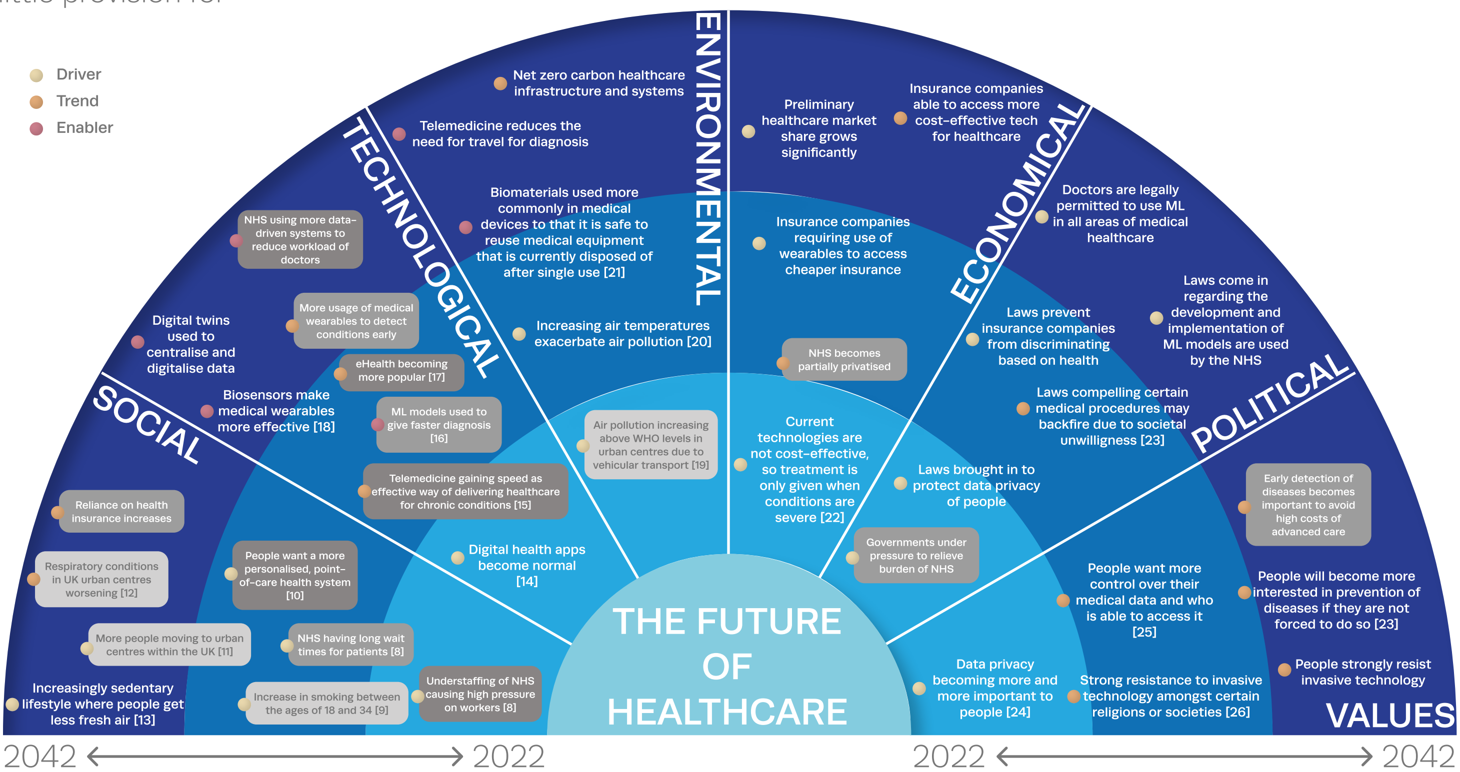
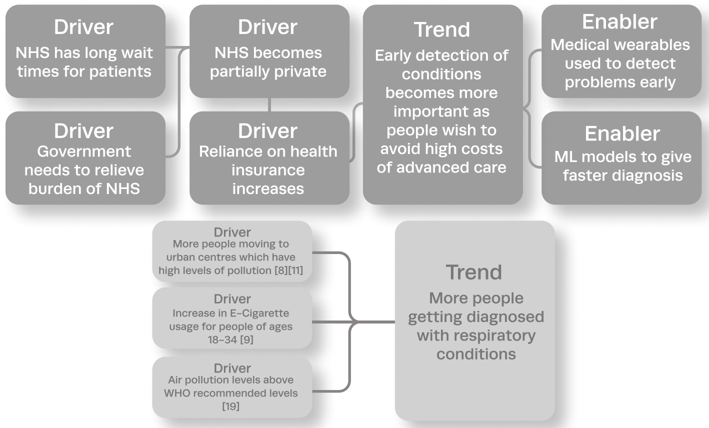


Figure 1 STEEPV Wheel



The identified drivers, trends and enablers were the basis of future project development, although other points made were also used supplementarily.

2.1.2 Futures Cone

To look at the future of the NHS, a Futures Cone was created (Figure 2). This helped to ascertain the bounds of probability of certain trends, and help to understand the most likely projected scenario, as well as what could be drawn on as plausible.

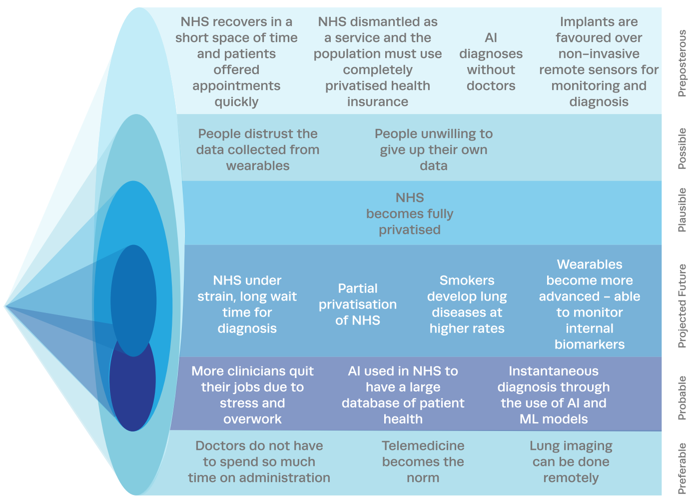


Figure 2 Futures Cone

2.2 Opportunity Identification

To aid project convergence, further research was done into the future of the NHS. This would narrow the future context into which the product-service-system would fit. The Futures Hospital Commission was a 5-year study [27] conducted by the Royal College of Physicians to address the falling standard of care delivered by the NHS. The study detailed three measures that must be taken to revitalise the healthcare system: the need for additional care to be administered outside hospitals and surgeries, improving patient experience by shortening wait times for diagnosis and treatment, and the implementation of a system which can continually improve the NHS. These three measures were then evaluated to see which one best achieved the aim of reducing the pressure on the NHS.

Table 1 Opportunity Identification

Number	Measure	Contribution	Reasoning
1	Providing more care outside of hospitals and surgeries	Y	Having more care available outside of hospitals and surgeries will reduce the number of people who are dependent on it, thus relieving the pressure on the system
2	Improving patient experience by reducing wait times for diagnosis and treatment	Y	Reducing the wait times for diagnosis will allow patients to be treated earlier, thus meaning that fewer people will require advanced care, meaning that there will be less of a burden on the NHS
3	Implementing a system of continuous improvement	N	Whilst this is helpful, it will not help with alleviating the pressure but will only be useful once the NHS is in a good state, to ensure that it continues in this way

Based on the evaluation of the 3 measures, a combination of 1 and 2 will be the most effective in reducing the pressure on the NHS. An early diagnosis that can be given without relying on the healthcare professionals is the best way of achieving this reduction.

As identified by the STEEPV wheel, there is a steady increase in respiratory diseases. As shown in the introduction, respiratory diseases already place a significant burden on the NHS. The WHO predicts that by 2030, 20% of deaths worldwide will be caused by lung disease [28], accentuating the burden on the NHS. Therefore, the project area was refined to be the early detection of respiratory diseases outside of the healthcare system.

Smokers are more susceptible to respiratory diseases. Smoking is responsible for 90% of COPD (Chronic Obstructive Pulmonary Disease) cases [29]. The increasing number of smokers between the ages of 18 and 34 [9] will mean an increase in the likelihood of respiratory diseases in the population by 2042. Smokers have therefore been chosen as the user group of focus.

2.3 Future Scenario

By 2042, long wait times and lack of resources will lead to a collapse of the NHS. It will become partially privatised, increasing reliance on health insurance. Insurance companies are legally prohibited from discriminating based on health, but are still wary of giving insurance to those who are at risk of poor health, such as smokers. They agree to provide insurance, as long as the policyholder submits to constant monitoring of their lung health, as they are at high risk of respiratory problems.

3 Project Definition

The aim of this project is to design a product service system that can monitor the lung health of a policyholder. However, it is also important to reduce the strain felt by the NHS by decreasing the workload of doctors. Alongside monitoring the lung health of the user, the product must also be able to aid in diagnosing any respiratory conditions that the patient has, thus reducing the doctors workload

The progression of technology, especially in the domain of biosensors and microsensors, will enable comprehensive, accurate and non-invasive data gathering to build a digital twin of the human body. In the future, machine learning will significantly reduce workload on doctors by automating parts of the diagnosis, enabling the doctor to make faster decisions. This technology will be trusted due to its accuracy and efficiency in comparison to the typical diagnosis process. The system should be designed with the confidence of patients and healthcare professionals in mind, by aiding diagnoses through the provision of reliable data. This will be facilitated using biomarker detection, wearables and an increase in the use of artificial intelligence and big data. By accumulating the requirements identified, the following design question was formed:

How might we passively monitor the lung health of smokers to generate an early diagnosis and aid the increase in telemedicine?

To see the full development of the future scenario, into design question, see Figure 3 Project Mapping.

4 Design Definition

4.1 Lung Diseases

All respiratory diseases fall into 3 overarching categories: airway diseases (affect gas transport by blocking and narrowing airways), lung tissue diseases (affect structural integrity of the lung through tissue inflammation and scarring) and lung circulation diseases (affecting blood vessels, resulting in scarring, clotting and inflammation and a subsequent shortage of oxygen). Pulmonologists may look for the following data points to diagnose respiratory conditions: lung capacity, blockages or unwanted structural alterations, breathing rate and airflow.

4.2 Monitoring Technologies

4.2.1 Biomarkers

A biomarker is a biological indication of normal or abnormal bodily processes used for disease detection and prevention, usually a molecule found in the blood, tissue or excretion of the body. Present day biomarker detection is predominantly invasive and can be categorised into four types: molecular, radiographic, histologic and physiologic. However, there is a trend towards non-invasive detection, and initial research is currently being done into their usage in detecting pancreatic and breast cancer [30]. Non-invasive biomarker detectors could focus on monitoring breath and sweat levels, through ultrasound or magnetic resonance elastography. The Journal of Thoracic Disease suggested integrating the use of computational tomographic imaging and artificial intelligence. AI models can then be utilised to discern between malignant and benign lung tissues [31].

4.2.2 Spirometry

The most common lung disease detection method is spirometry [32], which tests the lung capacity of the patient by measuring the speed of the airflow using ultrasonic transducers. However, it is often inaccurate because patients have difficulty exhaling

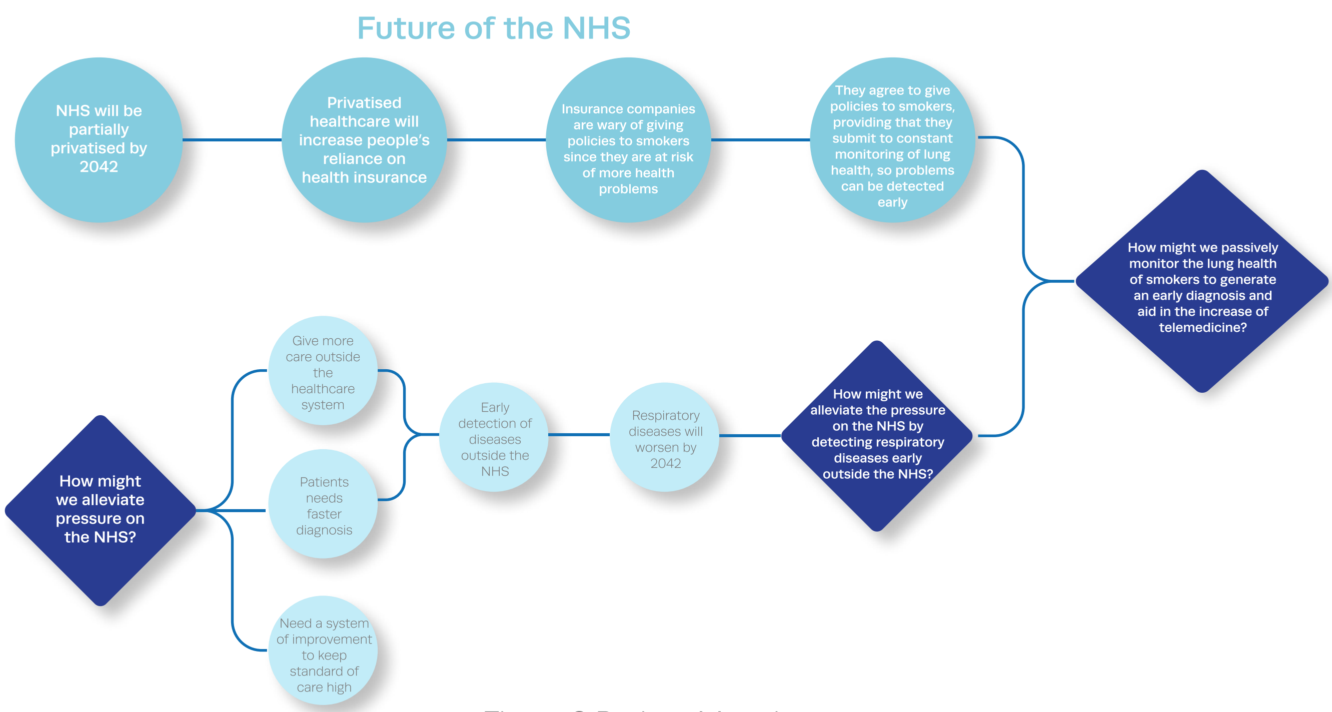


Figure 3 Project Mapping

fully into the spirometer. Other manners of measuring lung capacity include: measuring diaphragm and intercostal muscle expansion, and internal imaging of the lungs

4.2.3 Odour Sensing

Odour sensors can detect different smells based on molecule composition of chemicals. The Covid-19 pandemic saw an increase in the use of such sensors [33] to detect infected individuals. Respiratory diseases, such as Covid, result in changes in the organic compounds which make up body odour. Organic semi-conducting analysers can be used to detect such changes, and in the case of the pandemic, were yielding 99% accuracy results, thus potentially making them a method for non-invasively detecting lung conditions.

4.2.4 Acoustic Diagnosis

Acoustics has been historically used as a diagnosis mechanism for respiratory diseases. Clinicians frequently use auscultation, a technique for listening to lung sounds. Fine crackles are the earliest sign of inconsistencies, and can be detected long before symptoms are clear to the user. Crackles are short, discontinuous, and non-stationary sounds with frequency ranges predominantly appearing between 60Hz to 1.2kHz [34]. Lower frequencies indicate a restrictive condition, whereas higher imply obstructive conditions. A recent study exploring recordings of pathological mechano-acoustic signatures shows promising results for evaluation to allow for early detection or disease monitoring [35]. However, it should be noted that acoustic diagnosis alone is not sufficient to lead to a diagnosis, but can be used as a basis for assistive diagnostic tools.

4.2.5 Medical Imaging

Imaging is a vital part of testing, particularly for detecting structural inconsistencies. Both Electrical Impedance Tomography (EIT) and Ultrasound Computed Tomography (UCT) are used, and unlike a majority of imaging techniques, they are both non-invasive and non-radioactive. EIT uses low frequency electrical currents to ascertain conductivity differences across sections of the body, leading to an image of the lung being formed [36]. It is already being used for semi-continuous monitoring of lung aeration. UCT uses the transmission of ultrasonic waves to generate images of the tissue. The physical equipment that is used for UCT has developed from being large static scan consoles to handheld devices. The next major leap in this technology will be the incorporation of artificial intelligence [37]. AI's use in image recognition will improve UCT drastically, providing more accurate and reliable data.

4.2.6 ECG

Electrocardiography (ECG) is often a useful adjunct to many other pulmonary tests [38]. ECG technology is made up of several components: bioimpedance devices are used for measuring lung capacity, IMUs to measure chest movement and skin-mounted soft electronics to detect skin tension and movement. These combined components can lead to the development of an EDI (electrical activity of diaphragm graph), allowing healthcare professionals to help track lung tissue diseases. An array of sensors around the lungs can allow for accurate tracking of the expansion and contraction of the intercostal muscles. This can allow for accurate monitoring of the diaphragm's electrical signals and the expansion of the lungs, making this closed loop monitoring system highly effective in the diagnosis process. Diaphragm monitoring is a particularly useful way of diagnosing lung tissue diseases.

4.3 Parallel Industry Uses

The medical industry is known to react slowly to technological advancements, therefore contrasting fields were explored to uncover innovations that can be borrowed to aid health and wellbeing.

Acoustic Holography

Acoustic holography is a technique where internal structures can be mapped into a 3D space using an array of microphones. This technology is currently utilised by the construction industry to map 3D structures and spaces, enabling the identification of vibrations and structural weakness [39]. A similar technique could be used to examine the structure and vibrational resonance of the lungs.

Space Gases Chemical Testing

Gas testing on small scale chips is being used on NASA's Perseverance space rover. The chip can detect gases in the air that make contact with the chip. This is conducted through the use of a hexagonal lattice, where each face is a different metal. As the gas passes through each metallic surface, reactions occur and alter electrical properties, enabling measurements of chemicals in the air [40]. Space gas testing could be implemented in medicine, by measuring the gases associated with breathing or even the chemical make-up of the user's sweat.

4.4 Future of Data in Healthcare

4.4.1 Digitalisation of Health Records

The NHS Long Term Plan details the process of transitioning to a digital healthcare system in the next 10 years [41]. The aim is to provide patients with the digital tools and services required for autonomy over their own health [42]. This includes a secure, digital avenue for access to medical records. The implementation of such a practice has begun, with the BadgerNet Maternity Notes App in Gateshead NHS Trust [42]. This grants expectant mothers with real-time access to their maternity records. It is expected that a similar process, of continuous, digital documentation of health records, including respiratory health, will be developed in the next two decades. This gives rise to the idea of the digital twin.

4.4.2 Use of Artificial Intelligence and Machine Learning

The concept of a digital twin arose from the need to have a centralised location for patient healthcare, as well as the trend towards a more personalised healthcare system. Artificial intelligence, and machine learning models are the primary technological enablers behind this transition. AI can have a profound and positive impact on the NHS, due to its inherent ability to process large amounts of data at a very high speed. The NHS AI Lab set up the National Covid-19 Chest Imaging Database (NCCID) at the start of the Covid-19 pandemic, as a part of their AI in imaging programme [43]. Their long term goals involve commissioning and deploying systems for widespread use in screening and testing [44]. Currently, the long term goals of the NHS AI Lab involve maternity and diabetic care. Whilst this is not linked to the area of health of this project, it does provide insight into how the NHS is planning to use AI, and gives scope for the project outcome.

4.5 Future of Wearables

Part of the NHS's Long Term Plan is to harness the use of wearables for earlier detection and treatment of diseases, through continuous monitoring [41]. This will enable large scale prevention programmes, and contribute to a more personalised healthcare programme [45].

A technical report by Imperial College London detailed "the next generation of medical [wearable] devices is likely to be more invasive and able to give quantitative real-time measurements of biomarkers in point of care settings" [46]. Reliable diagnoses are difficult to administer without invasively monitoring biomarkers [46]. This has led to a stagnation of medical wearables. However, given that there is a trend toward non-invasive healthcare [47], it is likely that by 2042, there will be a need for non-invasive biomarker detection.

Wearables in the future are likely to adorn flexible electronics to enable portable and lightweight technology. Flexible batteries can significantly reduce the size and bulkiness of wearables, and can be integrated much easier into technology [38].

4.6 Technology Roadmap

Following research into monitoring technology, data and wearables, a map was made, looking at the future of technologies in 2042 as a basis for ideation. To see the map, see Figure 4.

Figure 4 Technology Roadmap

There are two aspects of data processing to consider: accessing medical images for GP diagnosis and signal processing for ML assistive diagnosis. These require different data structures to ensure accuracy. The original enablers have been refined so that imaging technologies (UCT, EIT) are the dominant as they can significantly simplify the diagnosis process for GPs (but require large-scale development in order to make them portable and therefore viable to be used in wearables). Acoustic and odour monitoring have been identified as possible sub-enablers as they are useful for providing long term data (helpful for the ML assistive diagnosis) and can back up the imaging data.

4.7 Design Requirements

Based on the future needs of the NHS, as well as technological enablers, the following project aim was developed:
The outcome of this project will be a product service system which can take frequent measurements of the respiratory health of smokers. Measurements are analysed using machine learning models, trained on the observations of past medical history, to generate accurate and reliable conclusions. Observations and lung health reports are automatically incorporated into the user's digital health records. Whilst this system could be used by anybody, it is particularly focused on smokers, due to their increased likelihood of developing respiratory conditions.
Using the project aim as a basis, the following design objectives were decided upon:

1. The monitoring system must monitor a sufficient number and range of data points which can result in a comprehensive picture of the user's lung health
2. The system should be able to use the user's past medical history, combined with the observations taken from data points, to generate an accurate and reliable diagnosis of respiratory conditions
3. The monitoring system should be able to contribute to the centralisation and digitalisation of the patient's medical data
4. The monitoring system should aid in the transition to a digital twin
5. The monitoring system should significantly reduce the workload of professionals within the NHS by shortening the pipeline of diagnosis
6. The monitoring system must be non-invasive
7. The system must not require active participation, either by the user or by an administrator
8. The monitoring system should be able to contribute to long-term strategies for managing lung health

5 Concept Development

5.1 Ideation

There are 2 parts to any idea: data collection and data analysis. Product ideation focused on data collection, as analysis will be done with ML models and user's medical data. Ideation was conducted collaboratively, through C-Sketching and SCAMPER and led to a wide variety of concepts.

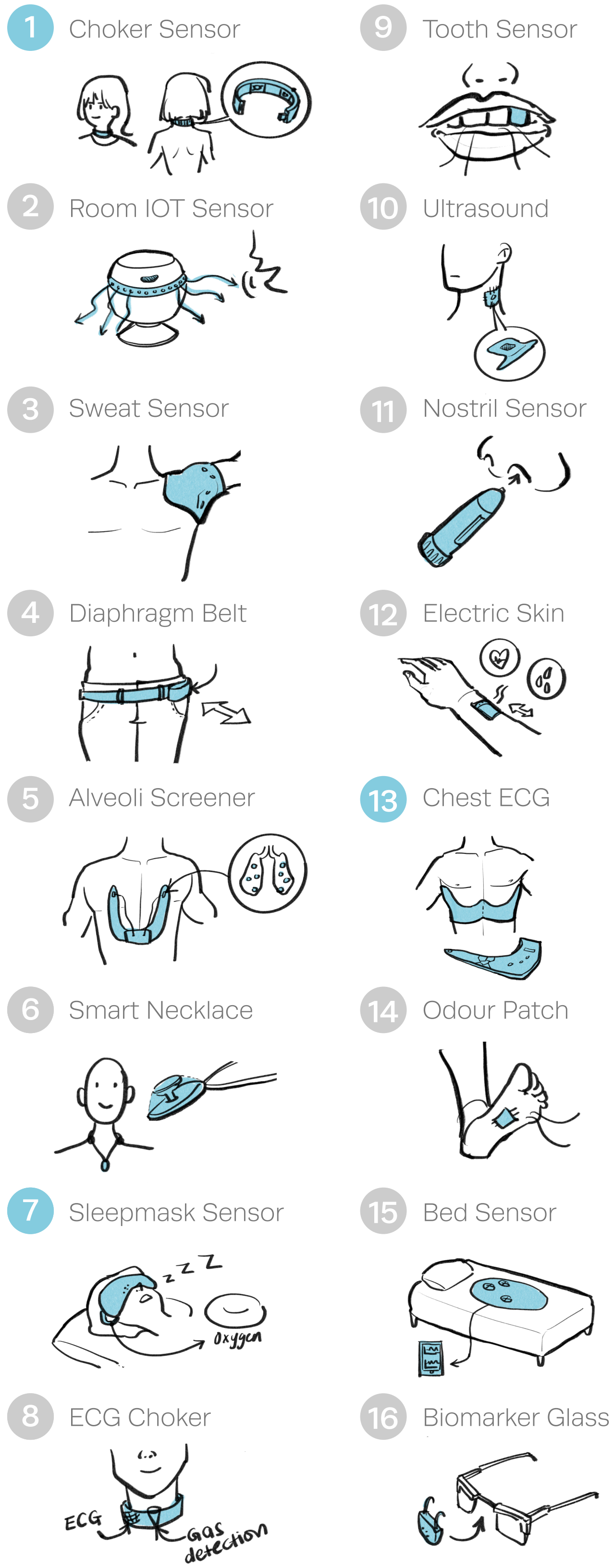


Figure 5 Ideation

5.2 Idea Affinisation

The C-Sketching process demonstrated overlaps in ideas, so an affinity exercise was conducted. Similar ideas were grouped together.

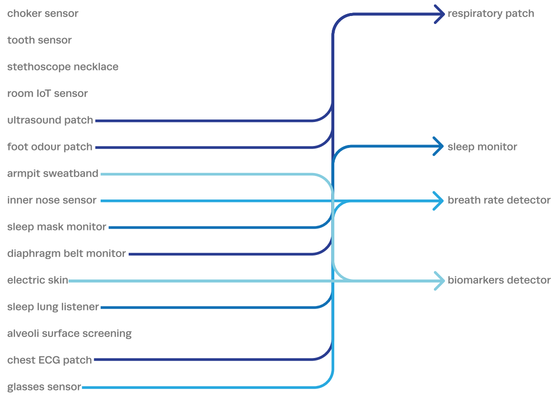


Figure 6 Idea Affinisation

5.3 Idea Evaluation

A Pugh chart evaluation was done, ranking ideas based on feasibility, usability, impact and innovation. The last metric, innovation, is particularly important to assess the relevance of an idea in 2042.

Table 2 Pugh Chart

Idea	Respiratory Patch	Teeth Sensor	Choker Sensor	Stethoscope Necklace	Sleep Monitor	Room IoT Monitor
Feasibility (/5)	4	2.5	4	4	5	5
Usability (/5)	3.5	2	3	4	4	5
Impact (/5)	5	2	4	3.5	3.5	2
Futurism (/5)	4	5	3	2	2.5	1
Total	16.5	11.5	14	13.5	15	12

Based on the ranking process, the three following ideas were selected:

1. Respiratory Patch
2. Sleep Monitor
3. Necklace Sensor

These were then further evaluated to find which concept should be advanced.

5.4 Three Concepts

5.4.1 Respiratory Patch

This concept is a lightweight abdominal patch, as shown in Figure 7. The curved shape considers the anatomy of both sexes. The tails of the patch detect abnormal breath patterns through resistive stretch sensors which measure lung volumetric expansion and contraction. Electronic impedance tomography and EDI sensors are scattered throughout the patch to gather muscle data and create a visual report of the lungs; lung tissue is significantly more resistive than other soft tissues resulting in high resolution imaging. Piezoceramic acoustic sensors identify wheezing points and damaged bronchioles. This device is specifically designed to help diagnose airway and lung tissue diseases.

5.4.2 Eye Mask Monitor

The sleep mask uses pressure, humidity and gaseous biomarker sensors located near the nostrils to track volume and quality of air exhaled. Acoustical sensors also surround the nasal passage to measure nasal and windpipe vibrations. This concept is designed to be used during sleep, limiting the possibility of external noise resulting in accurate measurements.

5.4.3 Necklace Sensor

This concept consists of acoustic and blood oxygen sensors built into a necklace, it measures lung respiratory rates and effectiveness of gaseous carry on the blood. The necklace can conduct basic acoustic measurements of the airway but is less accurate due to the small scale of the sensor. Biomarker sensors could also be used as these are used near odour and cavity areas.

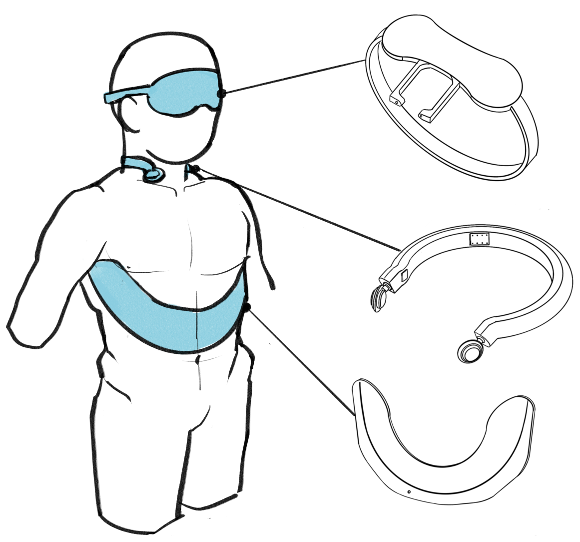


Figure 7 – Three Concepts

5.5 Evaluation of Concepts

5.5.1 Choosing Final Concept

The respiratory patch concept was evaluated as the best design amongst the top three ideas. The patch sensor is the least invasive and most discrete device. Assuming that the majority of its technology can be integrated into a flexible circuit system, the concept can be offered as a lightweight and comfortable body monitor. Due to its size and span, the patch sensor can be used to monitor a variety of biomarkers, as opposed to the sleep monitor and necklace sensor which are limited to specific areas.

5.5.2 Doctor's Opinion

The concept was then validated by Dr Hui Ying Ming, a general physician with a special interest in pulmonary health, who provided us with feedback on the idea and the future development that would be needed.

- Aside from imaging, finding wheezing points, lung capacity and blood oxygen level are useful to see
- Having an ECG monitor incorporated would help to diagnose any cardio-respiratory diseases
- The patch would not only be helpful for early detection and diagnosis, but also could be used for continued monitoring of treatments in patients with existing conditions
- Ultrasound or vibration detection is particularly useful to detect consolidation, effusion or abscesses
- It would be beneficial if sleep monitoring could also be done, as it is particularly useful to monitor oxygen levels whilst the patient is asleep
- If a correlation between heart rate and respiratory rate positions could be made, then it would be good to classify diseases further

Based on the feedback from Dr Ming, further development was conducted to ensure enough data points are monitored for a reliable and accurate diagnosis.

5.5.3 Technical Expert's Opinion

The technologies used in the concept were validated by Professor Thrishantha Nanayakkara, an expert in sensors and robotics.

- Ultrasound imaging requires significant power and can be difficult to do remotely
- Ultrasounds are only suitable for areas with soft tissue, due to disruption through the ribs, the chest is not a good site for ultra sounding
- EIT imaging will be a more feasible option, as they are less power intensive so more development will be done relating to it
- The acoustic sensors are prominent and clear, and can pick up sound from different body areas by signal processing
- Portable acoustics market is rapidly growing
- Sleep monitoring is going to be big in the future, it links sleep quality with health
- It's unlikely that data coming from a single wearable device can diagnose all lung diseases. future examinations are still required for accurate diagnosis

EIT was prioritised as the dominant enabler over UCT, as it is less power intensive, and will be more feasible in a wearable. Our concept was refined with the view that technology is driven by demand and supply, acquisitions happen laterally.

6 Final Concept

6.1 Pulmo

The final concept is a non-invasive multi-sensor wearable which provides a comprehensive view of the patient's respiratory health. Continuous monitoring of the lungs occurs, from which data is gathered and available to the user via an accompanying app. Any inconsistencies will lead to a preliminary diagnosis, which the user can share with the doctor, and the doctor can use for further investigation.

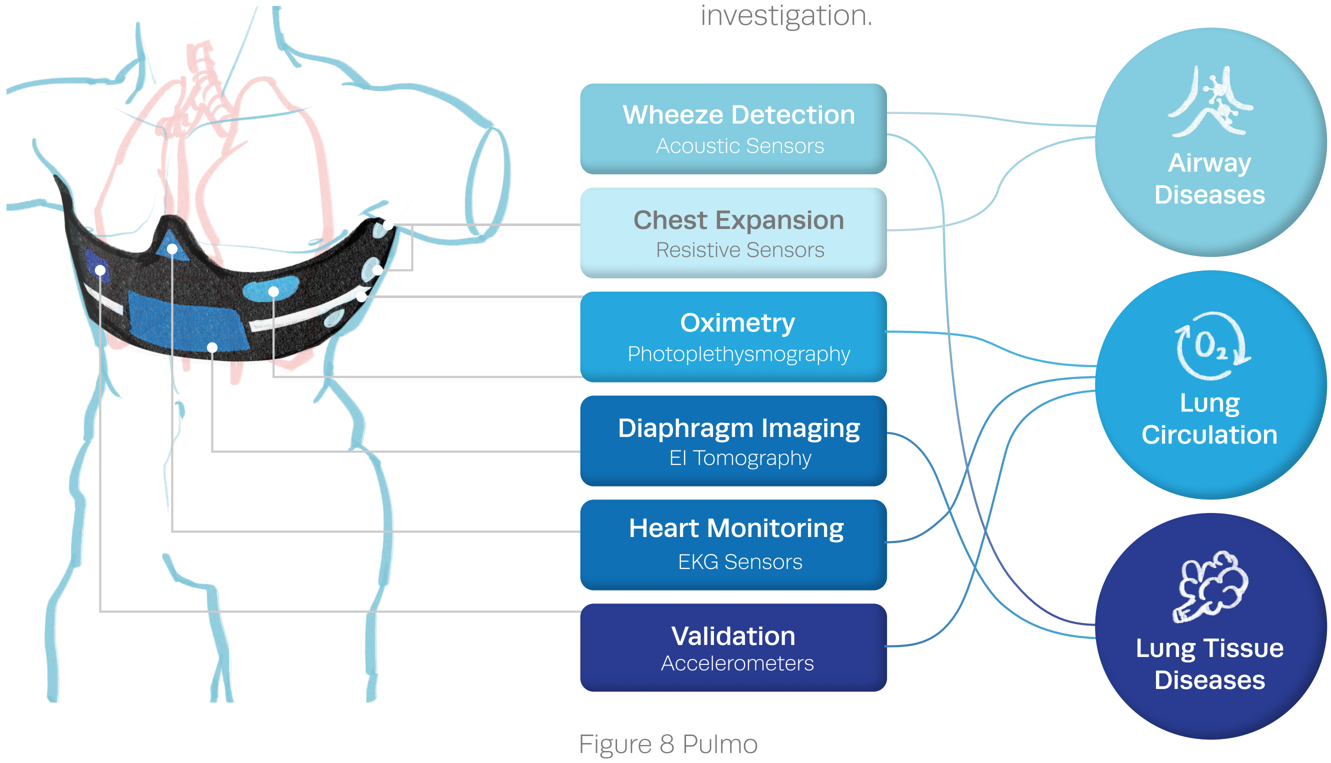


Figure 8 Pulmo

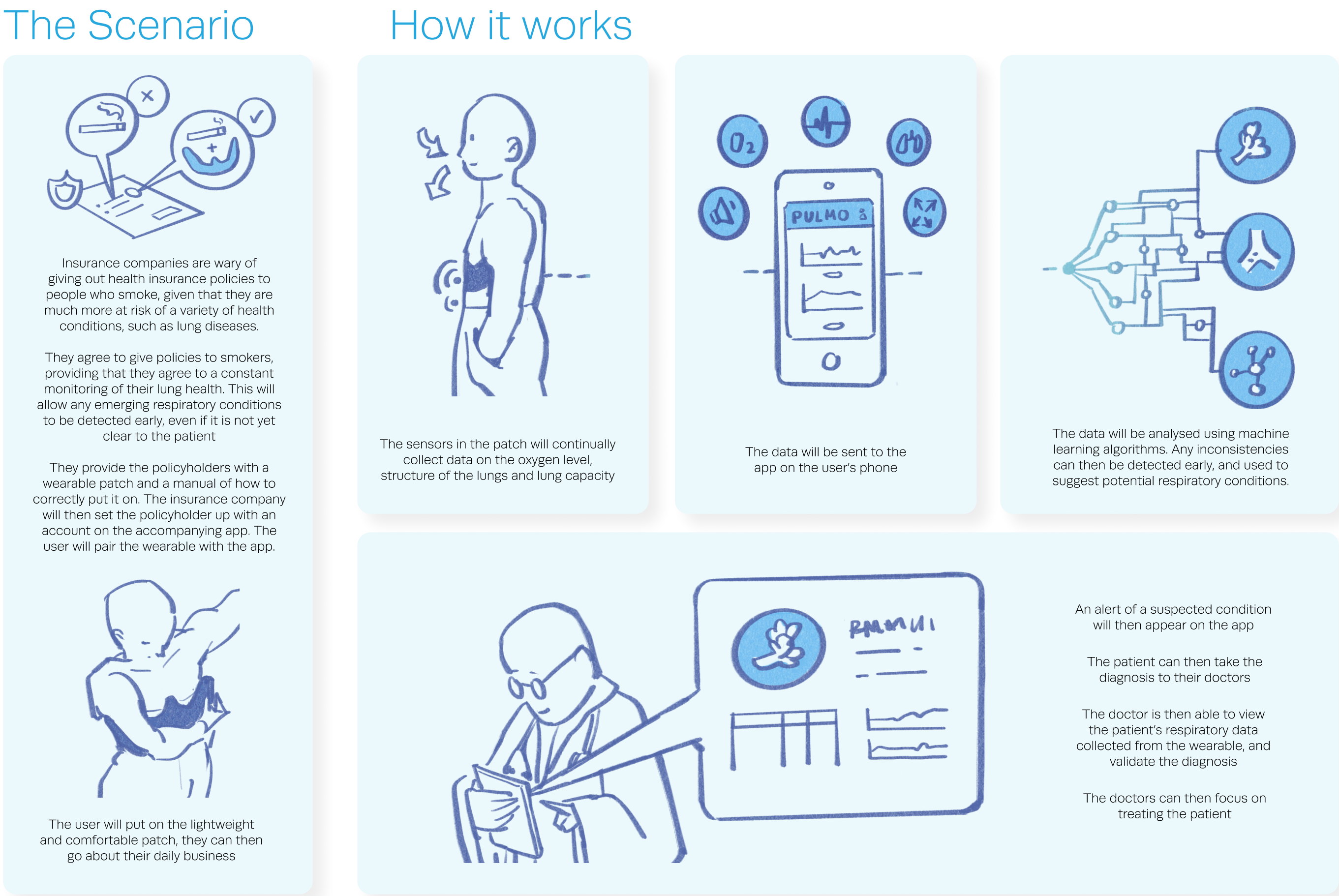


Figure 9 – System Diagram

6.2 Evaluation Against Design Objectives

Pulmo was finally evaluated against using the design objectives that were decided upon before ideation.

1. Pulmo will be able to monitor blood oxygen level, lung capacity and structure of the lung, so it is a useful indicator of the user's lung health
2. The data will all be recorded and an ML algorithm will be used to generate a suggested diagnosis
3. The data will be recorded digitally in one place, meaning that it will help to centralise the patient's data
4. The fact that the data is recorded digitally will help the transition to a digital twin
5. Pulmo will allow users to provide doctors with clear and comprehensive assistive diagnostic data, shortening the timeline of diagnosis and reducing the number of severe patients
6. Pulmo is a wearable patch, making it non-invasive
7. The user only has to put the patch on to start monitoring, meaning that active participation is not required
8. If Pulmo has a high adoption rate, this could allow the NHS to generate long term strategies for managing lung health, based on the data available

7 Conclusion

The concept has been developed from a technical standpoint, in terms of the positioning of the sensors and the development of the concept around that. The fundamental point of the design question has been answered. However, going forward, there are side elements which need to be developed further. The following questions will also need to be answered:

1. Given that patient data is being collected and possibly disseminated – how might we make ensure that a patient's data and privacy is respected and any transferring is being done in an ethical manner?
2. The patch must be comfortable to wear – how might we ensure that the patch causes minimum discomfort to the user?
3. The patch must be durable to last through the daily stresses of the user's life – how might we develop the patch so that it is waterproof, durable and easy to fix?

Further design development based around these points will lead to a detailed and functional final design. To finalise the product service system in order to make it viable, stakeholder views should also be taken into account. The primary stakeholder will be insurance companies, although further insight into their opinions will be needed.

8 Project Management

8.1 Methodology

To ensure consistent communication, a WhatsApp messenger group was set up and regular meetings occurred every Tuesday for 1 hour. In meetings, progress was discussed and tasks allocated for the next week. Weekly meetings were also conducted with the project supervisor to update him on project progress and ask specific technological questions. Emergency meetings were sometimes required, if a team member than run into a roadblock, affecting the smooth running of the project, or if there were any new developments that needed to be discussed. Notes from these emergency meetings would then be added to that week's minutes. All tools used were collaborative tools that could foster group work, such as Figma and FigJam, which helped to maximise productivity. Ideation sessions were done with all group members in person

Table 3 Risk and Mitigation Management

Risk	Likelihood (/5)	Impact (/5)	Severity (L x I)	Mitigating Action	Contingency Plan
Team meetings are not sufficiently productive	3	4	12	Set a strict agenda for each meeting and ensure that a strict chair is in place to ensure good progress	Schedule meetings more regularly and ensure that all team members are aware of the work to be done
Team members not showing up to meetings or contributing enough	2	4	8	Set consistent weekly meetings and clearly delegate individual tasks/ assignments.	Speak to the individuals about what they might be struggling with and discuss how meetings can be adapted to their communication style.
Team members become unwell or are unable to work due to other unforeseen circumstances	3	3	9	Ensure that work is equally divided up between team members, so the absence of one will not completely impede project progression	The team members who are able to work should meet and work should be redistributed to ensure that it is all completed
Time mismanagement preventing project completion	2	5	10	Set regular internal deadlines and distribute tasks equally, using a Gantt chart to track progress.	Hold a meeting to make a lot of progress on the deliverables, dividing tasks across members of the group and seeking advice from professional tutor.
Unfeasible prototyping	2	4	8	Assess concept embodiment with professor to ensure it is feasible and achievable.	Refocus to aspects that can be prototyped and communicated with the help from professor.

8.2 Reflection

As a team, the weekly meetings worked well. Many micro-meetings were also held, and in future, the progression made in these meetings should be immediately recorded in minutes for easy reference.

Sarthak
I learnt a lot through the futures cone and technology road map. Reading scientific papers was enjoyable as I learnt how future technologies can be developed into products.

Tanya
I was wary of ideating through set techniques as it felt constrained, however this led to more feasible concepts and was useful for logistics

Lauren
I realised concepts only comes to life when backed by research and validation, resulting in tangible and meaningful experiences

Jiayi
Deducing future scenarios was inspirational, I also practice rapid CAD modelling to communicate ideas more clearly

Anusha
The most informative part of this project for me, was learning about the possibilities of technology within healthcare, and how, if properly implemented, can revolutionise the field

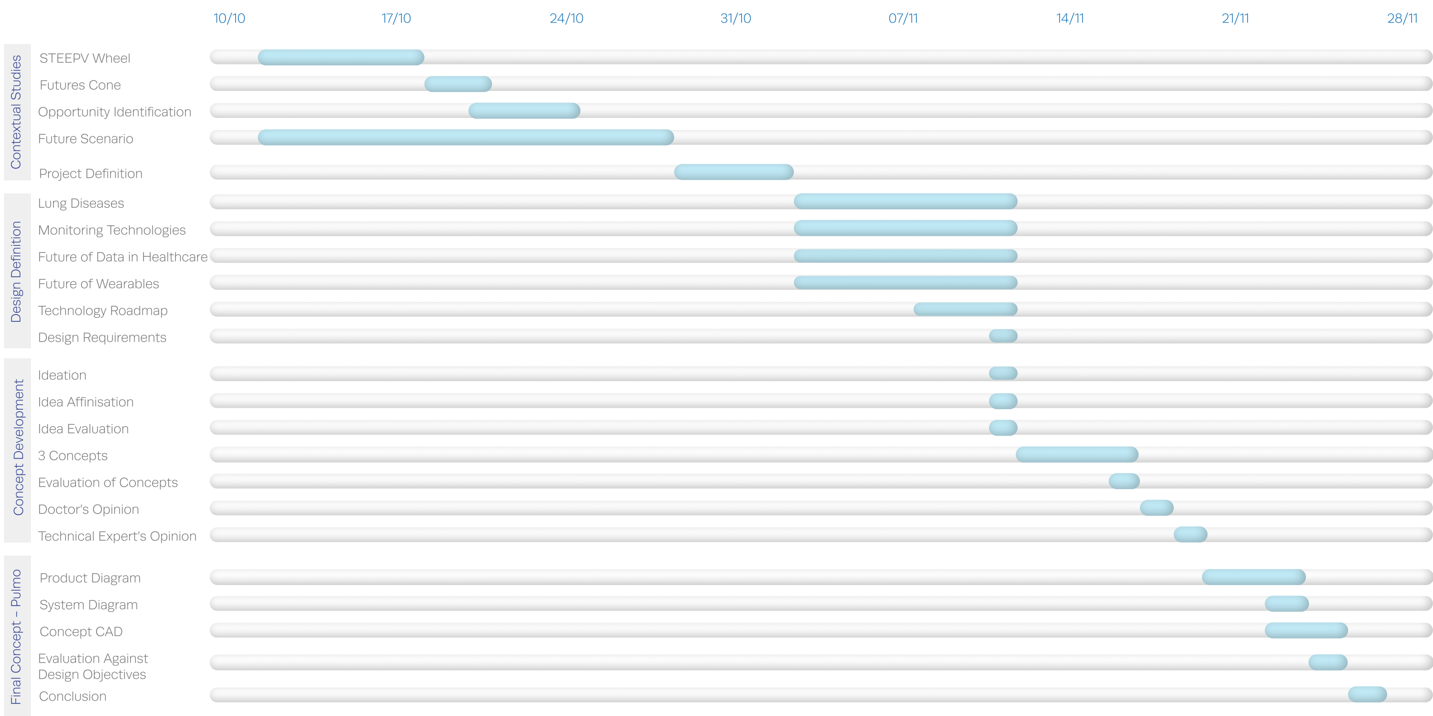


Figure 10 - Gantt Chart

9 References

[1] Department of Health and Social Care. The NHS Constitution for England [Internet]. GOV.UK. Department of Health and Social Care; 2021. Available from: https://www.gov.uk/government/publications/the-nhs-constitution-for-england/the-nhs-constitution-for-england Date accessed: 10th November 2022

[2] Triggle N. How many staff does the NHS need? BBC News [Internet]. 2015 May 1; Available from: https://www.bbc.co.uk/news/health-32535859 Date accessed: 10th November 2022

[3] NHS Digital. NHS Workforce Statistics – January 2022 (Including selected provisional statistics for February 2022) [Internet]. NHS Digital. 2022. Available from: https://digital.nhs.uk/data-and-information/publications/statistical/nhs-workforce-statistics/january-2022 Date accessed: 10th November 2022

[4] UK Parliament. Persistent understaffing of NHS a serious risk to patient safety, warn MPs [Internet]. parliament.uk. 2022. Available from: https://committees.parliament.uk/committee/81/health-and-social-care-committee/news/172310/persistent-understaffing-of-nhs-a-serious-risk-to-patient-safety-warn-mps/ Date accessed: 4th November 2022

[5] NHS. Better care for major health conditions [Internet]. NHS Long Term Plan. Available from: https://www.longtermplan.nhs.uk/online-version/chapter-3-further-progress-on-care-quality-and-outcomes/better-care-for-major-health-conditions/ Date accessed: 4th November 2022

[6] NHS England. NHS England» Respiratory disease [Internet]. www.england.nhs.uk. Available from: https://www.england.nhs.uk/ourwork/clinical-policy/respiratory-disease/ Date accessed: 18th October 2022

[7] TheBusinessDesk. More Than a Quarter of UK Adults Now Own an Exercise Tracker | TheBusinessDesk.com [Internet]. North West. Available from: https://www.thebusinessdesk.com/northwest/your-news/more-than-a-quarter-of-uk-adults-now-own-an-exercise-tracker Date accessed: 4th November 2022

[8] British Medical Association. NHS backlog data analysis [Internet]. The British Medical Association is the trade union and professional body for doctors in the UK. 2022 [cited 18AD Oct 22]. Available from: https://www.bma.org.uk/advice-and-support/nhs-delivery-and-workforce/pressures/nhs-backlog-data-analysis

[9] Cancer Research UK. Smoking among young adults increased by 25% during first lockdown [Internet]. Cancer Research UK – Cancer News. 2021. Available from: https://news.cancerresearchuk.org/2021/08/25/smoking-among-young-adults-increased-by-25-during-first-lockdown/ Date accessed: 10th November 2022

[10] Vicente AM, Ballensiefen W, Jönsson J-I. How personalised medicine will transform healthcare by 2030: the ICPerMed vision. Journal of Translational Medicine. 2020 Apr 28;18(1).

[11] UN. The World's Cities in 2018 Data Booklet [Internet]. 2018 [cited 22AD Oct 18]. Available from: https://www.un.org/en/development/desa/population/publications/pdf/urbanization/the_worlds_cities_in_2018_data_booklet.pdf

[12] Drummond M. B. (2014) Obstructive airway disease in urban population. Current opinion in pulmonary medicine, 20 (2), 180-185 https://doi.org/10.1097/MCP.0000000000000025 Accessed from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4131542/ Date accessed: 17th November 2022

[13] Public Health England. Physical activity: applying All Our Health [Internet]. GOV.UK. 2022 [cited 22AD Oct 19]. Available from: https://www.gov.uk/government/publications/physical-activity-applying-all-our-health/physical-activity-applying-all-our-health#:~:text=Physical%20inactivity%20is%20associated%20with

[14] Kent C. Over 350,000 digital health apps on thriving market, finds IQVIA report [Internet]. www.medicaldevice-network.com. 2021 [cited 22AD Oct 22]. Available from: https://www.medicaldevice-network.com/news/digital-health-apps/

[15] Omboni S, Padwal RS, Alessa T, Benczúr B, Green BB, Hubbard I, et al. The worldwide impact of telemedicine during COVID-19: current evidence and recommendations for the future. Connected Health [Internet]. 2022; Available from: https://oaepublishstorage.blob.core.windows.net/29034589-e30a-4598-82f4-38d0ab099eb7/4493.pdf

[16] Ahuja AS. The impact of artificial intelligence in medicine on the future role of the physician. PeerJ [Internet]. 2019 Oct 4 [cited 22AD Oct 23];7(7702):e7702. Available from: https://peerj.com/articles/7702/

[17] da Fonseca MH, Kovaleski F, Picinin CT, Pedroso B, Rubbo P. E-Health Practices and Technologies: A Systematic Review from 2014 to 2019. Healthcare [Internet]. 2021 Sep 1 [cited 22AD Oct 23];9(9):1192. Available from: https://www.mdpi.com/2227-9032/9/9/1192

[18] Pillai S, Upadhyay A, Sayson D, Nguyen BH, Tran SD. Advances in Medical Wearable Biosensors: Design, Fabrication and Materials Strategies in Healthcare Monitoring. Molecules. 2021 Dec 28;27(1):165.

[19] ClientEarth. UK Air Pollution: How clean is the air you breathe? | ClientEarth [Internet]. www.clientearth.org. 2020. Available from: https://www.clientearth.org/latest/latest-updates/news/uk-air-pollution-how-clean-is-the-air-you-breathe/ Date accessed: 17th November 2022

[20] Kalisa E, Fadlallah S, Amani M, Nahayo L, Habiyaremye G. Temperature and air pollution relationship during heatwaves in Birmingham, UK. Sustainable Cities and Society. 2018 Nov;43:111–20.

[21] Medical Device and Diagnostic Industry. Biomaterials: Addressing Medicine's Future Needs [Internet]. mddionline.com. 2011 [cited 2022 Nov 28]. Available from: https://www.mddionline.com/news/biomaterials-addressing-medicines-future-needs

[22] Newman-Toker DE, McDonald KM, Meltzer DO. How much diagnostic safety can we afford, and how should we decide? A health economics perspective. BMJ Quality & Safety [Internet]. 2013 Oct 1 [cited 17AD Oct];22(Suppl 2):ii11–20. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3786645/

[23] Porat T, Burnell R, Calvo RA, Ford E, Paudyal P, Baxter WL, et al. "Vaccine Passports" May Backfire: Findings from a Cross-Sectional Study in the UK and Israel on Willingness to Get Vaccinated against COVID-19. Vaccines [Internet]. 2021 Aug 1 [cited 19AD Oct 22];9(8):902. Available from: https://www.mdpi.com/2076-393X/9/8/902/htm

[24] Meehan M. Data Privacy Will Be The Most Important Issue In The Next Decade [Internet]. Forbes. 2019 [cited 2022 Oct 23]. Available from: https://www.forbes.com/sites/marymeehan/2019/11/26/data-privacy-will-be-the-most-important-issue-in-the-next-decade/?sh=62ac30051882

[25] Chakravorti B. Why It's So Hard for Users to Control Their Data. Harvard Business Review [Internet]. 2020 Jan 30 [cited 18AD Oct 22]; Available from: https://hbr.org/2020/01/why-companies-make-it-so-hard-for-users-to-control-their-data

[26] Lewis C, Latif Z, Hill M, Riddington M, Lakhanpaul M, Arthurs OJ, et al. "We might get a lot more families who will agree": Muslim and Jewish perspectives on less invasive perinatal and paediatric autopsy. Idler E, editor. PLOS ONE. 2018 Aug 9;13(8):e0202023.

[27] Future Hospital Commission. Future hospital: Caring for medical patients. London: Royal College of Physicians; 2013 Sep p. 21–2.

[28] European Lung White Book. Future projections - ERS [Internet]. www.erswhitebook.org. [cited 2022 Nov 24]. Available from: https://www.erswhitebook.org/chapters/the-burden-of-lung-disease/future-projections/#:~:text=By%202030%2C%20the%20WHO%20estimates Date accessed: 18th October 2022

[29] NHS. Chronic Obstructive Pulmonary Disease (COPD) Available from: https://www.nhs.uk/conditions/chronic-obstructive-pulmonary-disease-copd/causes/#:~:text=Smoking%20is%20the%20main%20cause,prevent%20COPD%20from%20getting%20worse. Date accessed: 3rd November 2022

[30] Li J, Guan X, Fan Z, Ching L-M, Li Y, Wang X, et al. Non-Invasive Biomarkers for Early Detection of Breast Cancer. Cancers [Internet]. 2020 Sep 27;12(10):2767. Available from: https://pubmed.ncbi.nlm.nih.gov/32992445/ Date accessed: 2nd November 2022

[31] Kammer MN, Massion PP. Noninvasive biomarkers for lung cancer diagnosis, where do we stand? Journal of Thoracic Disease [Internet]. 2020 Jun [cited 2022 Apr 14];12(6):3317–30. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7330751/ Date accessed: 2nd November 2022

[32] NHS. Spirometry [Internet]. NHS. 2020. Available from: https://www.nhs.uk/conditions/spirometry/ Date accessed: 8th November 2022

[33] Gokool VA, Crespo-Cajigas J, et al. The Use of Biological Sensors and Instrumental Analysis to Discriminate COVID-19 Odor Signatures [Internet]. MDPI; 2022 p. 1. Available from: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwjMjMvc8cT7AhUZhlwKHWkOAGkQFnoECBAQAQ&url=https%3A%2F%2Fwww.mdpi.com%2F2079-6374%2F12%2F11%2F1003%2Fpdf&usg=AOvVaw3fhRWMJhcmxP61vmoS5kY1 Date accessed: 5th November 2022

[34] Priftis KN, Hadjileontiadis LJ. Breath Sounds, From Basic Science to Clinical Practice [Internet]. Springer; 2018. Available from: https://link.springer.com/content/pdf/10.1007/978-3-319-71824-8.pdf Date accessed: 6th November 2022

[35] Gupta P, Wen H, Di Francesco L, Ayazi F. Detection of Pathological mechano-acoustic Signatures Using Precision Accelerometer Contact Microphones in Patients with Pulmonary Disorders. Scientific Reports [Internet]. 2021 Jun 28;11(1). Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8238985/ Date accessed: 7th November 2022

[36] Deutschman CS, Neligan PJ. Evidence-based practice of critical care. Amsterdam: Elsevier; 2019.

[37] Abramowicz JS. Obstetric ultrasound: where are we and where are we going? Ultrasonography. 2020 Aug 25

[38] George UZ, Moon KS, Lee SQ. Extraction and Analysis of Respiratory Motion Using a Comprehensive Wearable Health Monitoring System. Sensors [Internet]. 2021 Feb 17;21(4):1393. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7923104/ Date accessed: 7th November 2022

[39] Williams EG. Fourier acoustics: Sound Radiation and Nearfield Acoustical Holography. San Diego, Calif.: Academic Press; 1999.

[40] Marsh P. Gas sensor technology heads to Mars on board NASA's Perseverance rover | Envirotec [Internet]. Envirotec. 2020. Available from: https://envirotecmagazine.com/2020/08/04/gas-sensor-technology-heads-to-mars-on-board-nasas-perseverance-rover/ Date accessed: 16th November 2022

[41] NHS. NHS Long Term Plan» Chapter 5: Digitally-enabled care will go mainstream across the NHS [Internet]. NHS Long Term Plan. Available from: https://www.longtermplan.nhs.uk/online-version/chapter-5-digitally-enabled-care-will-go-mainstream-across-the-nhs/ Date accessed: 5th November 2022

[42] NHS. Digital transformation [Internet]. NHS Long Term Plan. Available from: https://www.longtermplan.nhs.uk/areas-of-work/digital-transformation/ Date accessed: 5th November 2022

[43] NHS. National COVID-19 Chest Imaging Database (NCCID) [Internet]. NHS Transformation Directorate. Available from: https://transform.england.nhs.uk/covid-19-response/data-and-covid-19/national-covid-19-chest-imaging-database-nccid/ Date accessed: 11th November 2022

[44] NHS. NHS AI Lab roadmap [Internet]. NHS Transformation Directorate. Available from: https://transform.england.nhs.uk/ai-lab/nhs-ai-lab-roadmap/ Date accessed: 11th November 2022

[45] Henshall W, Carkett M. The Watch Is Ticking: A Five-Year Plan to Harness Wearable Health Tech [Internet]. Tony Blair Institute for Global Change. 2022 [cited 2022 Nov 24]. Available from: https://institute.global/policy/watch-ticking-five-year-plan-harness-wearable-health-tech Date accessed: 19th October 2022

[46] Brophy K, Davies S, Olenik S, Cotur Y, Ming D, Van Zalk N, et al. The future of wearable technologies [Internet]. spiral.imperial.ac.uk. 2021 [cited 2022 Nov 24]. Available from: https://spiral.imperial.ac.uk/handle/10044/1/88893 Date accessed: 7th November 2022

[47] Bera A. The Future of Wearable Medical Devices [Internet]. Vicert. 2022 [cited 2022 Nov 24]. Available from: https://vicert.com/the-future-of-wearable-medical-devices/ Date accessed: 10th November 2022

[48] The Future of Flexible Electronics [Internet]. Global Electronic Services. 2020. Available from: https://gesrepair.com/future-of-flexible-electronic/ Date accessed: 8th Novmber 2022