C3.ai

Transforming UK Healthcare With a National Data Platform

Connecting care, ensuring privacy, improving patient outcomes

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Executive Summary

The UK's National Health Service (NHS) has an enormous opportunity to address operational and financial pressure following the COVID-19 response, as services and the workforce strive to keep up with demand. The NHS has decades of healthcare data siloed with local data owners. By connecting disparate healthcare data through C3 AI's federated data platform (FDP), the NHS can accelerate its transformation and achieve tremendous operational and patient benefits.

Far-Reaching Benefits:

1. Compliant, Secure Patient Data

Data is accessed through a unified federated virtual data image that leaves data in place with local data controllers. All data is encrypted, securely stored exclusively in the UK, and remains the sole property of the patient.

2. Data Available System-Wide with Permission

Privacy controls and anonymisation tools for each individual data element give patients complete control over their data on an opt-in basis. The system is fully compliant with the Data Protection Act of 2018.

3. Timely, Convenient Appointments

Advanced analytics and artificial intelligence (AI) models, combined with data segmentation tools, optimise resource planning to distribute optimised care equitably and efficiently. Patients are seen sooner, reducing queues for surgical procedures, and are provided with more convenient care options.

4. Enhanced Telemedicine

With C3 AI's FDP, secure system-wide medical records work seamlessly to support telemedicine by providing general practitioners (GPs) and other medical professionals with a complete picture of the patient, reducing unnecessary test duplication and enhancing care in geographically underserved areas.

5. Optimal Inventory Levels

A consistent data model and vocabulary for national data, combined with local insights, creates more accurate capacity and demand planning capabilities. The C3 AI FDP solution improves supply chain resilience and operational efficiency. Administrators will have increased real-time visibility to stock levels to ensure facilities maintain adequate supplies and medicines.

6. Improved Urgent and Emergency Care

Connecting disparate data through an FDP, and addressing critical issues such as capacity and scheduling, will reduce the overall pressures on the NHS, resulting in better communications and insights necessary for faster emergency response times for a limited workforce.

7. Improved Patient Experience

The C3 AI FDP solution enables personalised and proactive care, ensuring timely medical interventions and an overall better patient experience.

The primary opportunities in leveraging NHS healthcare data are privacy and interoperability. The NHS has made substantial investments in data infrastructure and services that have the potential to provide a more holistic view of patient health. NHS operations and will benefit from a consistent data model and vocabulary. Preserving patient privacy requires data platform capabilities that can be applied locally and to each data element, leaving the data in place and mitigating duplication.

The C3 AI FDP can leverage all the existing UK health and research investments in data and software services to grow flexibly with the NHS and its partners. The ability to anonymise and virtualise data through a unified, federated data image preserves patient privacy while providing real-time, secure data access. An open architecture provides interoperability and accelerates time to value for new tools and services. Rapid and reusable application development with access to no-code and low-code development tools increases NHS return on investment, while advanced analytics at national, regional, and local levels transform operations and patient care insights. Third-party application connections and a marketplace to access applications and services increases innovation and total deliverable value.

This data platform will differentiate UK healthcare in the breadth of its federated data usage and the number of users it benefits. It will support an unprecedented number of custom and prebuilt applications and tools that can be used directly by administrators, clinicians, patients, and researchers. The platform supports agile development of reusable applications for use cases including elective recovery, care coordination, population health, vaccinations and immunisations, and supply chain management.
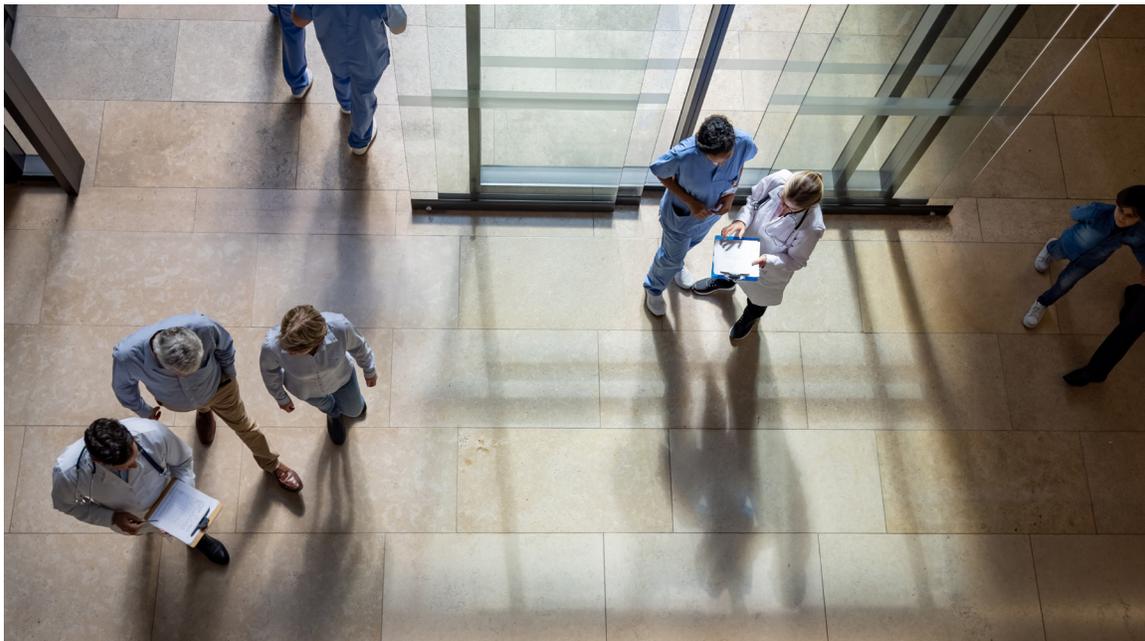
NHS Opportunities

The operational, financial, and healthcare delivery opportunities of the NHS can be addressed with intelligent and responsible data usage. The NHS can address the backlog of care needs aggravated by doctor and nurse shortages by using technology to better match healthcare capacity and demand. At the same time, the NHS can lower rising healthcare costs and improve public opinion. The C3 AI FDP makes personal records easier to access, while ensuring patient privacy. Intelligent and secure data usage improves patient outcomes and experiences while reducing NHS costs.

The NHS has identified five initial use cases that address key organisational opportunities through intelligent data usage. Those five use cases are population health, care coordination, elective recovery, vaccinations and immunisations, and supply chain management. The NHS can address population health by accurately matching its workforce and resources to service needs based on local healthcare data visibility. Vaccination and immunisation programmes will benefit from access and data visibility to support planning and delivery. Care coordination will become efficient as providers can share all patient-level data securely across organisational boundaries. Using the C3 AI FDP, the NHS will improve elective recovery scheduling and efficiencies to accelerate healthcare delivery throughput, decreasing wait times and improving quality of life for patients. Matching supply chain resource planning at the local level will result in faster care delivery and enhanced patient experiences.

Privacy and interoperability are the key opportunities to wider intelligent data usage. Data is currently controlled by many local data owners with unique operating systems, data models, and governance policies. The C3 AI solution would map each local data source to a common data model and vocabulary to create consistency. Interoperable data access must be possible regardless of the underlying physical data models, dependencies, or relationships. Effective data usage requires authorisation controls and low latency access for secure, real-time insights. The NHS must preserve patient privacy and give local data controllers the choice to ingest or virtualise data, leaving each data element at its source. Privacy preserving capabilities such as de-identification controls must be able to be applied at the local data source and for each data element.

Organisational NHS improvements will be delivered through applications built on the FDP. Separate data integration and application layers protect patient privacy by reducing data duplication and sharing. C3 AI applications are extensible, portable, and reusable for the NHS to scale organisational change. All C3 AI applications leverage advanced analytics, no-code tools, and AI to broaden usage and develop proactive and actionable insights.

NHS Technology Ecosystem

The NHS has an opportunity to develop a national system to securely connect its investments in data infrastructure and healthcare services. The amount of distributed, intelligent NHS data continues to grow through point-of-care collections and emerging health technologies such as health apps, wearables, and digital services. The supply chain and logistics data, such as the delivery of personal protective equipment (PPE), consumables, and other products, is another source that can be integrated with other healthcare delivery sources. Each system has its own model, regulations, and formats that were not designed for secure national connectivity.

The NHS has distributed investments in national components and services that must be connected to transform NHS operations. Each investment has clear benefits but is isolated, standing alone from other NHS investments, data infrastructure, and services. The summary care record application is a national portal enabling access to a view of core information from the GP record, such as medications and allergies. The personal demographics service provides access to patient information such as the NHS number. The electronic prescription service supports efficient and secure sending of prescription data from general

practice to pharmacies. The NHS has established data standards across the government to address data sharing including the Data Standards Authority and the Government Data Quality Framework. NHS Digital has delivered digital infrastructure and products such as the NHS App, NHS 111 online, and more than 80 core national systems.[1] The NHS AI Lab has funded over 80 projects to develop AI tools and services. The scale of impact grows with each investment that is connected to the data, analytics, and application platform.

The C3 AI FDP can address the gaps in the current approach. Patients and doctors will see immediate benefits from connecting hundreds of different IT systems not designed with native interoperability.

Some discrete examples:[2]

- A survey of medical record keeping across the NHS found 21 unique and commercially incompatible available electronic health record (EHR) systems in use across 117 NHS Trusts. These are often tailored to local Trusts and designed with less emphasis surrounding the sharing of data, with the user experience varying widely across systems.

- The same survey found 11 million occasions over a one-year period where patients attending a new hospital could not access their full medical record from a previous hospital.

- Many hospitals still use paper records, providing an opportunity to embrace electronic systems.

- Of the ten standards of interoperability identified by NHS Digital in 2018, only three were ready by May of 2020.[3]

C3 AI Federated Data Platform Solution

The C3 AI FDP will be implemented as a distributed solution comprising five distinct layers. The federated data harmonisation layer ingests and harmonises the data to make it readily available for upstream use. The data is cleansed and transformed into standardised logical data models. The privacy preserving analysis toolkit layer contains the tools applied prior to sharing data outside local data controllers. The data exchange and governance layer contains a binding architecture that facilitates data search and exchange across organisational boundaries. The AI/ML platform layer is tightly linked with the previous data layers to apply AI/ML capabilities to the AI/ML–ready data. The application development and business intelligence tools layer rapidly builds reusable visual applications that support workflow action.

C3 AI Federated Data Platform
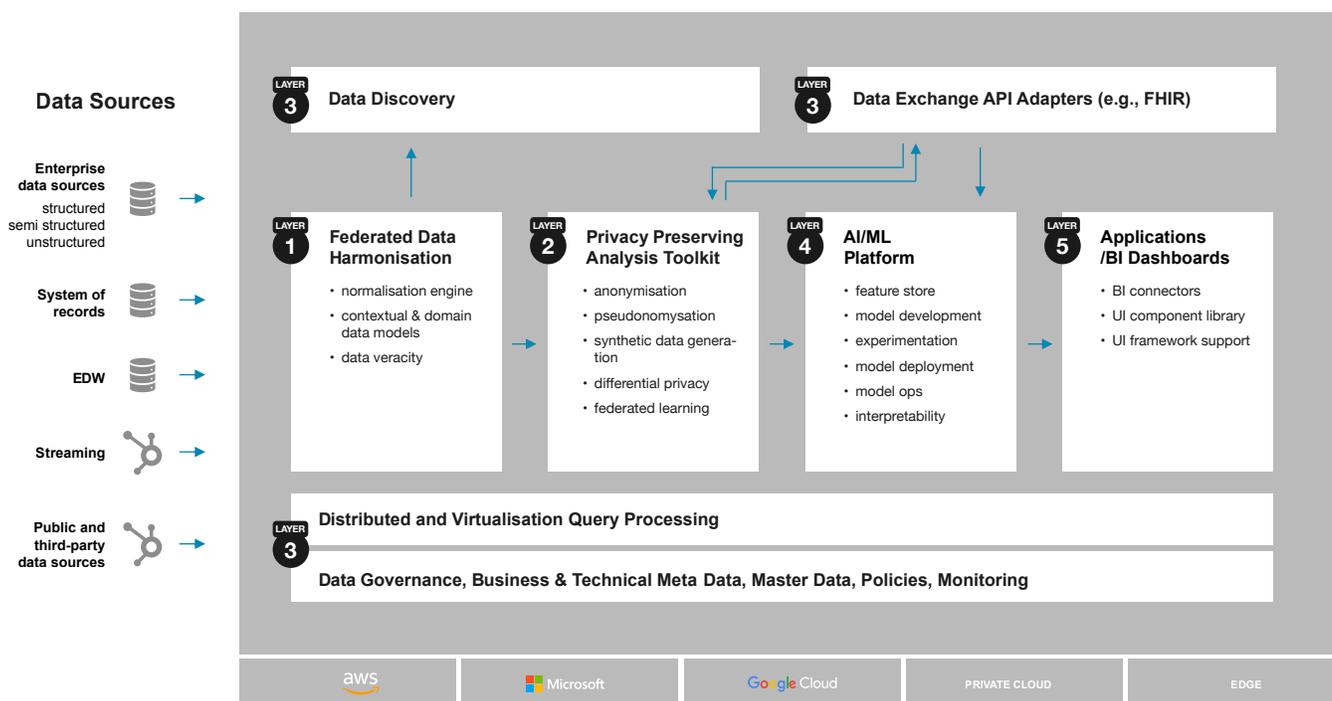
LAYER **1**

Federated Data Harmonisation

The federated data harmonisation layer is owned and controlled by each local data controller. The data controller can decide to host its layer on any of the public clouds as a secure compartment or can host it on-premises. The harmonisation layer of the FDP is responsible for ingesting and harmonising the data to make it readily available for upstream use as needed in a secure and performant manner. Harmonised data is used within the data controller's organisation to better support in-house analytics, reporting, and visualisation solutions. Data standardisation enables data controllers to leverage data from other trusted research environments (TRE) where needed.

Harmonisation involves unifying disparate data fields, formats, and frequencies into a unified federated data image. Key capabilities of the federated data harmonisation layer include:

1. **Data ingestion modes:** Control over how often and by what means data is ingested provides broad-based support for ad hoc data updates, periodic data arrivals, and real-time streaming data. The data could be structured, unstructured (e.g., image data) or semi-structured data.

2. **Model-driven architecture:** A model-driven architecture ensures data is represented in standardised and extensible formats. Prebuilt object models can be extended to accelerate the data harmonisation effort. This gives the contributors of data much needed flexibility and abstraction as the underlying data representations vary across the UK's health ecosystems and change over time. The harmonisation layer is responsible for creating a unified federated data image.

3. **Robust metadata support:** Metadata support captures data lineages to enable customised data sharing. For example, a patient can opt to share their medical data for research purposes but withhold mental health data. The proposed platform supports versioning with backward compatibility as data controllers use different versions of the metadata based on their internal upgrade plans.

4. **Data normalisation engine:** Time series provide historical information that can be analysed by AI/ML algorithms to generate and test predictive models. Time series data can represent the state of a process over time and predict future behaviour with the right cleansing, normalisation, and aggregation tools. The normalisation engine can consume raw data and perform preliminary data cleansing such as deduplication, extrapolation of missing values, elimination of overlapping data, and alignment intervals.

5. **Hosting agnostic:** The layer can be hosted on any of the public clouds or on premises. The data controllers can choose where to build this layer.

6. **Out-of-the-box (OOTB) connectors:** The architecture framework needs to ingest data from a variety of data sources such as relational databases, enterprise data warehouses (EDW), file/object stores, and NoSQL databases. OOTB connectors can quickly integrate data from across an organisation's footprint.

LAYER 2

Privacy Preserving Analysis Toolkit

The privacy preserving analysis toolkit layer resides locally at the data controller's site. It provides several state-of-the-art options to securely store and distribute data. The data controllers can configure how to manage their distinct types of data. For data needed within the organisation, for example, the controller may choose to use the raw data, whereas synthetic data might be more suitable for sharing with a research institution. Key capabilities of this layer include:

1. **De-identification:** Implementations of industry-standard anonymisation should be readily available for configuration by the data controllers, including:

    -   Data pseudonymisation: Encrypts data and robust key management solutions.

    -   Synthetic data generation: Algorithmically created synthetic data sets have no relationship with the underlying data, but they capture the inherent characteristics to support AI/ML work.

    -   Differential privacy: Provides tooling to the local data controllers to share useful aggregate/ summary statistics of sensitive datasets to the broader research community. The toolkit also needs to provide capabilities that prevent adversarial reidentification.

    -   Federated learning: Provides capabilities to support federated learning where applicable. This would ensure the data is not exposed and the trained model parameters alone are shared externally.


2. **Extensible:** Data privacy and security are critically important in the domain of public healthcare. Significant research is happening in this field, and hence, the framework must fundamentally be open and extensible to accommodate any emergent solution in the data privacy landscape.

Cross-Cutting Concerns: Data Discovery, Data Exchange, and Data Governance

The data discovery, exchange, and governance layer addresses sharing and usage capabilities that powers other layers of the platform architecture. The layer provides a consistent data model and vocabulary as a foundation of interoperability. Data can be searched and exchanged through transparent methods and exchanged with API microservices. These capabilities are supported with data veracity that configures data quality rules and monitors data health for each data controller. Together these capabilities drive confidence and convenience in data usage.
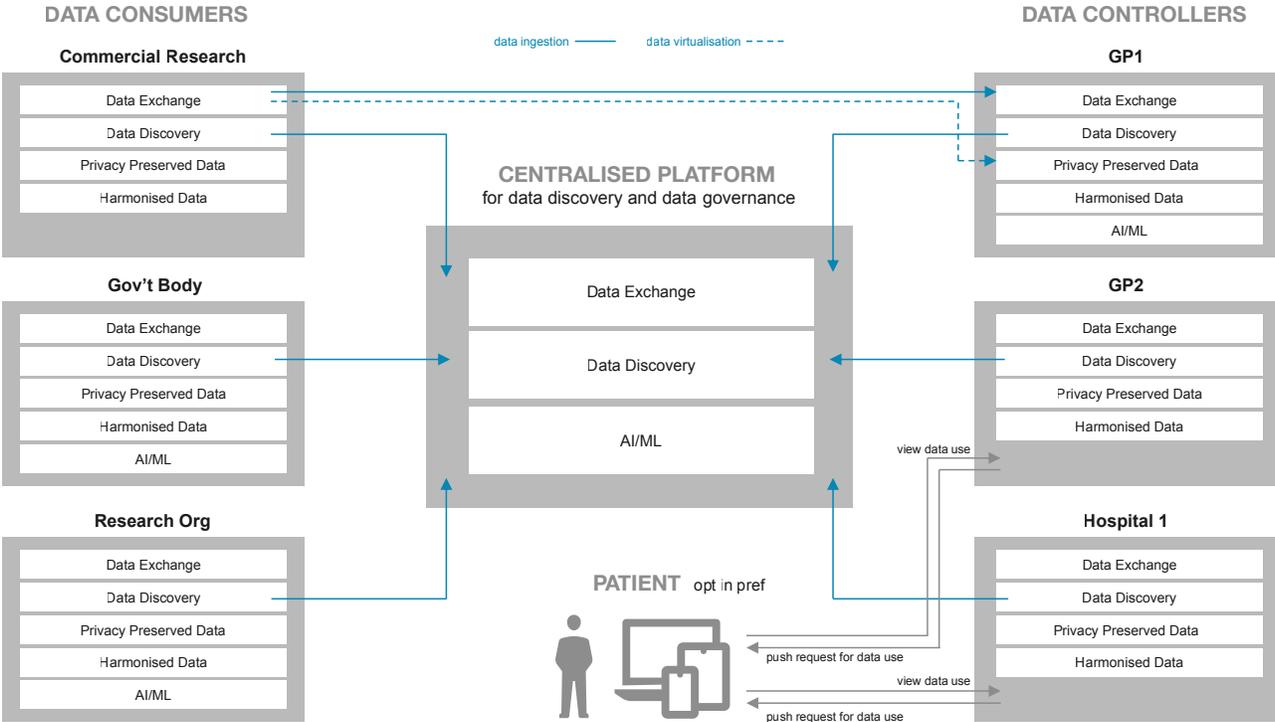
1. **Data Discovery**

- **Model-driven architecture:** Standardised logical data models to represent information are key to achieving powerful data discovery capabilities. The platform needs to be able to capture and publish the logical metadata surrounding the data. The metadata not only captures the underlying data but also traverses the relationships denoting how data is logically connected across the data ecosystem.

- **Common publishing platform:** The platform is the portal for upstream users, such as clinical researchers and policymakers, to traverse the logical data models of the data controllers to understand where data of their interest resides and make requests for purpose-based access.

- **Search capabilities:** Integration with powerful text search engines that can quickly narrow down the context of each search and provide relevant results.
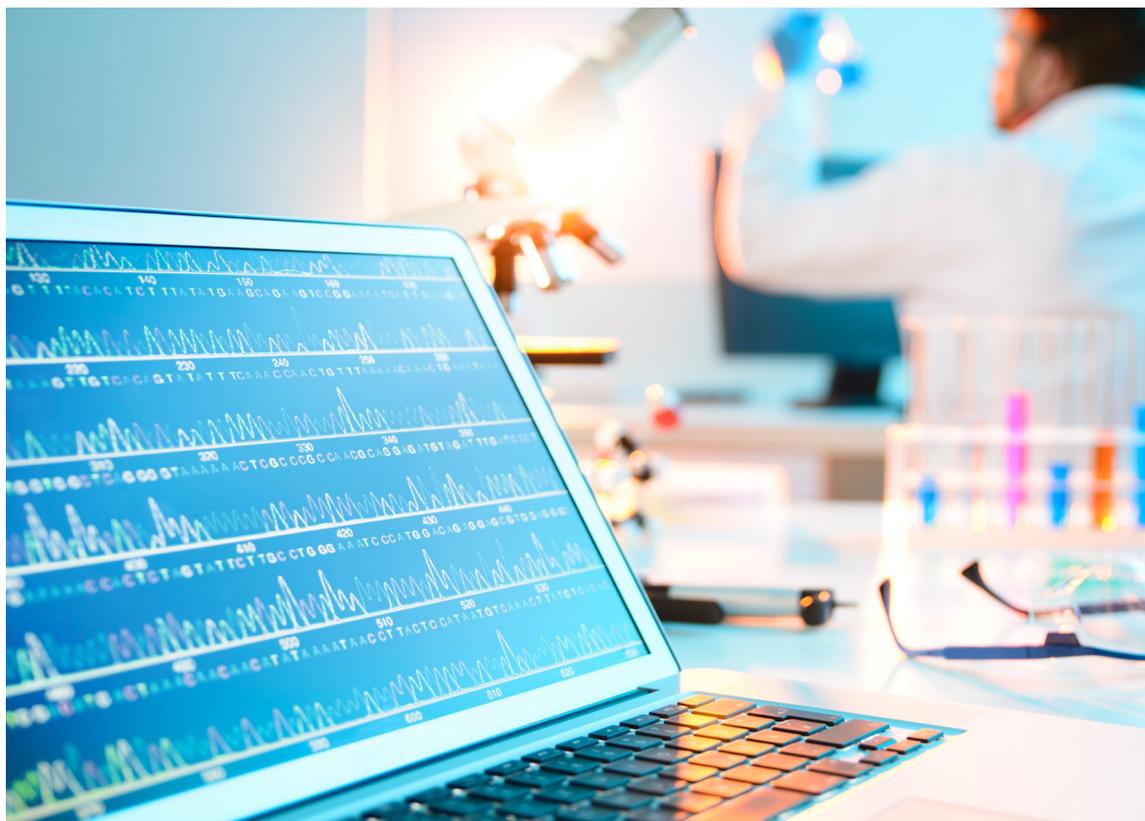
2. Data Exchange

- **Transparency:** Metadata needs to be captured against all forms of data shares/access and should be available to end users such as medical administrators, clinicians, and researchers. This gives them a clear visibility into their data, including:

  - All the data controllers that have their data
  - Any upstream sharing of their data that clearly states the purpose and timeframe of the data share
  - Ability to granularly manage access to their own data

- **Adapters:** OOTB adapters to convert the unified federated data image into some of the most popular interoperable standards (e.g., fast healthcare interoperability resources (FHIR)). The framework also needs to be flexible and extensible to build a custom adapter if needed. This is particularly beneficial, for example, to implement at-scale solutions to send notifications to patients about emergent conditions, or for contact tracing, as well as for integrating with other app developers if required.

- **Virtual data lake:** This capability allows external TREs to virtually access the harmonised data without duplicating the data in their environments. They can invoke analytics to explore data and build AI/ML models. Data virtualisation also gives full control to the data controller to turn off the data sharing after the agreed upon timeframe.

- **API-centric:** The transmission protocol needs to be based on industry standards (e.g., REST APIs). The solution architecture should provide inbuilt support for data transmission without any additional configuration.

- **Bidirectionality:** Ability to consume research data from other TREs. This will truly empower faster bench-to-bedside adoption.

3. Key Capabilities of Data Governance

- **Lineage:** Establish data lineage all the way from a prediction to the feature used to the raw data. This establishes trust in the prediction and provides reproducibility of the AI/ML component.

- **Granular access control:** Framework should have inbuilt capabilities to provide granular access controls to allow for least privilege-based access. Row-level and column-level security is a key feature.

- **Data veracity:** As part of the governance, ensuring data quality is paramount. The data veracity component should be available to configure data quality rules and trigger alerts when thresholds are breached. The data veracity component should also be able to learn normal behaviour and flag statistically varying data. Processes should be established at the local data controller level to address alerts and remediate data issues.

LAYER 4

AI/ML Platform

The C3 AI FDP also functions as a platform, enabling rapid AI/ML development and deployment. Harmonised data by itself is not especially useful until it's used to power applications that support NHS workflows. These applications provide predictive capabilities to enable proactive interventions versus passive reporting and visualisation of past data only.

The C3 AI FDP is designed to accelerate AI/ML applications with the following capabilities:

1. **Feature store:** Features are transformations of the harmonised data in a form that can be used as inputs to AI/ML algorithms. The feature store should inherently support reuse across different use cases. They should also be extensible and composable to enable the creation of new features from existing ones. Features also need to be wrapped in metadata, which allows for reuse and rapid development through discoverability.

2. **Model development:** Provide OOTB support for integrations with popular modelling algorithms/ frameworks (e.g., sklearn, TensorFlow, XgBoost). The framework needs to be futureproof by being extensible and flexible to support any emerging algorithms/frameworks.
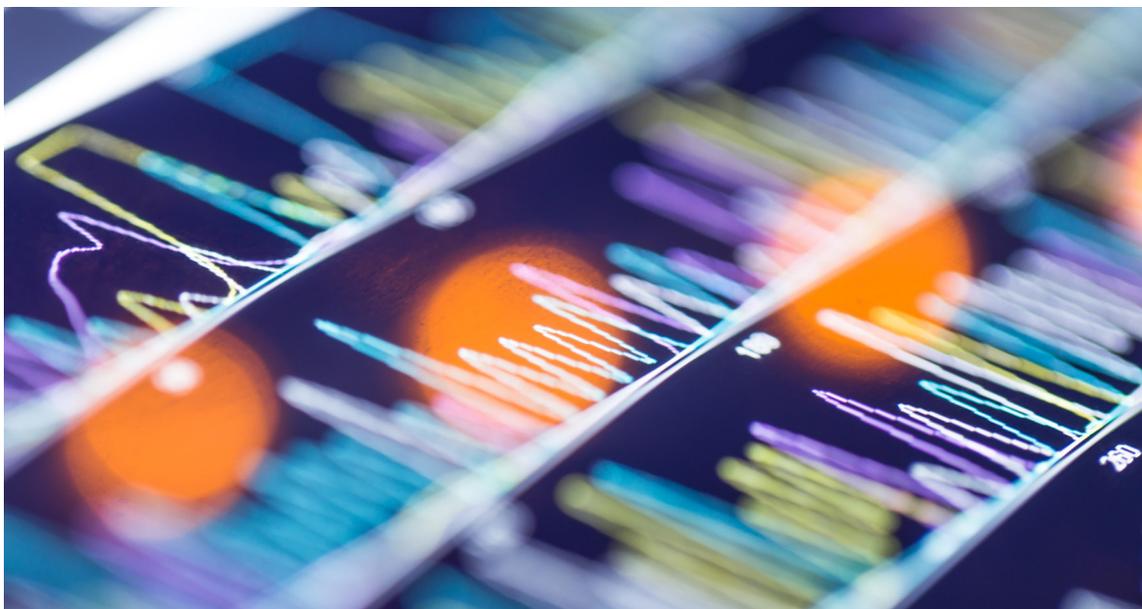
3. **Experimentation support:** The AI/ML lifecycle is often cyclical involving heavy experimentation of both algorithms and hyperparameters. A hyperparameter is a parameter whose value is set before the machine learning process begins. In contrast, the values of other parameters are derived via training. Choosing appropriate hyperparameters plays a critical role in the success of neural network architecture and has significant impact on the learned model. The platform would provide inherent support for experimentation and hyperparameter optimisation by automating experiment tracking, scoring the experiments against the decided metric, providing a massive parallel processing framework to run the experiments in a distributed and elastic manner, and visualisation of the experiment leader board, and additional features, such as early stopping and keep best model.

4. **Deployment and model ops:** An AI/ML platform needs to provide capabilities to rapidly deploy a trained model. This involves the ability to containerise and set up model-serving infrastructure to support either batch or real-time inference, providing OOTB support for sophisticated deployment strategies such A/B testing and shadow testing. It should also include tools to monitor model performance and drift; and it should remediate by retraining the models or promoting a challenger model. A key feature is also the ability to do all the above at scale where the platform can operate thousands of models simultaneously and efficiently.

5. **No-code/low-code tooling options:** Harmonised data is only useful when there is broad access to end users with varying levels of skills. The AI/ML platform needs to provide a variety of tooling options useful for the sophisticated data scientist as well as citizen data scientists with only a more general understanding of the use case and the data. The no-code tooling option is particularly useful at the local data controller level where access to data scientists may be limited, but business analysts are still able to leverage AI/ML capabilities. The tooling options might look like:

   - Deep-code tooling: For Python/R programming
   - Low-code tooling: For data scientists who prefer Jupyter notebooks
   - No-code tooling: A drag-and-drop visual interface to build models, targeted at citizen data scientists

6. **Interpretability:** To build trust in AI modelling, it is essential to surround the model results with context and provide interpretability of the predictions.

LAYER 5

Application Development and Business Intelligence Tools Integration

The proposed platform separates application development from the other layers to increase speed of development, reusability, and scalability. The abstraction layers make application development fast with minimal upskilling required and the ability to use familiar tools and technologies. Applications build upon the other layers to bring the model results surrounded by context to a non-technical audience. Integrators with dashboarding and business intelligence tools are critical for storytelling and reaching a wider audience. Key capabilities include connectors to popular business intelligence (BI) tools, integration with user interface (UI) frameworks, and a rich component library. A robust application development methodology puts humans at the centre of the design process, focusing it on delivering improved patient experiences and outcomes.

The C3 AI FDP is deployed both at the data controller layer and at the consumer layer. Each layer has specific capabilities and benefits to its users.

For data controllers:

- Harmonise data into standardised contextual and domain specific data models

- Apply appropriate privacy preserving methodology on top of the harmonised data

- Provide an API interface for data exchange

- Incorporate AI/ML tools for data analytics at the local level

- Create workflows to accept requests from upstream consumers and provide granular access

- Provide transparency to patients regarding their personal data use conforming to their opt-in preferences

- Consume external data where required

For data consumers (e.g., researchers, government agencies, commercial medical researchers):

- Rapidly create a purpose-based research environment

- Ability to request access through standardised workflow

- Ingest or virtualise data where access has been granted

- Access AI/ML tools for data analytics

- Share results of the study where applicable

Benefits to the NHS and UK Public

Compliant, Secure Patient Data

The C3 AI FDP delivers privacy to the public in an open and transparent way that secures the role of the NHS as a trusted entity in the UK. When patients have control and visibility into how their data is used, this creates the trust necessary to share their data for UK healthcare advancement. The C3 AI FDP accesses data via a unified federated virtual data image that leaves data securely in place with local data controllers. Patient data remains the property of patient, is controlled by the patient, and complies with the Data Protection Act of 2018. From 2016 to 2018, public support in healthcare data used for commercial purposes fell from 53% to 39%.[4] Although data sharing is critical to advance healthcare in the UK and worldwide, it requires public support. The human centred C3 AI FDP design will gather and incorporate input from the public and healthcare professionals to continuously improve the platform in a transparent way. Patients will be able to opt-out of data sharing; however, the opt-out percentage can decrease with upfront, candid communication regarding the use cases for their data. By design thinking, privacy and security are at the forefront of C3 AI FDP personal data decisions.

Timely, Convenient Appointments

Patients are seen by health providers and undergo treatment sooner, reducing record-long queues for surgical procedures. Patients can also view appointments and associated wait times near them and select the most convenient care option for their individual needs. Advanced analytics and AI optimise treatment scheduling by bringing together resource data across systems and modelling the uncertainty of limiting resources. Population segmentation and resource planning tools equitably distribute care and balance capacity with demand to increase available care in previously underserved areas. Data from July 2022 shows a record number of people, over 6.84 million, waiting for treatment. This number has increased by over 54% since the start of the pandemic in March 2020. In addition, the number of patients awaiting treatment for over one year has risen from 1,032 people in July 2019 to 377,689 people in July 2022.[5] The C3 AI FDP will deliver operational efficiencies by connecting disparate NHS healthcare data systems and by using advanced scheduling tools to deliver appointments sooner with more options for the patient.

Enhanced Telemedicine

Patients can access additional health services in the security and comfort of their own home, improving visit and recovery options. Telemedicine care options improve access for a variety of patients, including those in geographically underserved areas. Virtual wards and remote monitoring are empowered by the C3 AI FDP with real-time data connections. Secure connections to system-wide medical records ensure a holistic view of the patient necessary for accurate care. The NHS digital transformation plan includes improving population health and care support with the delivery of telehealth through the NHS app and video consultations to the national population.[6] The NHS has an opportunity to connect these services and make them fully available to the nation. The C3 AI FDP will accelerate national access with secure, real-time, patient data connectivity and rapid application development for its use.

Data Available System-Wide with Permission

Patients retain ownership and control of their data down to the individual element and can choose what data to share and how to share it for research, innovation, and improved care delivery. Privacy and anonymisation controls are applied through the C3 AI FDP at the local data controller level using patient direction. Data can be shared via an opt-in system to support improving UK healthcare. Researchers can see the metadata and schemas without accessing the underlying data, allowing them to develop research projects and then make informed requests to the local data owners. The steps to request and access data can be tracked by all parties in a transparent way. Patients remain informed of how their data is being used and the benefits they are supporting.

Optimal Inventory Levels

Patients have access to medications and other healthcare supplies in a timely and transparent manner. Administrators have real-time visibility into healthcare inventory and its supply to distribute to patients and facilities accurately and equitably. A consistent data model and vocabulary supports integration of disparate supply chain systems to create a single source of truth of healthcare supplies. This solution further increases visibility to the source systems and captures demand over time for improved planning and operational efficiency. There is an opportunity to connect full supply chain visibility with facilities for healthcare supply planning and distribution. The C3 AI FDP applies the common operating picture to improve inventory levels and therefore improve patient care.

Improved Urgent and Emergency Care

Patients receive improved urgent and emergency care through timely access to critical information, health professional coordination, and services planning. Health professionals require real-time access to a patient's care record to safely address their immediate health needs. Improved coordination with digital communication and data means the patient can be triaged faster and emergency health professionals experience fewer coordination delays. A consistent, national view of urgent and emergency service usage assists administrators in planning capacity, ensuring services are available where needed and improving health outcomes with more rapid emergency responses.

Improved Patient Experience

Patients receive more personalised and proactive care, delivering the right care, at the right time, in the right way. Connecting a patient's disparate health data allows for a more holistic and informed care approach. Real-time data access and individualised service invitation ensures more time for the patient and caregiver to make a shared healthcare decision. Currently, the limited time available for patient visits plus growing but unlinked health data leads to suboptimal care and patient experiences. The C3 AI FDP addresses this by connecting data and improving the entire experience for caregivers and patients.

C3 AI FDP Applications

Population Health and Person Insight

1. Opportunities

The NHS can modernise population health management systems that make patient information available to clinicians, researchers, and the patients themselves with a platform that connects NHS tools and data with advanced analytics and agile application development. The NHS can benefit from a platform to share information and develop predictive planning applications. The C3 AI system is fully integrated with management capabilities enabled at the local level and granular population segmentation tools that can modernise planning. This integrated system will assess variation in care and outcomes, identify gaps in delivering care to patients, and allow for targeted campaigns at the community level, not just for integrated care system (ICS) populations. The disparate data landscape creates opportunities in developing population level data assets, analytics, and statistics that meet the needs of stakeholders such as clinicians, researchers, and administrators.[7]

Notable opportunities include:

- **Updating ageing systems:** The NHS needs a modern, digital system to keep up with the volume and type of data requests by health providers and organisations.[8]

- **Linking data:** Within the NHS, health record data lives in many different formats (e.g., digital records, paper records) leading to data duplication.[9,10] For example, as of February 2022, 20% of NHS Trusts have no electronic patient records and 60% of social care providers continue to use paper charts.[11] Clinical teams are providing care with an incomplete view of the patient's total care.[12]

- **Secure data sharing:** Increasing access between primary care (e.g., GPs, pharmacies), secondary care (e.g., hospitals), health and social care, and administration will improve care coordination and efficiency.

2. The C3 AI FDP Solution

The C3 AI FDP collects data once and uses it for multiple medical and care planning practices. Care delivery teams leverage existing systems via the C3 AI FDP by:

- Linking disparate data sources and source systems into a single longitudinal patient health record.

- Providing data and segmentation tools to enable population management regionally and locally, supporting care coordination efforts.

- Incorporating AI/ML capabilities to identify, measure, and address variations in healthcare delivery, outcomes, and resourcing.

- Rapidly reporting based on need and end-user requests.

The C3 AI FDP aggregates data securely at its source through a unified federated virtual data image while applying the appropriate de-identification protocols. The data solution creates a means to link disparate data sources from multiple source systems.

High value sources to integrate in the C3 AI FDP include but are not limited to:

Type	Source Type	Data Souces	Examples of Informed Insights
Patient records	Clinical	Electronic records, inpatient, outpatient, emergency, orders (e.g., lab, radiology, Rx)	Continuity of care, Hx data reporting
Registries	Clinical	Immunisation	Public health reporting, population statistics, research studies
Administrative	Financial	Cost, scheduling, referrals	Cost, utilisation, patient movement, cost of care
Social services	Services	Programs (e.g., adult social services)	Distribution of services
Public information	Other	Deprivation (i.e., social determinants of health) and other social data sets	Population health, emerging health trends

3. Benefits

- **Care coordination:** With care systems shifting to a place-based health and social care system, including ICSs and clinical commissioning groups (CCGs), the C3 AI FDP delivers a longitudinal, linked patient view. Users can access the same patient information as those providing direct care need, creating data continuity across programs and care teams. It will also provide access to end users at the appropriate level to execute their duties and protect patient data.

- **Advanced insights:** The continuity of patient records within the C3 AI FDP creates opportunities to leverage applications and modelling to drive insights and analytics for patient cohorts and population segmenting through risk stratification, avoidable conveyance, or proactive interventions and capacity planning to identify patients who are most likely to require services.[13]

- **Strategic national planning and policy making:** Real-time statistical evidence to support long term strategic planning by policy makers informing funding and resource allocation, impacting public's perception of NHS fund distribution.[14]

Administrators can effectively monitor and evaluate population health initiatives, leading to more accurate long term strategic investment. Researchers and administrators have a consistent way to segment patient populations and model patient risk and impact. Clinicians can improve patient outcomes with accurate patient-centric services. Patients experience less healthcare inequality through demand planning and are invited into additional health-driven services that meet their health needs.

✏️ Vaccinations and Immunisations

1. Opportunities

The COVID-19 pandemic underscored the need for a system infrastructure that supports legally compliant data-sharing practices necessary to understand the spread of infection, manage hospital capacity, distribute vaccines, and provide much needed PPE and other consumables through the NHS supply chain. The UK made strides in developing a unified information governance model during the pandemic, but more work needs to be done to enable interoperability. The NHS will benefit from an FDP capable of supplying patients and practitioners with access to immunisation data through FHIR-based APIs that allow open exchange of critical health information. This transfer capability would aid in creating pathways to patient data currently locked in GP IT systems, all using a common, flexible language that scales well across organisational boundaries.

2. The C3 AI FDP Solution

A unified federated virtual data image can establish proper data flows to ingest real-time data. The NHS can differentiate their approach to vaccinations and immunisations by linking disparate data sources across care systems, social datasets, and the supply chain. The NHS can monitor key initiatives and derive new insights from patient cohorts. Example initiatives that can be monitored include, but are not limited to:

- Childbirth and immunisation rates over time and across youth cohorts
- How much vaccine has been supplied and administered
- Efficacy of treatments across population segments
- Equitable distribution of vaccines across population cohorts
- Disease transmissions and hubs for disease spread

Advanced emergency response immunisation programmes will require a data unification system that tracks:

- Community nodes, including neighbourhoods, cultural communities, and postcodes

- Community links, including interactions and public transit routes

- Patient demographics such as sex, ethnicity, and age

- Health conditions such as pre-existing conditions, diagnoses, incidences of new cases

The C3 AI FDP solution is differentiated by capturing the relevant features of a graph network and using model networks to analyse disease spread using:

- Susceptible-infected-susceptible (SIS) models

- Susceptible-infected-recovered (SIR) models[15]

- Temporal scale-free networks[16]

- Graph embeddings for node or link prediction

In the event of missing data, other viable modelling methods exist for optimising vaccine rollout. In partially observed networks, degree immunisation rollouts are highly effective. In mostly missing data, stochastic rollouts outpace other methods in minimising outbreaks.[17]

The proposed approach supports researchers and officials to:

- Optimise vaccine rollout to target communities currently at or susceptible to risk

- Characterise why certain areas/communities experience higher infection rates

- Equitably distribute excess vaccines across communities

3. Benefits

Administrators, clinicians, and patients all benefit directly from the proposed C3 AI FDP solution. Administrators will have real-time data on vaccine supply, delivery coordination, and resource management for accurate planning and logistics coordination. Administrators can monitor real-time intake of immunisations across community cohorts. Administrators will be able to identify communities where preventable services have the maximum benefits. Patients will receive timely and equitable distributions of immunisations and be able to control and understand their data usage in broad healthcare initiatives. Children and their families receive better preventative care and outcomes with improved vaccination programme performance.

Care Coordination

1. Opportunities

Patient and operational information is often incomplete and varied between facilities. These obstacles hinder frontline staff and managers from ascertaining the most appropriate care and services for each patient.[18] The NHS seeks to equip ICSs with the tools to coordinate data and operations, providing staff, commissioners, and managers with comprehensive information on patients and cross-provider capacity to enhance and personalise care for each patient.[19]

The NHS has several opportunities in care coordination, including:

- Giving providers a complete view of a patient's medical history. Developing complete treatment plans to increase quality of care and reduce resource waste.

- Making providers in one locale aware of available capacity in another location, decreasing wait times for patients.

- Increasing data upload frequency to ensure data is up to date.

- Developing a common interface to coordinate care plans and activities.

2. The C3 AI FDP Solution

Frontline staff, commissioners, and managers will have access to:

- Unified, comprehensive clinical data to provide longitudinal, up-to-date visibility of pertinent patient information.

- Unified data on cross-provider staffing and capacity.

- Virtualisation of data maintained by local owners ensures a consistent real-time view of planning resources and care requirements for an individual.

- Collaborative interfaces to enable providers to coordinate decision-making efficiently.

- An application layer built on a consistent data model and vocabulary that supports reusable and transferable applications and services.

The unified federated virtual data image will be anonymised in real-time, and then segmented by population, time, or location through pre-built tooling to support research and analytics. The platform will enable analytics teams to build predictive models[20] they can deploy to the front lines, such as:

- Forecasts of demand, capacity, and staffing to enable proactive allocation of resources.[21,22]

- Proper cohort segmentations to streamline patient monitoring.[24,25]

- Best-practice treatment recommendations identified based on patterns within cohorts.[23,24,25]

3. Benefits

Frontline staff, administrators, and patients will experience better coordination and therefore better overall experiences and patient outcomes. Frontline staff will have real-time information in one location to proactively coordinate care. Organising bodies will have knowledge of capacity across services and locations to better design end-to-end care for patients. The NHS will reduce costs from improved operational insights at the local, regional, and national level. Capacity and demand planning insights will be backed by confidence in the data quality used in the decision-making process. Patients will have greater options when and where they receive care, creating a far more personalised experience.

Elective Recovery

1. Opportunities

The UK is experiencing unprecedented wait times for treatments, which has been exacerbated by the COVID-19 pandemic and the need to postpone non-urgent elective operations in 2020. In addition to the current waitlist of 6.84 million people, it's estimated that an additional 3.3 million people need elective procedures who have yet to be identified.[4] Elective recovery presents opportunities for several reasons:

- Emergency rooms have had to operate at reduced capacity due to increased infection prevention and control (IPC) measures.[26]

- The health conditions of the patients in queue have deteriorated due to delays in receiving care, leading to more complicated procedures that take longer than originally expected.

- The measures adopted for waitlist management can be standardised across the NHS, increasing transparency.

- Increased targets for productivity without a system-wide process to support those targets have led to employee turnover and increased absences.[27,28]

- Operational capacity data is managed by different entities in different formats, making it necessary to develop a unified view of the current overall state.

- The NHS will benefit from a unified and consistent scheduling infrastructure.

2. The C3 AI FDP Solution

The C3 AI FDP builds on the elective recovery plan set out by the NHS that describes how the NHS will reduce the backlog and accelerate elective services over the next three years. Implementing a unified federated data image would aid in implementing the NHS's plan in the following manner:

- Standardisation, cleansing, enrichment, and unification of existing disparate datasets enable analyses that inform the decision-making process.

- Data governance capabilities ensure the accuracy and relevance of data sources over time.

- No-code solutions capable of integration with the image will allow healthcare professionals to quickly conduct relevant analytics and gain care insight.

Harnessing data under this unified system would deliver additional tangible benefits for improved scheduling, pathway management, and patient communication through AI/ML applications:

- AI-driven technologies can be designed particularly to solve problems related to managing, planning, and scheduling health and social care at scale.

- AI-assisted triage support tooling will enable hospitals to assess the risk and urgency of patients' conditions and make fast and automated triage decisions.[29]

- AI-based systems can use past appointment attendance and demographic data to predict patients likely to miss appointments. This helps in contacting people with customised communications and helpful links to optimise rearrangements for the hospital and limit the impact of patient no shows.[30]

Innovative technologies integrated with the C3 AI FDP deliver improved transparency across the individual patient's journey, resulting in better care offerings and improved communication between providers.

- Patients can be supported to 'wait well' as they await treatment. The C3 AI FDP will integrate remote symptom monitoring and reporting technologies.

- Doctors can be equipped with tools to match patients to other facilities based on patients' willingness to receive care from a different practitioner or a different facility.

- AI/ML can assist in identifying patients who are open to non-hospital treatments and in generating recommendations for alternatives.

The C3 AI FDP will be able to analyse waitlist data according to health inequality outcomes and characteristics including age, deprivation, ethnicity, and by specialty. In all the above, care will be taken to minimise digital exclusion due to socioeconomic status. Proper modelling and monitoring of usage of these digital tools will be a key factor to ensure proper intervention when digital deprivation is identified.

- The C3 AI FDP will be able to predict wait times for patients seeking appointments for consultation and/or procedures.

- This also enables hospitals to better design staffing plans and allows healthcare professionals to assess and respond more accurately.

3. Benefits

The C3 AI FDP will drive improved clinical outcomes using data-driven initiatives for clinical users and patients. Effective implementation will reduce:

- Waitlist patients' admission to emergency facilities

- Avoidable harm as measured by saved hospital bed-days

- Patient health deterioration as measured by a significant reduction in length of hospital stays and cost

- Surgeon burnout rate by better usage of surgeon time (shorter triage time)

- Independent sector rejection rate of NHS patients through better matching

- Waitlist backlogs

All patients will experience improved care access through more equitable capacity planning and delivery of elective care. They will have shorter wait times and achieve a higher quality of life more quickly. Patients will experience more consistency in the elective recovery pathway process and greater transparency in wait times.

Supply Chain

1. Opportunities

Shortfalls and inefficiencies within healthcare supply chains have demonstrated life-threatening consequences across the globe. The NHS supply chain is responsible for a robust supply chain system and on-time delivery of critical healthcare products and services for NHS Trusts and healthcare organisations. To fulfil its role, the NHS supply chain has several major opportunities:

- Create data visibility and actionable insights necessary for proactive supply chain management, safety stock planning, and demand management.

- Modernise the procurement process for medical devices to satisfy strict clinical requirements to ensure patient safety but also minimise cost and maximise on-time service delivery.[31]

- Connect fragmented data sources across multiple locations in various formats across the supply chain system to significantly reduce the time and effort required to monitor inventory, track supplier performance, and aggregate demand across multiple healthcare organisations.

- Reduce latency in the data integration process to facilitate real-time supply inventory and equipment usage monitoring, leading to matching in vaccine distribution, demand management, and care delivery.[32]

2. The C3 AI FDP Solution

Using the C3 AI FDP, supply chain managers, healthcare providers, and inventory planners should have access to:

- Unified data across the end-to-end supply chain system from procurement to patient consumers in a standardised format to reduce labour efforts in the data integration process.

- Integrated, relevant external data such as suppliers' product categories and rating, raw materials prices, and global events data to ensure effective procurement.

- End-to-end and near-real time visibility into distinct phases of the supply chain, including supplier performance tracking, inventory monitoring, and demand management.

This powerful data unification and end-to-end visibility with high-level data integrity and system scalability can drive a resilient supply chain system and better care delivery in multiple aspects:

- Reduce the time and effort for data collection, transformation, and validation, enabling healthcare workers to focus time and resources on patient care while ensuring continuous and precise data integration.

- Enable supply chain analysts to quickly access, examine and visualise data across multiple supply chain stages to identify root causes for unsatisfactory delivery services.

- Offer procurement planners a comprehensive review of suppliers using delivery performance, product offerings, patient ratings, clinical requirements, and external global events data.

- Ensure vaccine suppliers and distributors have near-real time and detailed information about vaccine available quantity, expiration dates, storing condition, and public demand.

3. Benefits

The C3 AI FDP solution will improve supply chain resilience and operational efficiency, leading to reduced NHS costs and improved healthcare delivery. Administrators will have increased visibility of where stock is needed to optimise planning and access to predictive demand planning capabilities that support more effective ordering. The NHS will have cross-cutting supply visibility linked to healthcare outcomes to gain spending insights and drive value-based procurement. National, regional, and local insights into where supply is most needed and having the greatest impact will inform outcome-driven distributions. Patients will have better and more equitable access to healthcare that can be delivered when and where the patient wants it.

Summary

Implementation of the C3 AI FDP will digitally transform the NHS and UK healthcare system end-to-end. Connecting NHS data into data-driven solutions will improve patient outcomes, patient experiences, and reduce NHS costs. Patients will be able to see and control how their data is used to protect privacy and support UK healthcare innovation. National and local administrators will gain access to real-time data to balance healthcare capacity and demand. Patients will also have greater access to services, including telehealth, and they will have more timely appointments to choose from. Patients will receive more individualised care whether at home, at a practice, or in emergency care. Frontline staff will also have access to accurate, real-time data so they can deliver better care and patient experiences. The above benefits will be delivered by the C3 AI FDP through the five use cases detailed while remaining flexible to future needs. Importantly, data remains in place with data controllers to limit duplication and provide privacy tools that can be applied locally and to each data element for maximum control. With a common operating picture of healthcare and a consistent data model and vocabulary that supports data unification, administrators will be able to accurately plan health and care services. Data integration and application development are separated to protect privacy and make applications reusable and scalable. Transparent data sharing protocols and synthetic data tools support research that fuels innovation for the NHS. No-code tools make advanced analytics and AI tools more accessible to NHS researchers and partners to enhance investigation capabilities. The C3 AI FDP gives value beyond immediate uses by supporting future technology integration and use case development to deliver rapid and recurring value to the NHS.

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