Pilot 9&10: Hyper-Acute workflows: Stroke and Sepsis management
&
Pilot 11: Asset management

1. Key Information

1.1. Involved Partners

Pilot 9 & 10:
- Philips (PHI)
- STICHTING ELISABETH-TWEESTEDEN ZIEKENHUIS (ETZ)
- FUNDACION PARA LA INVESTIGACION DEL HOSPITAL CLINICO DE LA COMUNITAT VALENCIANA, FUNDACION INCLIVA (INC)
- Technische Universiteit Eindhoven (TUE)
- UNIVERSIDAD POLITECNICA DE MADRID (UPM)

Pilot 11:
- Philips (PHI)
- STICHTING ONZE LIEVE VROUWE GASTHUIS (OLV)
- Technische Universiteit Eindhoven (TUE)

1.2. Involved Countries

Pilot 9 & 10:

- Netherlands
- Spain

Pilot 11:

- Netherlands

1.3. Keywords

- Workflow optimization
- Bottleneck detection
- Data quality

1.4. Task Description

The pilots focus on monitoring and characterizing workflows within a hospital using multiple data streams available within a hospital. A workflow typically consists of all the processes that get triggered when a particular patient arrives at the emergency department. For example, when a stroke patient arrives at the emergency department of a hospital, the patient needs to go through triage, have a CT scan performed and blood tests taken. Once the appropriate tests have been performed, relevant care providers (e.g., neurologist, radiologist) analyse the available data and decide on the correct form of treatment. Multiple data streams are used to make various predictions about the care pathway, such as automatic prediction of where a patient is within a particular care pathway or how long a particular part of the care pathway will take to complete. Pilot 9, 10 and 11 have strong similarities, however while pilot 9 and 10 use staff/patient tracking, pilot 11 targets assets.

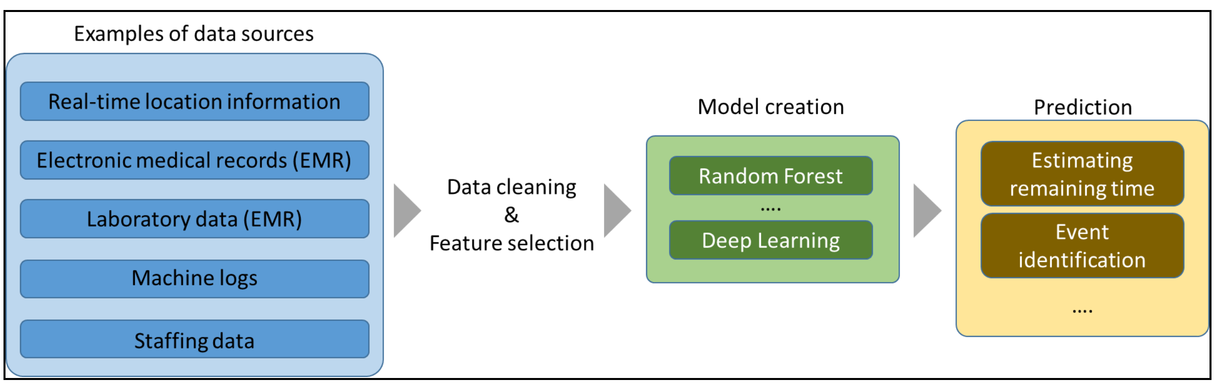

Figure 1 - Overview of Pilot 9, 10 & 11

As Figure 1 shows, data arrives from multiple sources, e.g., real-time location information, electronic medical records, laboratory data, machine logs, staffing data. Individual data sources will be cleaned and transformed, which is necessary to provide reliable results. Then a pipeline is created that integrates the data at the right level of granularity. The integrated data will be fed into feature selection algorithms and subsequently be used to develop predictive models. This will involve techniques such as random forest, deep learning. Tests will be performed to select the most appropriate model for eventual deployment in the pilot.

2. Building Blocks

2.1. Architecture

2.1.1. System Architecture

The Figure below shows the architecture of the Big Data platform used by the RTLS.

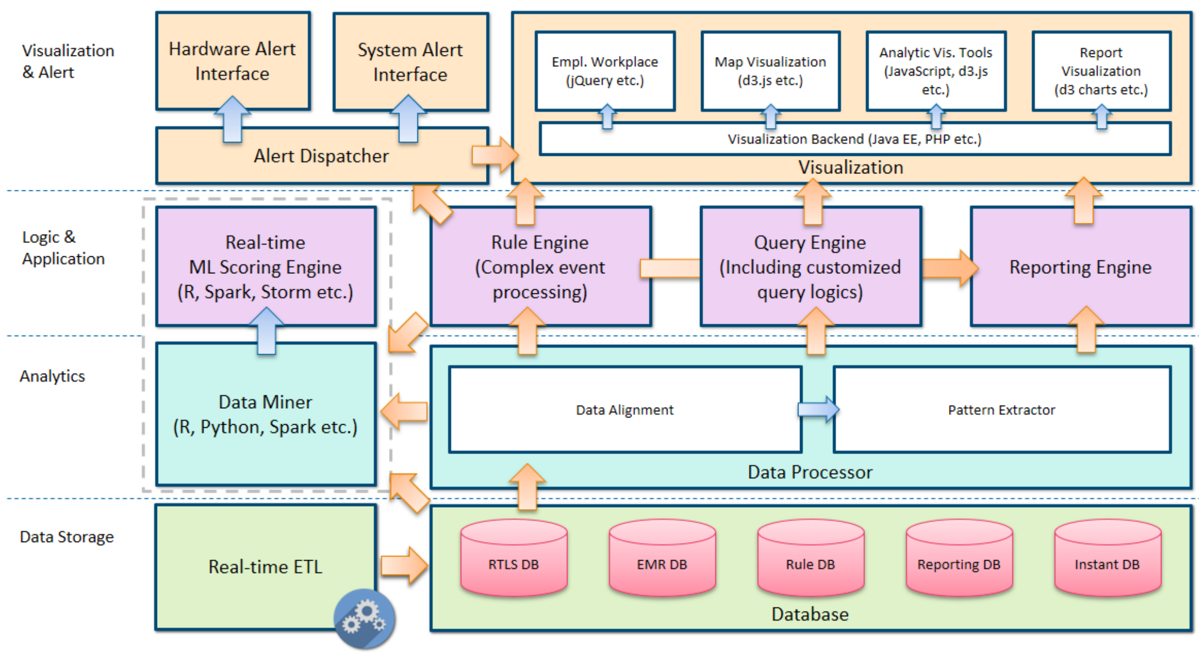

Figure 2 - Architecture of RTLS platform

The system consists of 4 levels. The basic level is the data storage. This level does job not only for data storage but also for the data ETL (extract, transform and load) in real-time. The data from different sources will be stored in separate databases.

On top of the data storage is analytics, which includes a Data Miner component, which does machine learning based predictions based on the database. Another component is the data processor, which does two jobs: align the data with different sources, for example, merge two data sources according to timestamp and entity ID. Pattern extractor, which extracts patterns from the merged data.

One level above the analytics is the logic & application level. There are 4 components in this level. First is the real-time ML (machine learning) scoring engine. There is an interface between this scoring engine with the data miner component from the level below. The models produced in the data miner will be deployed onto the scoring engine for real-time scoring. The rule engine is responsible for detecting interesting & risky patterns. The query engine can take queries from the user interface and translate the query into SQL, execute in the database and return data results. The reporting engine can run predefined reports given customized parameters.

The top level is the visualization & alert level. This is a level that directly interacts with users. It consists of two basic parts. The first part is the alert dispatcher. It can dispatch the alerts generated from the rule engine to specified users in specified channels. The visualization component is implemented by a java web server as back-end an HTML 5 based front-end. It visualizes the current status information and analytic results to the users.

2.1.2 Data Flow & Interoperability of services

The Figure below describes how data flows between different components in the system.

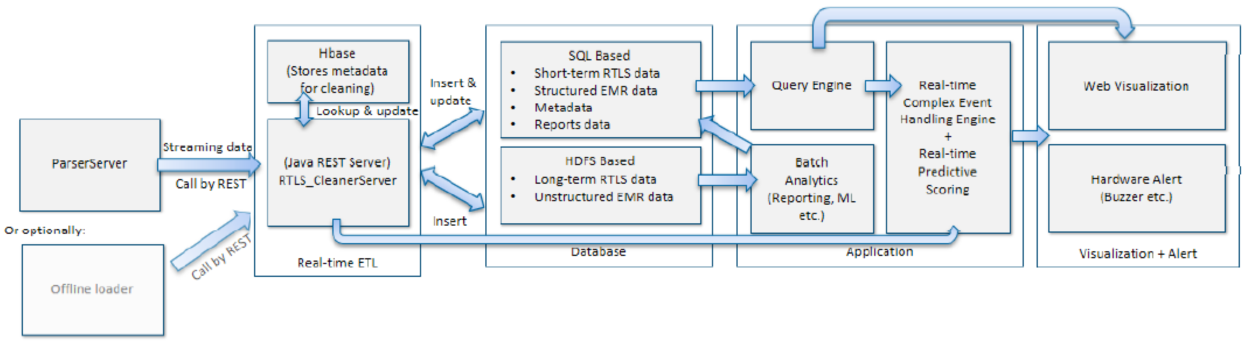

Figure 3 - Data flow

The components on the left side are the "sources" of the data inside our system. The parser server from the Real-time ETL component listens HTTP port for data packages from RTLS software. It translates the bytes package and sends the translated data entries into the cleaner server, which is another sub-component of the Real-time ETL component enriches and cleans the data according to the metadata store which is implemented in HBase. The cleaned data is then mirrored and sent to two data stores: a SQL based database and the Hadoop Distributed File System (HDFS). They are the data sources for the applications. In the applications, there are analytic components and the query engine, they run queries and analytics on top of the data in the data stores and store the result back to the data store or directly send the data to the visualization server in JSON. In addition, the cleaner server also generates event data. One copy of the data will be stored in the HDFS, another copy of the data will be directly sent to the rule engine.

2.1.3 Necessary Hardware

The main hardware needed for Pilots 9, 10 and 11 were the RTLS components.
Cable-free (wireless, battery operated) IR beacons are placed at the ceiling of rooms or hallway

zones, where localization is needed. The beacons emit (invisible) IR light containing a unique code representative for the zone, that reflects from the walls, floor and ceiling of the room, thus “filling” the room with the coded IR light signal. The tags of this system detect this IR code as soon as they enter the room, and subsequently send this zone code, together with their own unique ID, wirelessly to one of the receivers. These act like access points of the system, and take care of transferring the information to the central server which collects and processes all events.

A broad array of tags is available for this system, including patient tags, asset tags and staff badges of different sizes and with different features and specifications. Versions are for example also available that cannot only be used in areas covered by IR beacons, but also in areas only covered by a WiFi localization system, for course localization in parts of the hospital where room level accuracy and certainty is not needed.

The type and amount of hardware needed for a setup depends not only on the type of setup chosen (Wifi vs IR only) but also on the vendor used.

2.1.4 Software Components

Only in Pilot 11 there is a user facing Software component. This is an asset management solution from Philips PerformanceFlow. This allows the users to search and identify the location of the tagged assets.

Pilot 9 and 10 both have a dashboard that allows the responsible Physicians to visualize and analyze the various KPI’s related to the clinical workflow. These visualizations are derived from RTLS data and from combining RTLS with EMR data. This also allows for an easier comparison between EMR and RTLS data.

2.3 Data Processing

2.3.1 Processing of large structured / unstructured data sources

2.3.1.1 Data Sources

Data Source	**Description**	**Acquisition**	**Characteristic (Size, Patients, Years, Origin/Region)**
RTLS	Location data of tags (asset, patient and/or staff).	The data is collected using the RTLS hardware. The storage and transfer of data is done according to the	The data is collected in the Netherlands for Pilot 9 and 11 and in Spain for Pilot 10. In Pilot 9, location of

		requirements of the Hospital.	assets, patients and staff that are part of the Stroke workflow in the ED is being collected. In Pilot 10 the location of patients with suspected SEPSIS is being collected while they are in the ED. For both pilots, only patients who give consent are included in the study. For Pilot 11, asset location data was collected. All pilots combined involved the data of more than 200 patients, 150 members of staff and 600 mobile assets.
EMR (pilot 9 and 10)	EMR data of all the patients that provided consent to participate in the study. All the data fields collected are referent only to the workflow/condition being evaluated (Sepsis or Stroke).	In Pilot 9 the data is taken from the EMR database by the IT department while in Pilot 10 the data is manually taken from the EMR by the researcher from the Hospital.	

RTLS

Real-Time Localization Systems (RTLS) provide solutions for positioning or localization indoors, where traditional outdoor technologies like GPS do not work. Positioning refers to applications, such as wayfinding, whereby a device, typically a smartphone, determines its own location, using beacons of an RTLS system. Localization refers to applications such as tracking, whereby the RTLS system continuously monitors the locations of electronic tags, which can be placed on mobile equipment for asset tracking, on wristbands for patient localization, or provided in the form of electronic badges for staff localization.

There are many different RTLS technologies on the market, and new ones are still emerging. These can roughly be divided in two main categories: those using RF signals transmitted or received by static beacons in the building to estimate an (X,Y) coordinate with respect to the reference frame of static beacons (WiFi, BLE, UWB, etc.), and those using optical or acoustic signals, which do not pass through walls, to directly establish presence in individual rooms or zones (Infrared, Ultrasound).

For the purpose of these pilots (and most other healthcare applications of RTLS), room level accuracy and room level certainty are essential: we need to know with certainty if a patient has for example entered a specific room, or is still waiting just outside the room. Since RF signals pass through walls and ceilings, to date, room level certainty can typically only be provided by the non-RF techniques.

2.3.1.2 De-Identification and anonymization

De-identification is only applicable where EMR data of the patients is collected. This step is done by the Hospitals since in most cases no identifiable data can be transferred outside the institutions. The first step for de-identification happens in the selection of data fields that do not contain any data specific to the patients (e.g. IDs or rare diseases). For all pilots a Privacy Assessment was conducted were the re-identification risk of the data was assessed and the concept of minimization of data was applied.

To decrease the risk of identification we use reusable tags for the patients. For the staff, the tags were divided by role (e.g. nurse, doctor…) and randomly assigned to the Healthcare Professionals within that role. All roles have more than one health professional to which the tags were provided, and they were free to take any or switch tags within the same role. For privacy reasons of the staff and the patients all the areas of the department that were not deemed relevant were not equipped with beacons (e.g. toilets, common areas, dressing rooms…).

2.3.1.3 Acquisition

Data arrives from two main sources, the EMR and the RTLS. Proprietary RF technology was used to gather data from all tagged entities. Java was used to parse the incoming data.

2.3.1.4 Cleansing

Individual data sources are cleaned and transformed. The precise technique used for cleaning depends on the specific data source. For example, interpolation and noise reduction techniques are applied to real-time location data to ensure missing or erroneous data points are adequately addressed. Time stamps from EMR data are in certain cases corrected by insights derived from RTLS data.

2.3.1.5 Data Integration

Data is transformed and different data streams are combined to derive higher level semantics that describe particular events of interest within the target care pathway. Once higher-level events have been detected, feature selection techniques are applied to ensure relevant features are used to train, test and validate the models.

2.3.1 Multi-velocity processing of heterogeneous data streams

This section provides an initial overview on how pilots handle multi-velocity of heterogeneous data streams.

Stream name	Contents of stream	Stream velocity
Real-Time Locating System (RTLS) data stream	Data packets contain information about the location of tags, battery level, tag type, etc.	Every tag can transmit data up to once every 1.5 seconds. A typical large-scale deployment can generate around 500 data points per second.
Other Hospital IT systems, e.g. EMR	Contains times of medical events of the patient relevant to the workflow being tracked.	Updates occur in the order of minutes/hours.

Combination of different streams:
Different data streams are integrated in order to characterize the performance of the workflows. Integrated data streams are plugged into models which help predict the estimated waiting times/deduce position of a patient within a particular care pathway.

Challenges combining different streams:
Every data stream can have missing/noisy data at any point of time. This can make it difficult to combine data for deriving higher-level context information. Moreover, certain data streams can also have erroneous data.

Solution:
Data imputation techniques are used to fill up missing data prior to data integration. In addition to that filtering techniques are used to remove noise in the data streams.

Streams mixed	Technology used	Purpose of the process	Result (name if is a stream)
RTLS data Data from Hospital IT system (e.g. EMR, Laboratory, Staffing Records)	Java & Python	Create an integrated data stream before it is sent for storage and analysis.	Integrated/cleaned RTLS and EMR data stream.

Stream combination	Difficulties	Solutions
RTLS+EMR analytics input	Data is collected at different speeds and quality. Missing/delayed data on all data streams can make data integration a challenge.	Use data imputation methods or use predictive analytics (e.g. using a Bayesian network approach for estimation) to handle missing/delayed data.

2.3.5 Complex real-time event detection

2.3.5.1 Notifications

Table 7. Types of notifications and alerts to be issued

	Need for notification services			
Pilot	**Notification**	**Warning**	**Alarm (automated / manual reaction)**	**Other**

9, 10		Excessive time for particular workflow step	Time exceeded for particular workflow step	
11		Assets below required level	Asset out of bounds	-

2.3.5.2 Situations of Interest

Type of situations of interest

Table 8. Types of complex events to react on

	Type of situations of interest			
Pilot	**Simple**	**Trends (time-window / frequency based)**	**Complex (multiparameter / historical context)**	**Other**
9,10	If time exceeds a particular threshold		If patient enters a particular location	
11	If no. of assets fall below a particular level		If asset enters an area before being disinfected	-

2.3.5.3 Event Processing

1. **Type of event processing**

Table 9. Types of event processing actions

Pilot	**Filter**	**Transform**	**Other**
9,10	Tag spends more time in a location than a specified threshold	Reconstruct new event trace by aggregating RTLS and EMR data streams	
11	Tag spends more time in a location than a specified threshold		

2.3.5.4 Event Sources

1. **Event sources**

Table 10. Event source during complex-event processing

Pilot	Stream name	Contents of stream	Stream velocity	Description of the stream
9,10,11	RTLS data stream	Location and timestamp	Up to every 1.5s	Location data of a tag is reported every 1.5 seconds when the tag is in motion. The update frequency goes down if there's less movement.

2.3.5.5 Evaluation

The evaluation of these concepts was done using domain knowledge and data from the HIS (Hospital Information System). With both these sources we were able to verify if the data gathered and derived from RTLS made sense and gave a proper representation of the clinical workflow and its events.

2.4 AI Components

2.4.1 Deep learning for multilingual NLP and image analytics

Does not apply.

2.4.2 Prediction Algorithms

The Stroke pilot focuses on monitoring and characterizing workflows within a hospital using multiple data streams available within a hospital. A workflow typically consists of all the processes that get triggered when a particular patient arrives at the Emergency Department. For example, when a stroke patient arrives at the emergency department of a hospital, the patient needs to go through triage, have a CT scan performed and blood tests taken. Once the appropriate tests have been performed, relevant care providers (e.g. neurologist, radiologist, etc.) analyze the available data and decide on the correct form of treatment. Multiple data streams are used to make various predictions about the care pathway, such as automatic prediction of where a patient is within a particular care pathway or how long a particular part of the care pathway will take to complete.

2.4.2.1 Task

2.4.2.2 Data, Data Modelling

2.4.2.3 Features

2.4.2.4 Model

Data arrives from multiple sources, e.g. real-time location information, Electronic Medical Records, etc. Individual data sources are cleaned and transformed. A pipeline integrates the data at the right level of granularity. The integrated data is fed into feature selection algorithms and subsequently used to develop predictive models using techniques such as random forest, deep learning (e.g. LSTM).

2.4.2.5 Evaluation

2.5 Security and privacy of data access and processing

Pilots 9 and 10 have two sources of data streams: Real-time Locating System (RTLS) and Electronic Medical Record (EMR). Pilot 11 only has a single RTLS data stream.

RTLS data is collected locally at a server situated at the hospital. All data is encrypted prior to transmission over the internet. All data is transmitted to Philips over a secure connection.
EMR data is de-identified at the hospital and relevant fields are encrypted and manually uploaded to a secure Philips server over a secure connection. The de-identification of the data can be done in two steps:

- Manual selection of unnecessary fields
- Modification of fields necessary to the data analysis using an algorithm and/or manual verification. The goal is to change certain types of data making it harder to reidentify while maintaining the logic between the data fields to allow for data analysis.

2.5.1 Access Control

2.5.1.1 Authentication

Access to RTLS data stream is limited only to specific Philips personnel working on the pilot. Access to EMR data stream is limited to specific hospital staff members working on the pilot.

2.5.1.2 Authorization

(i) Local access with a standard Windows account authentication using a strong password with more than 8 characters which locks after a certain number of wrong attempts or (ii) remote access using a Philips-compliant remote access service.

2.5.2 Data Protection

2.5.2.1 Data at rest

Data will be encrypted before transfer using 7-zip with AES encryption

2.5.2.2 Data in transit

TLS encryption

2.5.3 Auditory and logs

2.5.3.1 System Auditory

All activities actions on the RTLS server, secure server for data storage and secure data transfer server are logged for auditing purposes.

2.5.3.2 Services Auditory

VPN/Windows logging

2.5.4 Privacy measurements

2.5.4.1 Data Privacy Impact Assessment (DPIA)

For each of the Pilots a DPIA was conducted which includes all parties accessing the data. This assessment includes the analysis of all the data fields collected by each data source. In the analysis we looked at the risk of re-identification of data and apply the minimization of data concept and de-identification steps accordingly (e.g. change all timestamps where possible, without removing the meaning of the data). For privacy, the amount of staff members participating in the study is also of big importance. Not only it is important to make sure there are enough staff members in each role when tracking staff (Pilot 9), but also it is important to know the number of and the variety of staff members that are handling Patients and Assets.

2.5.4.2 Legal/Ethical process

Together with Privacy, Legal and Ethics procedures were followed for each of the Pilots by Philips and the Hospitals together. To cover all the legal aspects of transferring and sharing data (including non personal data) from the Hospitals to and from Philips, extra legal agreements had to be done on top of the Consortium Agreement for each one of the partnerships.
The Ethics reviews added to the privacy and legal procedures were conducted as well before collecting any data. This included an assessment of all aspects of the study made by the parties involved in the design of the pilot activities. With the definition of a detailed protocol for each Pilot we ensured that the criteria for inclusion of participants and their participation are according to the Ethical standards of the Institutions and the Countries involved in the Pilots.

2.5.4.3 Processes for complying with the current legislation

Different Legal, Ethics and Privacy had to be followed to account for the variety of legislations per Country. The main differences found were regarding the privacy interpretations and nuances of GDPR in each country. In countries such as the Netherlands entities like the workers councils of the Hospitals have a bigger impact on privacy and ethics decisions of the projects.

2.6 Trustworthy AI

2.6.1 technology/user adoption and establishing trust

The characterization of workflows using RTLS is heavily dependent on the way humans interact and use the system. In these types of projects providing continuous information to the user about how the system works and its limitations in tracking their movements can have a great impact on the adoption of the technology. Regular feedback about the data being collected is also a powerful tool to improve adoption rates and establish a trust relationship with the technology. These processes can be done not only with information sessions but also with UI tools capable of representing the data that is collected with RTLS. In the RTLS Pilots 9 and 10 there were two extra steps taken to ensure the users' trust in the technology. The first was the implementation of a Data Quality Tool (DQT) that improves the quality of the data collected using RTLS and helps to distinguish phantom data or errors generated by the system, from the data that actually represents the paths that we want to monitor. The second was the combination with the EMR data. RTLS and EMR data together lead to a better interpretation of workflow data since it combines the real time movements of patients, staff and assets with what is declared by a system that is not always straight forward to use nor is absolutely aligned with the clinical workflows. The combination of these data sources also brings a source of knowledge to the RTLS that allows for better interpretation and recognition of the events by the users.

2.6.2 ethical principles

- respect for human authority

The technology used in the RTLS pilots depends on human interaction and trigger to generate data.

- prevention of harm

The use of the DTQ and the combination of the EMR data source are used to increase the accuracy of the information provided to the user and prevent any wrongful conclusions regarding the clinical workflows.

- Fairness

Removal of bias is an important step in the ethical assessment of each one of the RTLS Pilots that involves various stakeholders.

- Explicability

The UIs developed in the project were created together with the users so that they are easy to understand and make the technology transparent to the user.

2.6.3 key requirements

- Human agency and oversight

The data generated with the use of RTLS and EMR together empower the users to make informed operational decisions by characterizing with higher accuracy various aspects of their institutions (e.g. clinical workflows and/or assets).

- Technical Robustness and safety

Security assessment is one of the key steps of our Pilot set ups. For each pilot, adjustments were made to the architecture of the system to adapt to the requirements of the institution and country where the pilot took place.

- Privacy and data governance

Privacy procedures were followed for each of the Pilots by Philips and the Hospitals together. Data governance is part of the privacy assessment and procedures were put in place to ensure the quality and integrity of the data as well as to ensure legitimized access to the data.

- Transparency

The UIs developed in the project were created together with the users so that they are easy to understand and make the technology transparent to the user. For extra transparency on the technology throughout the projects information leaflets and sessions were organized to address any questions regarding the technology.

- Diversity, non-discrimination and fairness

For the context of the clinical workflow characterization all patients with a certain clinical diagnosis are given the opportunity to participate in the Pilots. For Staff, the only requirement is that they are part of the clinical workflow being assessed.

- Societal and environmental well-being

The technologies used and developed in the RTLS Pilots have the aim to assist the healthcare professionals and institutions to achieve a continuous improvement of the care provided to the patients.

- Accountability

2.7 System-Interaction

2.7.1 Human-Machine Interface / GUI

For the pilots using a commercial solution such as Performance Flow for asset management, the system-interaction is quite well established. The most common set up is to have the software accessible by healthcare professionals in the relevant departments equipped with RTLS.
While Performance Flow is used by all the Healthcare Professionals to find assets, the dashboards for workflow visualization created in Pilot 9 and 10 have a different target group. These were created having in mind the Professionals responsible for workflow analysis and optimization. Having that in mind the system-interaction is thought during an extensive co-creation process with these professionals from the Clinical Partners. With them we define the best ways to represent the KPIs and other relevant measures for the evaluation of acute workflows.

2.7.2 Education

All Pilots included some time for Staff Education regarding the studies. For this, key people in the departments where the RTLS was deployed were identified as the responsible for assisting the other staff members with questions related to the research procedures or the RTLS installation. The main methods used for education of Staff members were:

- Information sessions with Researchers from Philips where there all activities were explained including the functioning of the RTLS hardware and software (when applicable). Any questions regarding privacy of patients and staff was also clarified in these sessions.
- Leaflets left at key areas of the department with information about the study and instructions on how to use the RTLS tags (e.g. how to clean or place a tag in a patient)
- Project advocate in department

3. Learnings

3.1 Challenges & Barriers

- Architecture

The main challenge when it comes to the architecture of a RTLS set up is that there is no "one size" fit all. Different hospital structures (how many floors, adjacent rooms, etc.), hospital needs (focus on patient workflows or asset management), and technology availability (infrared or Wi-Fi) influence the design of the system.

- Processing of large structured / unstructured data sources

When it comes to using RTLS, the data build up can increase quite rapidly due to potentially every tag in the system sending an update every few seconds.

- Multi-velocity processing of heterogeneous data streams

While RTLS data comes in real-time, most of the times EMR data is generated retrospectively. In a Hospital setting most of the data is recorded before and after the actions to report on events that will happen in the future (e.g. "order medication") or that have happened (e.g. "medication was administered"). There is also no rule to the interval or order in which things are recorded so it is very common for events to appear out of order (e.g. order of medication with timestamp after administration of medication timestamp). Having this RTLS is an important tool to fill in the gaps of the EMR data, especially powerful for workflow analysis.

- Complex real-time event detection

For real time event detection, good quality and real time input data sources are needed. The biggest challenge was to increase the quality of the RTLS and EMR data to overcome all the data gaps that come from day to day use of the data collection tools. In the Healthcare environment, especially in emergency care where there is usually little time to make decisions data reporting is sometimes done in advance or in retrospective leading to erroneous data. It is important to detect and understand these patterns of use of the data tools to be able to augment the data quality for data analysis, which requires the involvement of multiple stakeholders and the use of prediction algorithms.

- Prediction Algorithms

Ground truth can be difficult to ascertain: Especially in the case of asset tracking and prediction, creating a test set that contains the ground truth is difficult. Since the use-case involves continuous monitoring of a large inventory of assets and people, acquiring a completely trustworthy ground truth would require each asset and person being manually tracked for the entire day.

- Security and privacy of data access and processing

Privacy and security are quite important in any project involving the clinical setting. In a setting where people or even assets are being tracked this becomes even more crucial to guarantee. Depending on the country and the institution there might be a need to involve more people in the discussions for security and privacy (e.g. workers council) besides the usual IT, Privacy and Legal and Ethics departments. Not only there's an inherent fear of tracking technologies by the professionals but also the multitude of decision makers can sometimes be challenging.

- Trustworthy AI

One of the aspects of using RTLS in a Pilot is to guarantee that the user trusts the technology and the data that is being collected and given as a result. If the user does not completely understand or trusts how the system works, that has a great impact on the quality of the data collected since it increases the chances of misuse of the technology. Alike to the EMR systems, RTLS also depends on the user to collect good quality data. In our Pilots we had to find ways to come across some of the most common causes for poor data quality and increase the value of the data collected. Only then we could guarantee the quality of the workflows characterized. The data quality process was a continuous work done in the individual pilots with learnings that were applied across pilots.

- System-Interaction

The misuse and lack of understanding of the system can lead to a decrease in the quality of RTLS data. Therefore, it is important to account for these factors when designing and implementing the system. Continuous and repeated education of the staff and people involved in the project is also important not only to maintain engagement but also to take in account the rotation of staff during the project timeframe.

3.2 Lessons Learned

- Architecture

Everyone needs to be involved from the start in the creation of an architecture that accounts for the different Institution and Country specific requirements.

- Processing of large structured / unstructured data sources

There are several ways to approach the processing of large structured/unstructured data sources. For the RTLS Pilots it is important to identify from all the RTLS data collected which data represents a relevant trace of an asset being used or a patient trace in the care workflow. The segmentation of the data using the DQT allowed for the identification of such traces as well as the overcome of gaps in the data generated by misuse of the system. Combining other sources of data, such as HIS with RTLS also helps to estimate the right segments of the data for analysis.

- Multi-velocity processing of heterogeneous data streams

When working with RTLS in combination with EMR or other HIS data it is important to apply tools to improve quality of RTLS data and to have a continuous verification of data. The quality of RTLS can be done with an algorithm to clean up the data and remove unnecessary data. For the verification of the data, not only is important to have the right set of rules for event detection but also to involve stakeholders with the domain knowledge necessary to interpret the data.

- Complex real-time event detection

Given the nature of EMR data, not only is it important to identify the right fields that are used to declare the events to be identified but also to consider that this data is not always generated in real-time. It is good practice to combine multiple data sources and to facilitate event detection and implement a co-creation and verification process that combines domain knowledge and clinical data.

- Prediction Algorithms

For the development and use of real time algorithms with continuous output, it is important to have the input of real time data sources to guarantee good quality analysis and insights. Traditional HIS do not have enough real time data since most of the data results of retrospective reporting or manual input. In the RTLS Pilots we found that IoT devices are crucial for generating good quality data to be used in real time predictions.
Another important step to take when talking about improvements is to implement a baseline phase with collection of real time data where no operational changes are made. This will provide a ground truth that represents the true workflows and allow for the refinement of the algorithms and data sources.

- Security and privacy of data access and processing

It is important to involve from the start all the relevant stakeholders and be able to adapt to the different country and institution settings.

- Trustworthy AI

It is important that people understand that they are not being monitored outside the boundaries of the area where RTLS is deployed and that the granularity of the tracking system does not allow for identification of the person. This can be explicitly discussed as part of the education process of the staff.

- System-Interaction

Continuous and repeated education of the staff and people involved in the project is really important not only to maintain engagement but also to take in account possible rotations of staff during the project timeframe.

3.3 Main (quantifiable) achievements

The interpretation of EMR data can be complex specially because of how it is used. The inaccuracy of manual input fields in the EMR can lead to artificial KPI calculations. A real-time location system helps to reduce EMR data ambiguity and to detect and mitigate bottlenecks in the workflow. In this project there was the unique opportunity to apply the same RTLS technology in different institutions and for different targets. This led to the discovery of different types of bottlenecks. The combination of the EMR system in each of the institutions brought up distinct challenges of implementation related to the unique way of use of the system by the healthcare professionals. In Pilot 9, the use of this system showed ambiguities in the time and

content registration in the EMR which resulted in new ways to improve accuracy in calculation of important KPIs such as door-to-needle time. While in Pilot 10, the combination of both data sources for the SEPSIS workflow allowed to not only overcome EMR inaccuracies but also to detect delays related to the interaction between the ED and other departments. Also, tracking the interaction of patients with staff and assets in Pilot 9 led to the detection and mitigation of structural inefficiencies that would be harder to spot if only patients were tracked.
Pilot 11 provided the unique opportunity to collect enterprise wide data on asset utilization in Healthcare using a real-time location system. Two RTLS systems were implemented, one using IR and another using the existing Wifi infrastructure of the Hospital. The insights collected support the idea that these can be used to reduce asset ownership costs and asset search time. In departments with closed door policy, the transparency of localization of assets brought by RTLS can even eliminate the search time of assets completely.

4. Output

4.1 Papers

Working on Papers at the moment.

4.2 Open Source & Resources (refer to ELG)

4.3 Demos