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PAPER TITLE: REVIEW OF LINEPIPE TAGGING AND TRACKING TECHNOLOGIES FOR ON AND OFFSHORE PIPELINE FABRICATION
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Dr. Gianluca Mannucci has been working on pipelines integrity assessment since 1994. He led the Structural Integrity group and coordinated several national and international projects on development and innovation on offshore and onshore pipeline topics (new materials, transport of CO2 and H2). Currently he works as Senior Business Development Manager and interfaces with Customers both manufacturers and end users. He is a member of EPRG and author of +30 papers.

Martin Connelly has almost 30 years experience in the manufacture of SAWL linepipe, with expertise in welding, NDT, metallurgy, plate rolling, mechanical/corrosion testing and many other areas associated with line pipe. He is a member of the EPRG Plenary Committee, and currently chairs the EPRG Materials Committee. Additionally, Martin is also a key member of the API Task Group on Line Pipe and has been key in the development of API5L and ISO3183. With over 2.5MT of carbon steel SAWL manufactured, Martin has been involved with many of the most demanding line pipe projects over the last 30 years.

ABSTRACT

Tracking of individual pipe joints from the mill to girth welding and then installation is currently a mostly manual process, based on recording codes on the pipe. Present linepipe tagging and tracking systems are based upon hard stamps onto the pipe surface and/or paint/ink marks or stickers on the pipe coating surface during manufacture. Tracking on receipt at the pipeline fabrication location and through the welding operations is normally performed by manual tracking of this identification code. This is

inefficient, prone to errors and has limited flexibility for data storage, analysis and reporting. Moreover, market offers partial solutions both for tagging and tracking without a global vision of the full chain.
This paper is focused to carry out a state-of-the-art review of available pipe tagging and tracking technologies to identify the requirements for a common non-proprietary platform for use by all stakeholders. The final objective has been the identification of a standardized system which has the capacity to automatically read the identity details and to capture the data. The identity tag must have durability and integrity to withstand the processes that occur potentially both during manufacture and subsequent operations including transferability at coating mills. The focal point driving the study has been: where do the stakeholders need vs want the tracking process to start?
The main result, obtained by applying an integrated Delphi-AHP approach, is the definition of three different technical solutions to implement a common non-proprietary platform that matches the main technical and functional requirements and at the same time the recommendations of the stakeholders and experts. These solutions are the result of several technological surveys, used to identify the better suitable techniques, and the consultation of an Experts Panel (composed of Manufacturers, EPCs and Operators) to address the main recommendations for the technical application. The activities result suggest performing a first feasible step for the realization of a common European Pipeline Tracking Database (EPTD) cloud system. EPTD is the backbone of every solution and therefore it is the first step in any implementation of a common tagging and tracking system. The EPTD system, composed only of software components, will communicate with stakeholders own tracking systems in a seamless way, and will provide functions to reconstruct the whole history of the pipe during all production, treatment, shipping and installation steps. An example of this approach could include the published API RP 5MT detailing the minimum data requirements for electronic certification support.

DISCLAIMER

1. INTRODUCTION

Tracking of individual pipe joints from the mill to girth welding and then installation is currently a mostly manual process, based on recording codes on the pipe. Present linepipe tagging and tracking systems are based upon hard stamps onto the pipe surface and/or paint/ink marks or stickers on the pipe coating surface during manufacture.
Tracking on receipt at the pipeline fabrication location and through the welding operations is normally performed by manual tracking of this identification code. This is inefficient, prone to errors and has limited flexibility for data storage, analysis and reporting. Depending on manual management of production data is also an obstacle to the wider implementation of automated manufacturing technologies and to achieving further production efficiency improvements. In addition, each pipe manufacturer makes use of its own developed system, and this makes the use of pipe manufacturer's data by the end user less easy since it depends upon the specific manufacturer system. A standardized system for tagging and tracking linepipe could provide benefits to pipe producers, construction contractors and pipeline operators.
This work has been focused to carry out a state-of-the-art review of available pipe tagging and tracking technologies to identify the requirements for a common non-proprietary platform for use by all stakeholders. The final objective has been the identification of a standardized linepipe tagging and tracking system which has the capacity to automatically read the identity details and to capture the data. The identity tag must also have sufficient durability and integrity to withstand the processes that

occur potentially both during manufacture and all subsequent operations including transferability at coating mills. This system would allow for computerized recording of pipe identification and retrieval of data necessary to allow other systems in the firing line to manipulate or route the pipe according to the data associated with its identification. This data could relate to pipe end shape, pipe type (transition/anode) and can be determined by the pipeline fabricator or could be provided as part of the pipe procurement process. Furthermore, the system should also be able to integrate with geo-spatial technologies so that the tracking and monitoring capability can be extended to in service life and integrated with pipeline integrity management systems. This work has been focused on offshore applications but the implications and benefits for onshore pipeline construction will be considered.

2. APPROACH

The approach carried out on this study is based on a decision model including an integrated Delphi-AHP (Analytic Hierarchy Process) method utilized to identify important requirements and their quantitative importance to realize a standardized line pipe tagging and tracking system (Figure *1*). This model includes the consultation, by online web surveys in several steps, of a Panel of Experts to collect the opinions and insights for identifying strategic recommendations for technologies selection.

The panel of EPRG Members was organized including 15 experts, with different expertise and belonging to companies and organizations working in the pipeline field (9 Manufacturers, 2 EPCs and 5 Operators). All the participants accepted the conditions of treatment of the personal data according to art. 13 GDPR 679/16. The description of experts profile is shown in the Figure *2*

The definition of requirements and related KPIs is obtained by consultation in two rounds of survey, the first being dedicated to definition of requirements and associated KPIs (Delphi-like consultation), while the second was focused on prioritizing and weighing KPIs using Analytic Hierarchy Process (AHP).

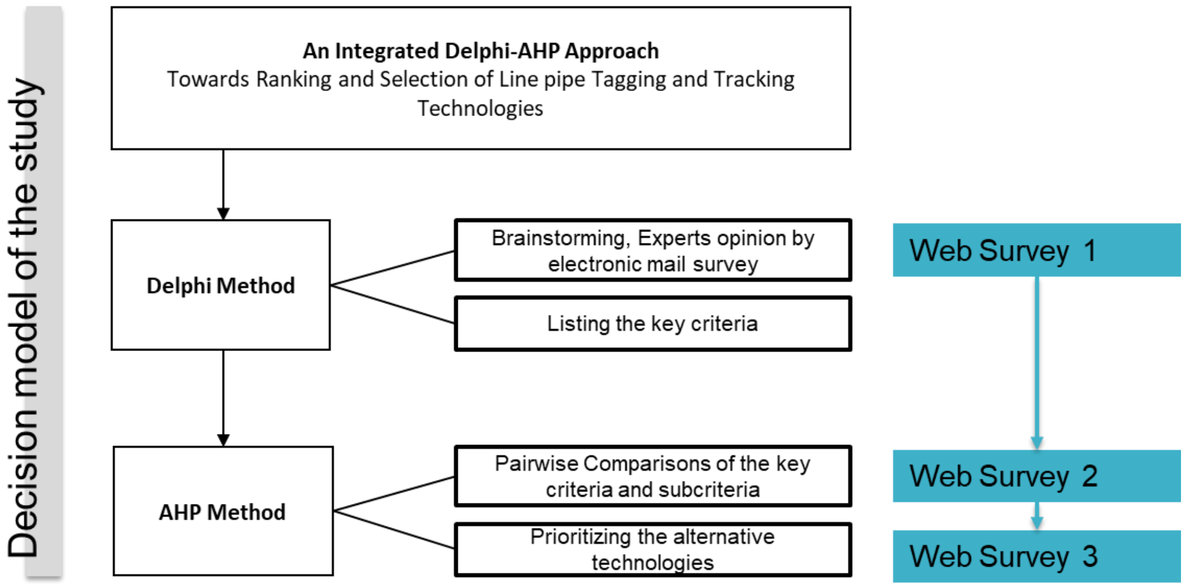
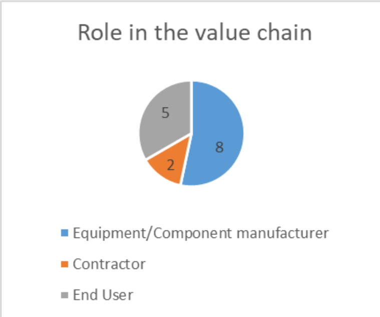


Figure 1 Decision Model of the Study

Pairwise comparisons were prepared for the decision criteria. Each criterion has been matched with other criteria as pairwise and the expert had the option of expressing preferences between the two as equally preferred, weakly preferred, strongly preferred or absolutely preferred. In the third and final round of AHP panel, it was asked to experts to rate the solutions identified in the activity against the KPIs defined in the preliminary phase. This final round provided a rating of the identified solutions both as a whole and in terms of single KPIs.
Finally, for each of the identified solutions, a SWOT table was created on the basis of the experts' opinion and of post interview analysis and a roadmap for the implementation was also defined.



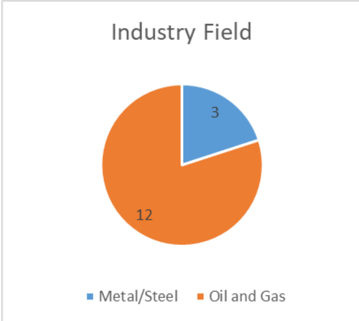


Figure 2 Panel Experts profile

3. REQUIREMENTS ANALYSIS AND KPIS DEFINITION

The review of available state-of-the-art technological solutions for pipe tagging and tracking allowed the identification of a series of alternative Key Performance Indicators and requirements for a common non-proprietary platform to be adopted for use by all stakeholders, including pipe manufacturers, pipeline operators, installation contractors and service providing companies.

The identified KPIs and requirements were submitted to a final consultation, in order to collect relevant insights from the panel of EPRG stakeholders and experts in the areas of pipe manufacture, pipeline design and operation with the scope to identify the most likely characteristics for the new solution to be developed. The investigated main requirements and respective descriptions are included in the following table.

Requirements	Short Description
Tag installation	The start of the tagging process of the pipe, i.e. the manufacturing step in which the tag should be applied to start tracking (e.g start of the manufacturing process, before/after coating, end of manufacturing, before/after transport, etc.).
Data	Which data are needed to be included within the tag and the architecture to be defined to collect and properly manage them along the pipe lifetime.
Tag lifetime	The tag life span, i.e. the operating timeframe in which the tag system should be able to operate without compromising its features and capabilities.
Stress conditions	The typical operating conditions of the pipe, i.e. typical environment in which the tag is expected to be operated and the conditions it will be exposed to (e.g. offshore, underground, etc.).
Database interaction	The expected kind of interaction between the new system and the existing legacy system, to properly manage the integration of a novelk system within already operating systems.
Tag geometry	The physical and geometric form of the tag as well as its location and positioning with respectr to pipe geometry (e.g. external, internal, inside coating layer, etc.)
Power supply	The suitability of including power supply to the tag solution (e.g. batteries to supply energy to active tags fro remote or long-rage communication)

Pipe thickness	The possibility to locally reduce pipe wall thickness to embed the tag on the inner or outer surface of the pipe, e.g. creating a groove to host the tag.
Suitability to the fabrication process	The possibility to tag the pipeline during/after manufacturing with minor modification to the production process itself, assuring unchanged mechanical/operating properties of the final product.
Data reading and retrivial	The possibility to access tag data through a reader device remotely or in close proximity, in accordance to final pipeline location.

Table 1 List of most relevant requirements identified by surveyors

The above-mentioned requirements have been summarized in a series of questions in order to be submitted to the stakeholders.

Ranking	Weighted average [0-1]	Criteria	Statements
1	0,51	Robustness to partial damage to the tag, in terms of tag readability (even partial)	In case of tag damage, the presence of redundant system can recover the ID pipe
2	0,35	Easily integration with existing proprietary pipe management systems of the pipe producer, pipe laying contractor, pipeline operator	The data-exchange is compliant with the actual protocols and open to new ones
3	0,30	Ability to use for onshore and offshore line pipe	The tag is robustness for offshore and on shore pipelines installation
4	0,24	Tags Robustness	Robustness of the solution in terms of resistance to mechanical agents (rubbing, friction, impact etc.)
5	0,23	Tags Robustness	Robustness of the solution in terms of resistance to environmental agents (chemical resistance and temperature resistance)
6	0,23	Ability to use for onshore and offshore line pipe	The system provides services to record the sequence of construction for off shore line pipe
7	0,23	Operability in absence of power bank	The tag can be read without power bank
8	0,20	Optimization of the installation operations and optimization strategies with traceability and availability of process information	Time spent by technicians to read the tag along the chain
9	0,20	Data availability, flexibility and updating along the whole chain	The pipe data contains a minimum set of common data (e.g. pipe number, heat number, length, cert number, date of production, name of producer, etc.) and additional reserved data
10	0,19	Speed of access to the data (connection speed and band width)	The tracking system allows preliminary data download for batch of pipes before operation

Table 2 Ranking List of the first ten criteria selected by Experts Panel

4. TECHNOLOGICAL ANALYSIS

Technological analysis has been performed by alternating scouting and experts panel web surveys activities in order to obtain a complete overview of available solutions and how they are perceived by stakeholders in the field of tagging and tracking technologies.

4.1. Scouting

Scouting activities was performed to provide a comprehensive scenario from a technical and technological point of view in the field of the tracking practices. The activities take into account the scouting of solutions already available in the Oil & Gas (O&G) sector (commercial solutions), as well as innovative and alternative solutions in early stages of Research & Development (R&D) both from O&G or other sectors.

At first, a patent analysis has been carried out and elaborated considering the most recent inventions in a temporal range of 7 years (2015-2021) querying worldwide intellectual properties database by using detailed keywords and IPC codes. The International Patent Classification (IPC) is a means of achieving a uniform international classification for patents and has as its primary purpose the creation of an effective search tool for retrieving patent documents for intellectual property offices and other users in order to establish novelty and assess inventive step or non-obviousness (including assessment of technological progress and utility) of the technical contents within a patent application.

China represents the most active country in terms of published patents followed by the United States. European patents (EP) cover a relevant share of total with an important contribution by Germany. Other representative countries are reported in the map below:

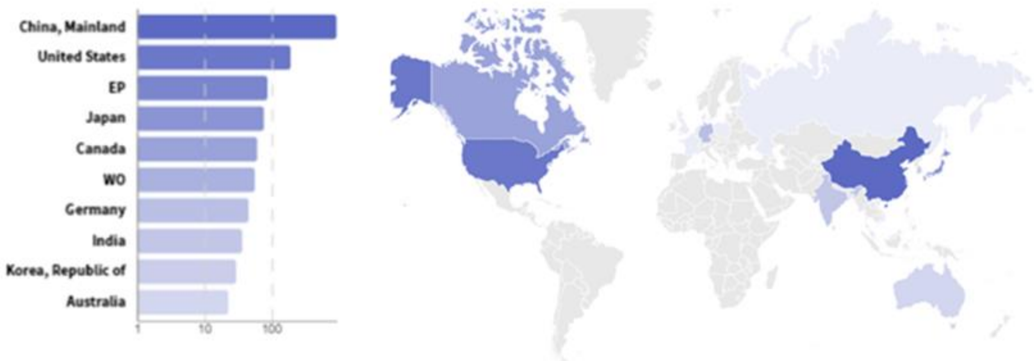


Figure 3 Distribution of published patents in the world (2015-2021)

The analysis of the most active players highlights again the importance of China-based companies and Academic Institutes. The list (Figure 4) includes also two players from US (Northeastern University and Halliburton), having published 5 and 10 patents respectively. The majority of players can be easily traced back to the sector of Oil & gas

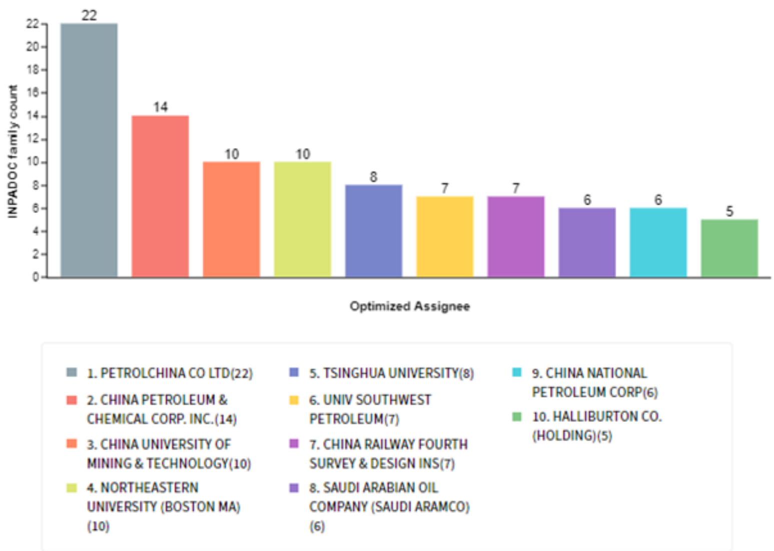
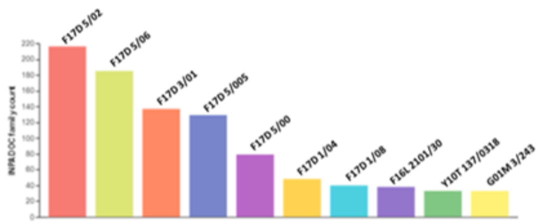


Figure 4 Patents distribution by organizations

The analysis of IPC Codes can provide an overview of the main technical fields derived from patents classification, as reported in the figure Figure 5.

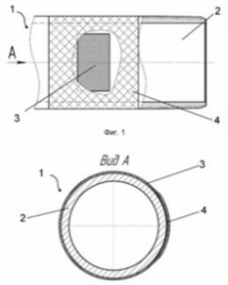
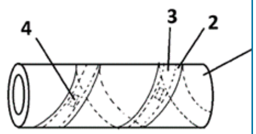
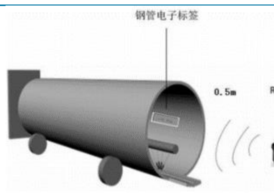
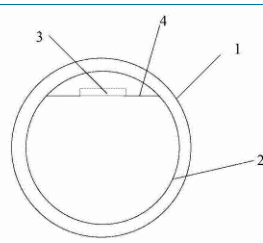
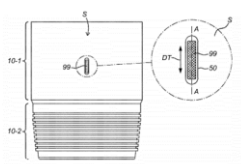


F17D 5/02	Preventing, monitoring, or locating loss
F17D 5/06	Preventing, monitoring, or locating loss using electric or acoustic means
F17D 3/01	Arrangements for controlling or supervising the conveyance of a product
F17D 5/005	Protection or supervision of gas pipelines
F17D 5/00	Protection or supervision of installations
F17D 1/08	Pipe-line systems for liquids or viscous products
F16L 2101/30	Inspecting, measuring or testing pipes
Y10T 137/0318	Fluid handling processes
G01M 3/243	Investigating fluid-tightness of pipes

Figure 5 Decision Model of the Study

The solutions identified in the scouting activity are relevant to the O&G sector mainly and they represent a collection of innovative and recent solutions for asset tracking and management by using RFID/Bluetooth communication technologies. Many of the solutions in this section involve physically altering the pipe surface/wall for embedding the RFID tag solution (e.g. Tri D Dynamics, Tuboscope, Xerafy and NOV), however this aspect must be considered in the context of final solution identification taking into account the tolerable structural integrity of a typical pipe. An alternative solution involves attaching a RFID tag to the pipe without affecting the wall thickness by using a clamp (Norma Germany) as last step before the pipe installation or by using a robust magnet (Aisino Corp) that must be resistant to handling and logistics movements. Taking everything into account, the pipe coating process must be considered and it is necessary to determine when the pipe tracking has to start accordingly with the manufacturing process. To attach a tag to a non-permanent part of the pipe (eg: pipe end caps, if any) seems to be a suitable but not valuable solution. In fact, end caps are removed and replaced quite commonly during the logistical chain, moreover, end caps are removed before coating, and the same cap is rarely put back on the same pipe it was taken from.

A brief list, as example, of the main innovative solutions identified is reported in Table 3.

Solution Provider	Short Description	Sector	Figure	Strength Points
EchoRFID www.echorfid.com	Method and software tool for collecting and organizing RFID data from utility assets, including pipelines. It uses passive UHF RFID tags installed on the pipes	Asset management software and solutions		Integrated software-hardware solution for data collection after pipe installation
Shawcor https://www.shawcor.com/iline	RFID end caps technology, in order to tracking and tracing pipes from manufacturing to installation, protecting at the same time the system from damage.	Asset management and inspection		Traceability of pipe data from the end of manufacturing to installation
Research And Production Center Samara (RU) Patent: RU194449U1	RFID tag (or Near field communication as an alternative) hosted on the outer side a pipe and covered by a thermoplastic casing, ensuring good RFID communication.	O&G, Refining		Embedded RFID passive tag with thermoplastic cover
Smart Textiles Sp Zoo Patent: EP3522138A1	RFID labels for object identification attached to the outer side of pipes and covered by thermoplastic material layer.	Thermoplastic pipes		RFID tags included in a strip for simple application on outer side of the pipe
Aisino Corp Patent: CN111178475A	Magnetic electronic label with RFID system for asset tracking in steel pipe manufacturing.	Steel pipes manufacturing		RFID magnetic tag for asset tracking during manufacturing
Guangzhou Xingya Plastic Pipeline Co Ltd Patent: CN205261043U	Thermopastic pipe including RFID and GPS chips on the inner side. The RFID chip can act as sensors to monitor parameters, while GPS chip provide exact location.	Pipeline infrastructures		RFID tag included in the inner side of the pipe No external element subject to damage
Tri-D Dynamics www.triddynamics.com	Digital components physically embedded within the walls of the metal pipe via additive manufacturing. Plug and play sensor nodes (e.g RFID, temperature sensors) are distributed along pipe with data and power transfer cables,.	Advanced manufacturing		Sensor node or tag included in the pipe body Possibility to insert cables based on the sensor types
Tuboscope Norge As Patent: US10619423B2	The piping comprises a Radio frequency identification (RFID) tag for identifying piping embedded on the external side of the pipe, in a dedicated groove.	O&G, Drilling		External RFID tag embedded in a groove No modification on the external geometry, with modification on pipe section

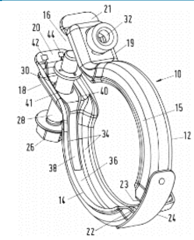
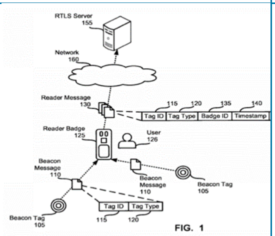
Solution Provider	Short Description	Sector	Figure	Strength Points
Xerafy https://www.xerafy.com/	RFID tags added to existing inventory as a retrofit, or directly embedded by manufacturers in their tools, equipment, pipes and other field assets.	O&G, Drilling		External RFID tag embedded in a groove No modification on the external geometry, with modification on pipe section
NOV Inc. https://www.nov.com/products/tracid-drill-string-life-cycle-management	Field-proven RFID technology and proprietary software solutions, Tags are installed during manufacturing or retrofitted into existing drill pipes.	O&G, Drilling		External RFID tag embedded in a groove No modification on the external geometry, with modification on pipe section
Norma Germany Gmbh Patent: WO2021023705A1	A clamp system with RFID for asset identification, in which the RFID is activated only in case the clamp is closed	Engineering, automotive.		RFID embedded in pipe clamp
Tile Tracker https://www.thetileapp.com/en-us/	Companion mobile app for smartphone to track the devices and locate lost items through Tile (tag) Bluetooth 4.0.	Consumer electronics		NFC solution for object tracking and tracing, with high accuracy. Active solution need power supply (e.g. batteries)
General Electric Company Patent: EP3563385A4	Apparatus, based on active RFID tags embedded in the personnel badge, monitors asset in healthcare environments.	Asset monitoring in Health sector		NFC solution for object tracking and tracing, with high accuracy. The system can be developed for industrial sector

Table 3 List of of the main R&D O&G and other sectors solutions

4.2. Expert Panel final review

The experts panel has been involved into a online final web survey based on the results of technological analysis of R&D and commercial solutions regarding tagging and tracking systems for pipes. The main important nine topics have been extracted from the previous studies in order to submit them to the different stakeholders of O&G pipeline, from production to commissioning.

Q1- When to start the tagging process of the pipe

The answers to Q1 appear split between the possibility to start the tagging process at the start of the manufacturing process (53.33%) and the alternative solution of starting the tagging at the end of the manufacturing (46.67%). At first, it is possible to indicate that the starting of the tagging from the beginning of manufacturing would mean a significant problem with existing legacy systems at the manufacturing plants and should be carefully evaluated. The analysis of answers by category of respondents indicates that EPCs agreed on the need of starting the tagging at the beginning of the manufacturing, while Manufacturers and Operators answers are equally split between the two alternative options, with a slight preference for the start at the beginning of manufacturing for Operators and at the end of the manufacturing process for Manufacturers. Starting at the beginning of manufacturing, while possibly desirable for the purposes of tracking manufacturing progress, may be too much of a change due to the investment in bespoke manufacturing execution systems.

Q2 - Tag functionality

The answers to Q2 clearly suggests a preference from all respondents: an online record database, collecting the anagraphical and operating data of pipes along its lifetime. A similar architecture could be realized through the adoption of a Cloud-based infrastructure. Given the strong preference hereby identified by respondents, another aspect should be further clarified, related to the entity that should be responsible for tagging system management along the value chain and pipe lifetime. This role could be covered e.g. by the pipe manufacturer, or alternatively by an industry body, in charge of this infrastructure for all registered manufacturers. However, there is a question over extent of responsibility if this were the case – the pipe manufacture could only be responsible for data pertaining to the time when the pipe was in their control. The same argument applies to the coating process and even the EPC contractor. Ultimately, the main take away from this question was the need for an online database to be maintained by a declared entity.

Q3- Typical life span of a tag/pipe

Regarding Q3, most of the respondents (60%) agreed that the tag to be adopted should have a life span comparable to the lifetime of a pipeline, i.e. greater than 15 years. Other respondents, however, indicated that also shorter life span could be considered. The analysis of answers reveals that all the respondents indicating shorter life span belong to the category of Manufacturers.

Q4- Typical environment/operating condition

Responses to Q4 show that all possible environment and operating conditions are covered, highlighting the need for a robust and reliable solution. At the same time, the most recurrent answers identify the typical parameters of gas transmission lines with moderate applications as the most representative use case. The fragmentation of answers, as well, indicates that the solution to be developed would need to focus on the possibility to address all possible operating and environmental conditions.

Q5- Interaction between new system and the existing legacy system

Respondents indicated in Q5 answers that the preferred interaction (66.67%) between the new system and the existing legacy system should be based on automatic data entry. At the same time, 40% of replies indicated a supplementary system, based on the integration of automated and manual data entry, as an acceptable solution, and this should be probably more realistic and simpler to be implemented in the short term. Minor preferences were given to manual data entry (6.67%), the complete substitution of currently existing systems (6.67%) and no interaction with manufacturers legacy execution systems (13.33%).

Q6- Physical form and location for tag

Responses to Q6 clearly identify the external attachment of the tag as the preferred option, being alternatively applied on the bare pipe (66.67%), after final corrosion coating (66.67%) or after any CWC (46.67%). The complete analysis of answers shows that 4 manufacturers and 1 operator indicated the possibility to include the tag as an internal attachment to the pipe. This could indicate the need to have the tag applied in a location where it could be better protected during manufacture and shipping, and the search for a solution not requiring reapplying the tag during coating or CWC, allowing the tag not to interfere with pipeline operation. Internal application of the tag does bring concerns re impact on flow, however, and it is felt that answers to this question would lean towards external eventually.

Q7- Need to avoid any localised reduction in wall thickness

The responses to Q7 show a clear preference to avoid any type of localised reduction in wall thickness and this should be related to the importance of avoiding any change to mechanical and structural integrity or the pipe. There were 20% of respondents (including an operator and two manufacturers), however, who indicate that reducing wall thickness could be a feasible option and do not exclude this possibility. This aspect should be further deepened with the experts of the sector and in particular with the involvement of experts focused on structural integrity issues.

Q8- Concern if the tag requires to be powered

The answers to Q8 appear split between respondents indicating that the tag power supply could be a relevant concern and respondents indicating that no major concerns are foreseen for the power supply point of view. Moreover, this requirement needs to match with the life span of the tag, indicated in Q3 to be preferably longer that 15 years. These indications seams to identify that the most promising option could be a passive tag, that did not require any external power supply and could last over the identified lifespan.

Q9- Optical reading of tag

The final question Q9 clearly identify that the preferred solution must include non-optical reading, paving the way to technologies based on radio-frequency communication and excluding the solutions based on optical reading only

5. SWOT ANALYSIS

The combination of the general requirements and the recommendations, by the results of experts' survey, identified different solutions for the pipe tagging and tracking system. In particular, three main solutions have been defined by selecting the more suitable technologies available in the market (Table 4).

Each solution has been defined through the combination of the technology/recommendation that matches with the specific requirement.

The proposed solutions share the same technology for the requirements of Tag type (RFID), Lifecycle (system available for more than 15 years) and Data Architecture (storage and management in cloud). Different approaches are adopted for the requirements of Tracking start (bare pipe or after coating), responsibility for the system management (manufacturer or industry body) and software integration (automatic or combined with manual operations).

	SOLUTION 1	SOLUTION 2	SOLUTION 3
Tracking Start	Bare pipe	After coating processes	After coating processes
System management	Manufacturer	Industry Body	Industry Body
Legacy SW Integration	Automatic data entry	Supplementary (manual & automatic)	Automatic data entry
Architecture	Cloud (European Pipeline Tracking Database)		
Life	>15 years		
Tag Technology	RFID		
Sensors	Passive	Active	Passive

Table 4 Technical solution identified for tagging and tracking system

SWOT analysis is carried out for each of the identified solutions to highlight the most relevant positive and negative points of attention related to the identified solutions and identify the most promising characteristics for the tag and track solution to be developed.

The SWOT analysis (acronym for Strengths, Weaknesses, Opportunities and Threats) is a useful instrument to support early stages of decision-making processes, supporting in identifying the internal and external factors that are favorable and unfavorable for each of the systems analysed

The **first solution** takes into account the application of tagging in the whole pipe chain. In this case the tracking will start at the beginning of the manufacturing processes and the manufacturers play a fundamental leading role in the management system, providing a new service to the whole value chain. The management of system by the manufacturer is also related to difficulties for the adoption of the solution and the correct update of data along the entire value chain and to a technical challenge for the manufacturer, in particular referring to automatic data entry.

In this solution the cheaper RFID passive tag is the best choice to adopt as system tagging with the possibility to change and replace it during the transformation processes of the pipes.

The adoption of passive RFID tags, with no need of embedded power supply (i.e. batteries) as well as the maturity and robustness of the RFID technology represent a point of strength for the solution. Moreover, the absence of batteries allows to maintain compact dimensions of the embedded system, limiting the need of maintenance along its lifetime. Finally, form the hardware point of view, the application of a surface coating allows to protect the tag from external wear and tear, preserving functionality along its lifetime and enabling the adoption of the tag in challenging environments (i.e. high pressure, temperature).

The cloud architecture allows to access data remotely, managing and monitoring asset data from a centralized common platform assuring a for real -time access. The cloud could be also related to threats deriving from external data theft or cyber-attacks that should be carefully taken into consideration and managed. The adoption of a passive tag is also related to some weaknesses, mainly related to short range communication, the need of an external reader device and low accessibility, in case a coating is applied, when maintenance interventions or controls are required.

STRENGTHS	**WEAKNESSES**
- Long lifetime (passive RFID) - Compact dimensions - No battery required - RFID is a robust and mature technology - Cheaper solution - No maintenance required - Cloud architecture enables remote data access - Tag protected by coating application, not subject to wear and tear	- Short range communication - Need of an external reader device - Coating removal needed in case of tag substitution due to tag failure - Pipe manufacturer involved in the whole system management along the product value chain - Unlikely that tag could be applied and remain on pipe from start to end of manufacture due to contacts, environments and handling associated with pipe manufacture - May require multiple reapplications - Ability to integrate with legacy systems
OPPORTUNITIES	**THREATS**
- Automatic data entry should simplify data collection and aggregation - The coating enables the adoption of the tag in challenging environments (high pressure, temperatures) - Opportunity for manufacturers to provide a new service to the value chain	- Difficulties for the adoption of the solution and the correct update of data along the entire value chain - Automatic data entry represents a technical challenge for manufacturer in charge of system management - Cloud architecture could be affected by external data theft or cyber attacks

Table 5 SWOT analysis for the first solution

The approach of **second solution** is to start the tagging process at the end of manufacturing process. This solution reduces the problems deriving from the inclusion of the system in an early stage, avoiding to be submitted to production processes of the pipe and allows the application of higher performing tags to the pipes in order to exploit the full potential of active RFID.
Active RFID tags can communicate over long range distances with no need of a nearby external reader device, but the presence of a battery for power supply imply the need of battery recharge or substitution, making maintenance and other interventions more frequent. The solution is also characterized by larger dimension and slightly higher costs with respect to passive tags.
At the same time, the adoption of active tags paves the way to the contemporary integration with partnered technologies (GPS, sensors, etc.), increasing the potentialities of the overall system.
In this case the system management should be administrated by industry body that ensure data validation along the value chain, while the manufacturer should only provide to the system the main data for the pipe history. This data update could be provided offline and in an automatic way by software interface with the production systems. Also, in this case cloud architecture allows to access data remotely, managing and monitoring asset data from a centralized common platform assuring real -time access. Although, as already mentioned, the cloud could be also related to threats deriving from external data theft or cyber-attacks that should be carefully taken into consideration and correctly managed

STRENGTHS	WEAKNESSES
- Long range communication - Direct communication with no need for external reader device - RFID is a robust and mature technology - Easy access for maintenance or battery change - Cloud architecture enables remote data access - The system management by industry body ensure data validation along the value chain	- Shorter lifetime with respect to passive tags (in case of use of a battery) - Power supply needed (battery or wired) - Active RFID is a pricey solution - Larger dimensions - The tag may be exposed to wear and tear
OPPORTUNITIES	**THREATS**
- Opportunity for industry bodies to provide a new service to the value chain - Increased tag abilities with partnered technologies (GPS, sensors, etc.) - Supplementary data entry enables a short term adoption	- The external tag must be protected by the end-user taking into account the environmental conditions - Cloud architecture could be affected by external data theft or cyber attacks - Supplementary data entry could be influenced by human factor (eg: errors, timing)

Table 6 SWOT analysis for the second solution

The **third solution** adopts the same approach, tagging start after production, but reduces the risk of active RFID tags by substitution with passive ones.
This solution is designed to reduce the technological and managing risks of the entire system, adopting the cheapest and safest technologies to be able to keep the tracking system as efficient as possible over time.
In this way the system reduces all the automatic solutions of data reading and communication leaving the execution of many operations to the human operators.
Unfortunately, this approach increases the possibility of introducing errors and threats into the system.
As said for the first solution, the passive RFID tag represent a robust and mature technology with no need of embedded power supply (i.e. batteries) allowing compact dimensions and limited need of maintenance interventions along its lifetime.

In this case, too, cloud architecture enables remote access to data, as well as managing and monitoring asset data from a centralized shared platform with real-time access. As previously stated, cloud computing may be linked to threats arising from external data theft or cyber attacks, both of which must be properly considered and managed

STRENGTHS	**WEAKNESSES**
- Long lifetime (passive RFID) - Compact dimensions - No battery required - RFID is a robust and mature technology - Cheap solution - No maintenance required - Cloud architecture enables remote data access - Tag protected by coating application, not subject to wear and tear - The system management by industry body ensure data validation along the value chain	- Short range communication - Need of a nearby reader device - The tag may be exposed to wear and tear
OPPORTUNITIES	**THREATS**
- Automatic data entry should simplify data collection and aggregation - Opportunity for industry bodies to provide a new service to the value chain	- The external tag must be protected by the end-user taking into account the environmental conditions - Automatic data entry represents a technical challenge for manufacturer in charge of system management - Cloud architecture could be affected by external data theft or cyber attacks

Table 7 SWOT analysis for the third solution

The solutions described before represent most relevant options for the pipe tagging and tracking system defined by selecting more suitable technologies available in the market: the solutions have been shaped based on the combination of the general requirements identified by the present study as well as the recommendations resulted by the collection of experts' opinion and feedback thanks to their direct engagement through the survey. These solutions cover quite well the scenario of possible alternatives, representing with a good approximation the different technical and operational pathways that could be followed for the development of a pipe tagging and tracking system. At the same time, the solutions above presented are not intended to be the sole solutions possible and a range of other alternative "hybrid solutions" could be envisaged, including different combination of the technical features and elements described.

Finally, considering all the spectrum of possible solutions, it is possible to identify very distinct and common questions that should be taken into account prior to the design and development of a common tagging and tracking solution across the industry. These questions are:

1. When to start the tagging and tracking? (Including the definition of aspects related to managing the tag impact on the pipe/coating and the legacy systems at each manufacturer or other stakeholders affected)
2. What technology to use? (Including all the practical implications derived form the selection of a specific technological solution, e.g. passive/active, RFID/other, etc)
3. How to manage and access the tracking information? (Identify common strategies for data management and acces, at diffent levels including European/Global approach or parochial to the single manufacturer)

Only once consensus on these questions has been achieved within the affected industrial community, it will be possible to start working on the identified pathway towards the common pipe tagging and tracking system.

6. RESULTS

The main result of the activities of this project is the definition of three different technical solutions for a common non-proprietary platform for pipe tagging and tracking system that matches the main technical requirements and at the same time the recommendations of the stakeholders and experts.
These solutions are the result of a preliminary technological survey, used to identify the better suitable techniques, and the consultation of an Experts Panel (composed of Manufacturers, EPCs and Operators) to address the main recommendations for the technical application.
In accordance with the requirements and the recommendation recommendations emerging from the results of experts' survey, the general solution identified is based on the robust and mature RFID technology, for pipe tagging, with its flexibility in the pipe application and its readability (non-contact technique). The data management should be organized in a cloud system in order to assure a common platform for real -time access that should be maintained for all piping supply chain cycle (> 15 years), from manufacturing of single pipe, its coating, girth welding and finally to its installation and maintenance.
Compliance with the recommendations of the experts, three distinct solutions have been identified and all of them are based on the previously defined general pillars.
Each proposed solution is now not available in the market as a single commercial product, but it is a combination of different offers of sensors, hardware equipment, software and tracking system integrated just in a partial area of the tracking pipe chain.
Therefore, the implementation of one of the selected solutions requires an integration of different market products already available with the opportunity to develop additional features to resolve the actual threats that emerged in the SWOT analysis.
In particular, the choice of suitable RFID tags and their integration into the general data acquisition systems could require a preliminary step of validation to assure the respect of the requirements defined in this project. Additional protection solutions could be adopted for the tag in order to resist the environmental conditions. In this framework it is fundamental to highlight as each type of RFID tag presented in the present report is characterized by different pros and cons and each solution need to be customized and engineered according to the specific use case and it is not feasible to identify an absolute best solution. A number of question are related to the specific pipe application, for example: the form of the tag (i.e. flat RFID adhered to surface or not), subsea/underground applications, long distance readability, interference with thick coatings (e.g. in case wet insulation is needed) or concrete weight coating and sensitivity to heat tracing just to name few.
In case of critical scenarios the RFID tag can be supported by operational procedures and other variables in order to assure the pipe identification. This is the case of the pipeline construction where each pipe is welded, placed and it won't be removed for a long time. The tracking of the construction operations and the use of GPS coordinates can replace the identification of pipe in case of RFID could not be yet readable after many years. This example proves that a robust tracking system must take advantage of both hardware tools but also a good organization of the data.
Another critical aspect of the data cloud solution is the security from theft and cyber-attacks. For this reason, the complete data chain, based on market solutions, must be evaluated, tested and strengthened at the most critical points for entering and reading data. An industry body willing to take on the overall responsibility is not a simple issue to solve. As to when to start tracking, the resistance to dropping bespoke and established systems will be significant, and unlikely to be supported. However, if both questions are considered together, another solution could be considered.

In summary, the three primary conceptual questions that need consensus within the affected community before the starting of solution development are: When to start the tagging and tracking; What technology to use and How to manage and access the tracking information.
During this study a roadmap to implement a common European Pipeline Tracking System has been designed in three main steps:

A. Design and realization of a common European Pipeline Tracking Database (EPTD) as repository of the pipe tagging & tracking data with interfaces for read and write it.
B. Hardware development of tag sensors and reader systems to apply to the tracking route according to the solution chosen and the starting phase.
C. Development of tools and models for data analysis devoted to the supply chain optimization and to support the decision-making processes for the manufacturers and stakeholders involved in the tracking route. This pillar is an add-value based on the exploitation of the repository data that can be available by the realization of pipe tagging & tracking system.

In Figure 6 the estimated roadmap for the implementation of a common European pipeline tracking system.

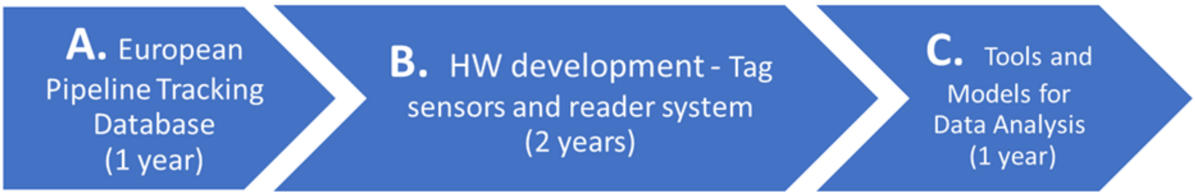


Figure 6 Roadmap of realization of the Pipe Tagging & Tracking System

The results suggest performing a first feasible step for the realization of the EPTD cloud system (phase A). as the backbone of every solution and therefore it is the first step in any implementation of a common tagging and tracking system. The EPTD system, composed only of software components, will communicate with stakeholders own tracking systems in a seamless way, and will provide functions to reconstruct the whole history of the pipe during all production, treatment, shipping and installation steps. Each stakeholder can provide a tag at the end of their process for each pipe and upload agreed data into EPTD secure cloud location, then said data could be accessed by anyone with a reader. In this way, any data pertaining to bare pipe manufacture would be uploaded by the pipe manufacturer and this database will be accessed via the unique pipe identifier (number or via RFID/QR code etc). The pipe coater would address any coating data and manage via a separate RFID/QR code. The same could apply to shipping, installation and maintenance steps. The only downside of this would be that there would be multiple RFID/QR tags, and anyone reading them would need to know the difference. In such a scenario, the potential usage of blockchain technology to validate and store pipe data could be evaluated.

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