Information Society

CERP

Cluster of European RFID Projects

Working Paper on future RFID Research Needs

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1 Introduction

The “Cluster of European RFID Projects“ (CERP) was established in January 2007 in order to collect and organise all relevant research results obtained in recent and current European research projects on RFID, while also making use of the expertise built-up in the project teams involved and identifying and building upon synergies across projects.

Understandably, CERP participants had to focus more on application domains and research topics already identified or even verified in the frame of their respective projects: Their first conclusions, including the “research roadmap”, therefore only cover a portion of all those application domains which RFID may cover in the long term future and only a subset of all the research fields and topics that need to be explored and addressed in order to realise the RFID vision.

Even if the focus of the CERP group is defined within the frame of the aforementioned limitations, there is already evidence that RFID is no longer just a futuristic vision – but rather a technology, which is now being deployed in many industry sectors. As an example, two large European airlines are already preparing a switch to RFID solutions for improving passenger baggage processes at their main hubs. If they go ahead only months after the bar code technology has finally reached IATA-wide implementation, then they must have determined that only RFID will both bring the substantial further process optimisations and meet the increasing security requirements which their industry requires.

In a similar manner, a wide array of other B2B applications, mainly in the manufacturing and logistics industries, and in the retail area have progressed in all necessary technical and organisational matters, to the point where the go-ahead for a large-scale implementation is only months away. All these “realistic RFID domains of the next future” have in common that:

a) there is general consensus among their essentially B2B stakeholders regarding the essentials (technology, standardisation requirements, rules), and

b) their potential returns include not only the positive economics for their stakeholders but also quite tangible improvements that also benefit the general public and wider community: A more efficient supply chain, for instance, may by itself contribute to substantial energy efficiencies, while eliminating bogus parts in airline maintenance and fake medicines in the supply chain for health products will directly benefit transportation safety and public healthcare.

Regarding “RFID domains for the farther future”, i.e. with a time horizon between “medium term” and “futuristic”, it is obviously more difficult to determine where vision supersedes realism. Some essential features are known: For instance that there must be a paradigm change from the – relatively – simple “identification of objects at a distance” which may suffice in the current supply chain projects, to the much more challenging “communication between objects” and the even more challenging “distributed intelligence (or Internet) of things”, which implies that there must be a scaleable, efficient, reliable, secure and trustworthy infrastructure, in order to link all involved objects. This is ***challenge 1*** in the ICT FP7 Programme.

This in turn implies that the “intelligence rules” by which the linked objects will react must have been defined and analysed (***challenge 2***), that hardware and software components both for the network and the interacting objects have been developed, and made available and affordable on a wide-scale (***challenge 3***), and that the complex sets of rules and protocols governing all the interactions can be accessed with the required speed and quality (***challenge 4***).

These four challenges are of a rather scientific nature, and can only be met through a combination of both fundamental and applied research efforts.

Regarding the domains of application for such an “Internet of things”, the current vision has selected three, which constitute “***application challenges 5 to 7***”.

- healthcare
- independent living
- mobility

They all call, albeit to varying degrees, for an “Internet of things for the citizen”, putting the citizen at the centre of the new scenarios. (Note that the citizen does not play such a central role in the substantially “riper” B2B scenarios already under development). In other words, acceptance- and “political acceptability” as well – will be of paramount importance for realising these future visions.

This means that the technological research into antennas, decision rules, network structures, etc. will need to be complemented by research – both fundamental and applied - into human behaviour and drawing from all human and social sciences, including psychology, health, education, and other social aspects such as privacy, which “pervasive networks”, even for things, may increasingly put at risk.

For example, it is certainly plausible that an “Internet of intelligent electrical appliances and mains plugs” may substantially reduce the energy needs of the average household, e.g. by replacing so-called stand-by modes and other wastes of energy. Additionally, an “Internet of moving things” may avoid collisions and reduce traffic jams.

However, the full potential of such an intelligent environment will only be fruitful if the user/consumer/citizen gives his proactive support: Transferring the “collision avoidance system” of civil aviation into millions of cars by the way of an Internet of cars will only lead to similar very positive results, if the public can be persuaded that no Big Brother shall be watching them, while their too frequent behavioural excesses are being brought under control.

The projects of CERP compiled this paper on RFID research needs according to their expertise within the following RFID application fields[1]:

- Logistical tracking & tracing
- Production, monitoring & maintenance
- Product safety, quality & information
- Payment

For each RFID application field the state-of-the-art, a vision, and as result a gap analysis and the according research targets are depicted.

[1] A detailed description of these RFID application fields can be found at: www.rfid-in-action.eu/public/rfid-reference-model

2 Logistical Tracking & Tracing

2.1 State of the art

Information is of primary importance in logistic processes. Improved transparency makes information on the location and availability of materials and equipment accessible to all authorized stakeholders regardless of their location. This development is promoted by the implementation of automatic identification and tracking systems. Classical inventory systems keep track of lots or batches, whereas RFID systems allow the unique identification of items and a shift to a 'per unit' or serial-level inventory system, which allows the tracking of individual items throughout the supply chain. This poses new requirements for the existing IT systems. Integration of the RFID system in existing IT systems, such as ERP systems, is critical to the success of the implementation. Different commercial applications are available.

In this context, RFID can be seen as an enabling technology for automatic tracking and tracing systems. To date, RFID has slowly started to replace and complement manual labels, trading stamps, barcodes as well as methods based on optical character recognition. However, barcode technology is by far the most widely adopted technology for identification in logistics applications.

International retailers like Wal-Mart, Metro Group and Tesco are leading the development and have boosted the introduction of RFID in logistics by mandating their largest suppliers to implement RFID on containers and pallets. Because of this, the retail sector has become a global development environment where the RFID solutions are being tested, piloted and implemented. Other business sectors are closely following these experiments and making preparatory work to utilise the new technology. Effective utilisation of RFID may require large changes in the existing processes, a fact that potential users might not have considered.

Until now, RFID applications have mostly concerned separate, closed and in-house systems. The use of passive UHF RFID technology is increasing the most rapidly, due to the low price, good standardisation situation and sufficient performance (3-4 m reading range). Due to their increased use, UHF RFID tags which are designed for specific applications (e.g. mounting on metal) have also become commercially available. A growth in active RFID technology is foreseen in RTLS (Real Time Location Systems), due to improved standardisation, lower prices and the possibility for integration with existing IEEE 802.11 (WLAN) infrastructure.

RFID development has mostly concentrated on components. As the maturity of RFID systems improves, the type of products which vendors offer changes from individual tags and readers to completely integrated systems (complete environment of identification portals including antennas and interfaces to existing IT systems).

Even though the focus at present has been on tracing the higher level logistic units (containers, pallets) pilots involving item level tagging of products sold to consumers (open loop, B2C) have been introduced. This could dramatically extend the use and potential of RFID applications towards the end of the supply chain. This has aroused concern among some consumers who are worried about their privacy. Consumer protection organisations are advocating a policy whereby the consumer should always be told when an item contains an RFID tag and have a choice to have it removed or destroyed (or deactivated).

Ratification of the EPC UHF Class 1 Gen 2 Standard at the end of 2004 and the ISO-18000-6C based on the Gen 2 specification in 2006 has removed a major obstacle to the implementation of low-cost RFID. In addition to the technology standardisation, efficient utilisation of RFID requires agreement between stakeholders on common modes of operation. Interoperability will be particularly important in global supply chains.

More pressure and demand for new identification solutions are generated by the new modes of operation such as pull-based flow control, reducing inventories, legislation (tracking of food, pharmaceuticals etc.), cost reduction, automation, communication between partners and visibility of the supply chain, decreasing waste and improving security. The main factors that have slowed down RFID implementation are the investment costs which are regarded as high and the uncertain expectations for the return on investment (ROI). There is not enough or not specific enough information about the benefits, especially for manufacturers and suppliers of parts, who bear the cost of tagging. On the hardware side especially the UHF readers are rather expensive. Unsuccessful pilots with low readability rates have created an image of immature technology for passive UHF RFID technology and delayed implementation, although there are also reports of continuous improvements in the technology, especially when the latest firmware modifications are applied to readers.

2.2 Vision

Automatic identification develops towards systems, which can read the IDs of all products automatically without the need to stop the process or manual intervention. The technology used has to be able to read each of the individual tags.

The long term vision in logistics is a system providing the necessary real-time information on the supply chain, this information being extensively utilised. RFID is the key technology to make this happen. Real-time information on the location, contents and conditions of individually identified shipments, products, transport units, and transport vehicles can be gathered in a controlled manner. The collected data can be combined with the planning information and processed into appropriate information to be used at different stages of the process. Product history will become available via B2B networks. The information can be distributed effectively and in real time to the stakeholders.

The price of RFID tags will decrease below 5 cents and item-level tagging will be applied on a larger scale. Miniaturised reader modules and microchips promote the integration of RFID readers into mobile phones and PDA devices. Also the prices of readers will decrease (100–200 € ?). RFID will be integrated with other systems for improved performance and RFID based applications and services will strongly increase. This development will be assisted by the improved capacity of computers and networks and ubiquitous sensing. RFID will become part of the product design and will thus be an elementary part of many products. Legislation, regulatory and quality demands will set requirements for certain branches (pharmaceuticals, explosives, transportation of dangerous goods, foods, etc). Cold chain compliance is a key requirement for pharmaceuticals, hospital transfusions, clinical trials, foods and perishable items. RFID can be used to fight counterfeiting and RFID can be used to enable compilation of an electronic pedigree of a product.

RFID systems provide item and product visibility within the supply chain. This visibility can further be translated into actionable data and predictive changes with additional information attained through sensors. RFID transponders with sensor functionalities (active, semi-passive, passive) will be developed, which will further enhance their usability and applications. As an example, they will allow the automated monitoring of transit and environmental conditions through the supply chain. Intelligent sensors can combine sensing, computation and communication into a single, small device. The future vision for RFID technology consists of completely automated sensing networks that can react to external changes in real time. Printed RFID solutions will decrease the price of tags and help in integration of antennas, batteries, sensors, displays, keypads etc.

In the framework of the RFID Roadmap project in Finland in the beginning of 2006, a survey on the use of RFID in logistics was sent to major actors in Finland in the logistics sector and the RFID industry, to which 49 answers were received. The national Finnish vision 2015 for different identification levels predicts the following:

Transport

- All transport units and vehicles can be identified automatically. All vehicles are equipped with tags.
- Tracking and tracing as well as incident management of vehicles and valuable goods is in use (satellite positioning, in terminals)
- Agile transport control is in use
- Electronic transport documents are in use. These support the use of RFID identification.

Transport items / units

- Major RFID solutions of industry and trade are in use
- Other types of applications are also in use (in situations where RFID is less suitable or more challenging e.g. bulk, metal, liquid etc.)
- Standards and codes exist and are in use
- Information system integration exists

Products

- On product level valuable goods, certain food products, clothes, electronics, dangerous goods are equipped with tags
- The price of a tag is under 5 cent

Personnel

- RFID is widely used for access control

2.3 Gap Analysis

Doubts about the maturity of technology and standards were still the biggest concerns of potential users in 2006. Also costs and benefits, which can not be verified, slow down the implementation in logistics applications. According to the RFID industry, improvements in standardisation and performance in the recent years make RFID ready enough for implementations, but this message has not yet been assimilated by potential users.

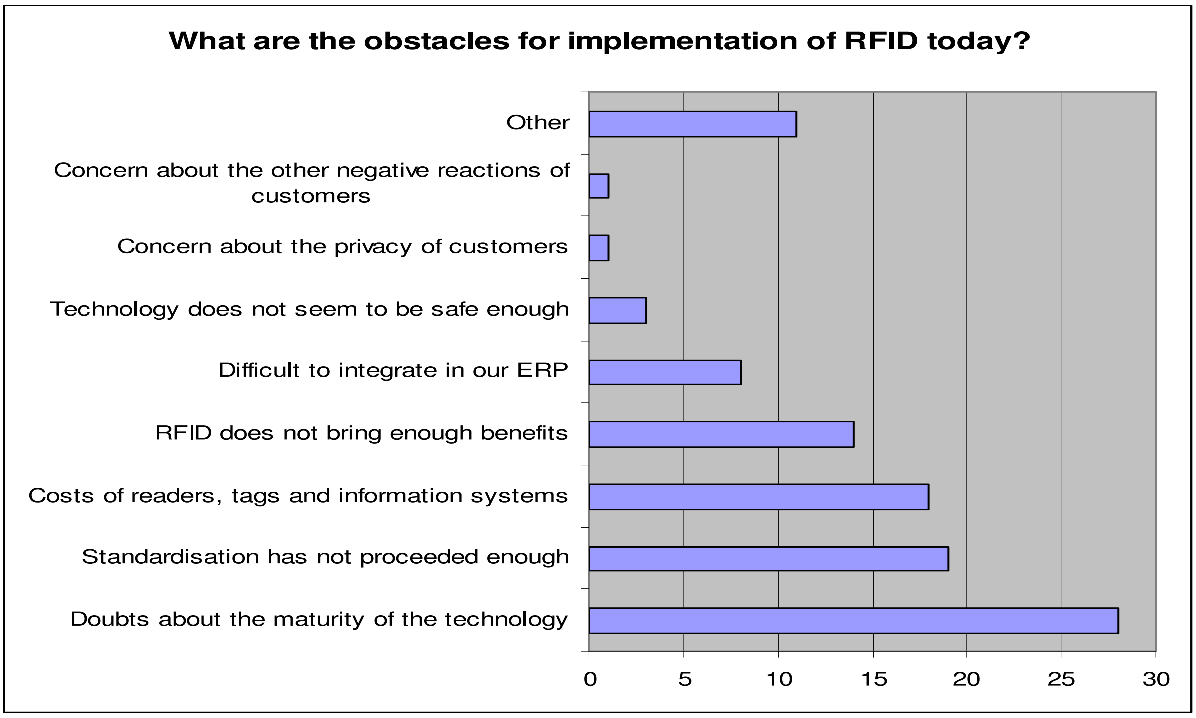
In the logistics sector, the introduction of RFID technology is expected to start from the side of retail but a better target could be e.g. technical wholesale. Retail trade has also bad experiences from earlier pilots. Consumer Packaged Goods, consumer electronics, healthcare, pharmaceutical, aerospace and defence and high-tech industries will be the first adopters.

The company management has the key role in investment decisions and implementation. The benefits and ROI should be justified to them. In any case RFID will be implemented first in closed systems. Companies should put effort into wider and more open logistics applications and multi actor supply chains.

EPC and RFID hold great promise for the automation of product identification within the supply chain. At present, companies are implementing RFID technology with great expectations for its far-reaching potential to improve operations. Many valuable uses for product information have been envisioned, but new innovative applications are needed to turn such ideas into reality. The next stage of RFID development requires data sharing among multiple partners calling for a new generation of network applications that help companies store, share, and secure RFID generated data over the EPCglobal Network.

Large R&D efforts and new standards are needed for the vision on RFID based sensor networks to come true. The EPC Network standards provide for subscription to observation-based event data across the supply chain – but do not yet manage access to sensor data.

Standards for re-routing options and pro-active alerting need to be developed and adopted. In many branches and industry sectors, standards are needed to agree on common modes of operation. Standards covering all industry sectors are not available. Interoperability of systems including hardware and software interfaces needs to be improved. The overall costs of RFID technology need to come down.



Source: RFID Roadmap project in Finland in the beginning of 2006.

2.4 Resulting Research Targets

Technological research: Hardware (tags, readers, embedded systems)

- The overall system performance needs to be improved: the target of 100% readability is a real challenge. Especially in environments with a wide variety of products (material, size, orientation,…) the use of RFID is very challenging. High readability is needed to avoid the use of backup identification systems, mainly involving manual intervention.
- Tags suitable for harsh environmental conditions and processes (extreme temperatures, vibration and shocks, outdoor conditions, chemical substances, etc.)
- Tags operating in metallic and moist environments (metal packages, liquid containers, etc.)
- Miniature tags with higher operational range (e.g. high frequency: 2,45/5.8 GHz, near field tags, etc.)
- Low power integrated circuits to increase operational range (passive tags) or prolong battery life (semi passive, active tags).
- Multi-protocol, multi-frequency integrated circuits and appropriate antenna solutions for tags
- Integrated circuit with sensor interfaces, integration of batteries, displays, keypads …
- Improved security features for passive UHF tags. Authentication between reader and tags, data security, etc.
- Smart systems, e.g. sensor enabled tags, tags with displays (to read data without using a reader), and integration of actuators.

- Ambient intelligent RFID systems: distributed/decentralised data processing and storage, extensible data structures on tags to allow integration of RFID in different applications.
- Low cost reader modules and ICs to help miniaturisation and integration and reduce costs of reader devices.
- Improved reader performance: higher operational range, higher dynamic range, improved performance under interference and in multiple reader / dense reader situations, adaptable RF front end to cope with reflections and detuning, improved antennas, etc.

Technological research: Software/System aspects

- Ensure data security and integrity in large networks (e.g. by defining reading/writing rights, access authorisation => safety and security aspects).
- Ensure data quality (implementation of business logic and edge computing to deal selectively with large amount of data, e.g. data transformation and data mining).
- Integration of RFID-systems into different applications (e.g. business applications, payment via cards and telephones (e.g. combination of GSM with NFC-functionality)).
- Solutions that can be used to reduce counterfeiting of products.

Technological research: Networks

- Look-up services for efficient data retrieval (e.g. Supply Chain and Manufacturing Management applications).
- Models for data-sharing among multiple partners (selective data retrieval, access rights issues).
- Support for distributed decision-making further than just data sharing. Technical mechanism to be able to create and distribute autonomous decision-making agents that can be programmed to monitor for particular exception scenarios (e.g. sensor data exceeds threshold for prolonged period of time / delays in transit) and trigger alerts that actually cause corrective behaviour to happen – ideally automatically.
- Shift from isolated RFID systems to networked RFID systems
- Interoperability requirements and standards
- Network security (e.g. access authorisation, data encryption, standards etc.)

Promoting employment of RFID technology: Privacy

- System concepts to guarantee privacy where personal and private data is involved.

Promoting employment of RFID technology: Evaluation of economic and societal benefits

- Evaluation of market size (e.g. number of potential users, cost-benefit analysis, conditions of successful implementation of RFID solutions).
- Pilots to test performance of technological research results.
- Pilots to assess economic benefits of results (cost-benefit analysis) to e.g. support Supply Chain Management, anti-counterfeiting, traceability of goods, product safety, etc. in various sectors.

Promoting employment of RFID technology: Information for stakeholders

- Need to prepare strategies to disseminate information and guidelines for (potential) RFID users. There is a need for a body to disseminate accurate, unbiased information about

RFID technology and logistics solutions. Local RFID-Labs operating already in some countries could be/are such bodies. Dissemination activities should be widely supported.

- Set up system solutions for SMEs e.g. easy to handle, low cost (e.g. open-source) solutions.
- Research on and assessment of acceptance of RFID technology by users and consumers.
- Develop strategies to make consumers and citizens aware when they get into contact with RFID systems and provide information about the technology and benefits.

Promoting employment of RFID technology: Regulation and Standards

- Identify standards and regulation topics related to the European RFID research strategy.
- Define actions to promote these standardisation and regulation activities through the projects funded within the Framework Programme 7.
- Co-operation is needed inside supply chains or industrial sectors in order to harmonise systems and ways of action. Without this co-operation, it is difficult for a single actor to proceed in implementation of RFID applications.
- Worldwide frequency harmonisation in UHF range, wider bandwidth for Europe, elimination of the ‘Listen Before Talk’ requirement from the ETSI 300 220 standard
- Standards for sensor interface, RFID networks

3 Production, Monitoring & Maintenance

3.1 State-of-the-Art

Most of the RFID-based solutions used today in the field of manufacturing & maintenance are limited to tracking and tracing of parts or tools. Compared with the previous identification means, RFID provides a fast and automatic capability to identify parts without the need to see or contact the ID. However, the reading performance of RFID tags (reliability, range…) for several products/processes is not yet totally sufficient to guarantee the economic benefit of adopting RFID compared with the well established systems using barcode, 2D matrix or even name plates with written part or serial number.

Most of the RFID-based solutions are either “closed loop” (RFID is not used outside a company) or “semi closed-loop” (RFID is not used outside a supply chain), although “open loop” solutions (RFID is used anywhere during the product lifetime) would be of great use, especially for maintenance purposes. Monitoring of product usage and status during their service life is important to allow the development of condition-based or predictive maintenance services. RFID tags are a key element to this since they can wirelessly communicate the identity of a unique product to an information system where this identity can be merged with other data and processed. However, the available RFID technology has not yet the performances to allow industrial use: in terms of robustness, temperature capability, sensing and communication functions, miniaturisation.

The standards for identification/coding of parts, objects and services related to manufacturing or maintenance are generally already established (although different from one domain to another) and RFID shall comply with these standards.

The competitiveness of manufacturing and maintenance enterprises is strongly determined by their ability to quickly integrate customer requirements for new products and services within complex business networks (i.e. from SME type organisations up to global actors with diverse organisational and technical maturity levels).

In this regard, the integrated enterprise management still lacks solutions for both self-organisation of single network entities, as well as for continuous dynamic adjustment of the overall network of actors, with particular emphasis on the need for a ubiquitous-but-secure access to product related data and services.

3.2 Vision

Initially, manufacturing and maintenance will benefit from RFID-based solutions developed for track and trace of components allowing better automation of supply chain and resource management.

Beyond this, further benefits from RFID-based solutions will be obtained by using the unique capability given by RFID tags to be read wirelessly and automatically without human triggering and processing in order to inform the surrounding information system in real time of its identity, through which a connection can be made to possibly significant data content directly “attached” to it. Note that in some scenarios, additional data will be recorded to an RFID tag, while in other scenarios, a simpler tag is used, carrying a unique ID or ‘licence-plate’, which is then used for identifying sources of information on the network, as well as retrieving relevant records, since the unique ID read from the tag can also be used as a database key.

The networking of information systems will then make it possible to know in real time, from anywhere, the configuration of an individual product throughout its lifetime, to access necessary information on this product and provide tailor-made added value services like:

- Event-driven auto-adaptation of process, workflow, tools and resource allocation to the flow of parts being processed (references and status)
- Automated manufacturing or maintenance documentation and distributed decision making tools tailored to the actual product configuration (references and status),
- New and more complete “all included” services for product operation including real time remote monitoring of products.
- Automated detection of counterfeit, misused or poorly maintained parts.

The RFID technology itself will develop from simple identity devices to include broader sensing, mobile data storage and networking capabilities. This will allow both more sophisticated and local processing, taking into account the product history and status and the changes of configuration.

These services will be provided either locally (by the machine or product monitoring systems) or remotely (by service providers via the internet or dedicated connection). The real time, complete, accurate and shared information on the status of individual products would directly facilitate the dynamic detection and integration of changing market needs or disturbances.

This perspective for RFID developments shall not be considered by itself, but only in a global perspective of ICT developments. In the same way, RFID may not be the best solution for every case of product identification and will not immediately replace all other means for part identification. RFID-based solutions shall therefore remain interoperable with them.

3.3 Gap Analysis

Before this vision can be realized, four main types of gaps need to be filled:

System integration

- To take full benefit of the RFID tags, key problems will be integration: to shift from isolated-RFID-solutions to global networked-solutions integrating the RFID paradigm into the diverse systems, while maintaining the quality of services of the ICT systems and the continuous workflow in the shop floor or in the field.
- This integration of RFID-enabled systems (e.g. tags for equipment, machines, operators, products, material, and consumables) in a global service network introduces new challenges regarding the support of diverse and heterogeneous data models and ontologies, which are imposing diverse demands on data exchange and (intelligent) transformation, due to the decentralised and partly new requirements for data interpretation.
- Currently, RFID technology is handled as an add-on and not fully integrated in the overall product life-cycle, still imposing additional efforts to integrate RFID with the product itself (e.g. attaching RFID readers in mobile phones, mapping RFID specific data to manufacturing/ maintenance data) within the manufacturing or maintenance process.

Standards and regulation

- These RFID data models and ontologies can only be adopted in an efficient way if proper standards and standardisation roadmaps exist to give directions and confidence to all technology providers and end users.
- As mentioned above, RFID will enable remote monitoring and autonomous behaviour of products and machines. Generic solutions will be needed to assure the integrity of services, especially when considering security of users and workers, and the cost of downtime of products and machines. These solutions will need to be reinforced by standards and regulations.
- There are generally no models for data-sharing among multiple partners, taking into account intellectual property, data ownership and lifetime management, company

confidentiality or user privacy requirements, and multi level access rights issues. Connecting in real time the identity and status of an individual component to an information network will certainly worsen this gap.

- In the same way worldwide standards need to converge and stabilize for the RFID technology itself (frequencies, power, read protocols etc…).
- Furthermore, wide and global adoption of standards is often hindered by the time to finalise the standard development as well as the terms of usage w.r.t. availability and licence costs.

Confidence of stakeholders

- Before decision makers launch long term investments in a RFID-enabled solution, they need to get confidence in the viability and durability of the solution. This is not the case today: RFID related technologies (hardware, middleware and system integration…) are evolving, standards are in progress and many legal questions remain unanswered.
- Several aspects of the business model of RFID-based systems are difficult to quantify – for example: evaluation and sharing of the added value (especially information sharing), actual practical performance of RFID tags, cost of maintaining a RFID-based system operating reliably in harsh industrial environments. This evaluation is made even more difficult by the lack of education, the difficult access to reliable information and to experts who are independent from technology solution providers.
- On the other hand, the chip manufacturers need to have confidence that a market exists before they invest in high performance, high margin specialized RFID chips that might only be produced in low volumes.

Technology

- From the generic characteristics of manufacturing and maintenance processes as well as products operation, RFID enabled solutions face physical problems such as: Harsh environments (temperature, vibrations, chemical threats) of component during e.g. processing, coating, cleaning, operation (imposing a physical impact on the component and on attached tags by manufacturing tasks like forming or welding).
- Difficulty to define a tag and attachment solution for the complete lifetime of a component, from early manufacturing to disposal, with satisfactory performance for all RFID-enabled purposes, working reliably for perhaps several decades.
- Difficulty to read tags in an environment strongly constrained by the process (metallic surfaces, complex shapes, limited space available for readers, etc.). The use of active tags is limited by the difficulty to install and maintain batteries during the required service life of the tag or part to which the tag is attached.
- Lack of sensing and communication capability of tags
- Lack of multi purpose readers (hardware and middleware) with the capability to interface to several kinds of tags with several applications. At the moment multi-purpose readers are only available as stationary gates; still missing are e.g. multi-purpose readers in mobile phones or planes.

3.4 Research Targets

To fill these gaps and aiming at the realisation of the visions described above, a number of different and quite heterogeneous research targets need to be addressed. Therefore, the following presentation of major research targets is structured in research targets which (a) are directly addressing the enabling RFID technology (i.e. tags, readers, general issues) and (b) which are aiming at enabling and facilitating the integration of RFID in global information systems. This is followed by a conclusion, representing the prioritised key research target, which shall be addressed as first priority.

The ***technical performance of the enabling RFID technology*** needs to be significantly improved in several aspects:

- RFID tags
  - Chip for RFID Tag with sensor interface for more integrated functionality (sensing and communication, etc.)
    - integration of interfaces into RFID chips (measuring bridge, AD-input, bus interface, etc.)
    - sensor development (ultra low power, very small size, etc.)
    - sensor integration into RFID chips
    - system integration of sensors and RFID chips on RFID tag
  - Housing technologies for RFID tags for robust applications
    - protection against high/low temperature, mechanical, chemical impact, etc
  - Improved/new semiconductor manufacturing processes/technologies for higher temperature ranges
  - Miniaturisation
  - Long term reliability
  - Long life low maintenance energy sources for active or semi passive tags
  - Means of attaching tags, providing repair or exchange capability
- RFID reader (reader and reader antenna)
  - Reader with broadband RF front-end for UHF (860MHz to 960MHz) e.g. for international use in aviation because of the different national regulations on the use of RFID frequencies
    - system integration in RF technology
    - multi frequency RF chips for RFID reader
  - Reader with modular or reversible RF front-end for UHF and µ-wave (2,4 GHz to 5,8GHz) as well as for passive, semi-active and active RFID tags to use the same reader with different RFID front-end technologies in the same time for the same application
    - system integration in RF technology
    - multi functional RF chips for RFID reader
  - Structure and surface conformal antennas for easier system integration, such as integration into aircraft
    - antenna design methodologies
    - material technologies for structure/surface conformal antennas
- RFID technology in general
  - Read range in difficult environments
  - Microwave RFID technology (at 2,4GHz and 5,8GHz; passive, semi-active and active) to reduce the size of antennas, to use the directivity of antennas, etc.
    - RF development at µ-wave (at 2,4GHz and 5,8GHz; passive, semi-active and active) e.g. chips, readers, antennas, tags, etc.
    - system integration in µ-wave RF technology

Research is also needed on ***how to enable and facilitate the integration of RFID solutions into global Information Systems***:

- Providing advanced sensor systems and middleware to facilitate the use of real time identification and events into manufacturing and maintenance processes.

- Extending the RFID-enabled paradigms to the overall process chain along the product life cycle from e.g. process planning, early problem identification, production order status tracking, control of specific tasks in the workflow up to after sales services.
- New models for data storing, process control and process management to determine which degree of distributed systems need or can be attached to specific objects in manufacturing and maintenance processes.
- New, human centred solutions for the interaction of the worker with increasingly intelligent processes and environments.
- Defining appropriate methodologies for modelling complex interaction patterns within distributed business networks, where enhanced RFID based systems for distributed networks are promising to deliver diverse business benefits. This is specifically important to allow SMEs to use or contribute to the RFID-enabled solutions.
- New approaches for assuring security and trust in networked services (i.e.: considering safety aspects and financial impact of system breakdown)). Future research shall specifically address technical as well as organisational issues to be addressed by SME type actors, not requiring centralised authorities, while aiming at “design for secure and trustful applications”.

All of the above mentioned research efforts shall be associated with a strong standardisation effort in order to facilitate the networking of research efforts. A strong and efficient European standardisation policy is also likely to be a key factor for the success of solutions developed in Europe.

Moreover the need for standardisation of the technologies associated with RFID (frequencies, power, read protocols etc…) must also be highlighted.

On the top of that, research work is needed to improve the visibility on the market from both points of view of supply and demand:

- Business models need to be developed to determine the profitability for large organisations and SME’s to integrate RFID-enabled, networked systems.
- A reliable information database shall be made available to entrepreneurs to evaluate the pros and cons of an RFID project. A network of independent experts shall be developed.
- Business models are needed to determine the ROI for chip manufacturers to invest high amount of money to develop high performance/ high cost chips

However, based on this analysis, ***the following key research targets were prioritised***:

- RFID technology for long life, reliable tags that can operate in harsh and metallic environments.
- Extending the RFID-enabled paradigms to the overall process chain along the product life cycle from e.g. process planning, early problem identification, production order status tracking, control of specific tasks in the workflow up to after sales services.
- Appropriate methodologies for modelling complex interaction patterns and distributed decision paradigms, also including models for data storing, process control and process management, within open-loop business networks.
- Providing advanced sensor systems to facilitate the use of real time identification and events into manufacturing and maintenance processes.
- Interoperability/ interfaces and new approaches for assuring security and trust in networked services.

4 Product Safety, Quality and Information

4.1 State of the art

At the current point in time, RFID technology is beginning to pervade the domain of trade with tags being introduced mostly to logistical units such as pallets, but not so much on the item level, yet. There are already several examples of pilot installations also targeted at consumers, most notably the Future Store initiative of the Metro group, which is pioneering the trials of RFID related applications for the benefits of the end consumers.

Manufacturing and production industries are in general still quite hesitant regarding the adoption of RFID technologies for reasons of missing interoperability standards and also because of lack of knowledge about best practices. There are however already some success stories in the field of product safety and quality, even for fast moving goods, such as a project on RFID for the food supply chain between Chiquita and the RFID Center at the University of Arkansas, in which a temperature tracking system using RFID is implemented. Similar activities are carried out by the coffee retailer Starbucks at several distribution sites in the US.

In general however, most producers lack both the knowledge of the respective processes (esp. with regard to safety regulations) and the potential connections to related technologies that make sense for integration in the field of product safety and quality such as temperature or humidity sensors.

4.2 Vision

When we regard the issues of product safety and especially product quality, we have the clear objective to provide detailed information about the history of a product to the end consumer. This will help to create trust and transparency in sensitive product areas such as perishable or sensitive goods, but also pharmaceutical and luxury goods and high-value goods, some of which are highly composite products. Depending on the consumer’s context and demands, correct and complete information has to be provided. The classical “pull” mode, where consumers actively search and query for information, could easily be extended by a “push” mode in order to ensure the provisioning of up-to-date information at the right place, at the right time.

We want to achieve fully RFID-enabled product lifecycle processes for the businesses in the trade domain. After packaging and labelling the respective cases, pallets, and potentially even items with RFID tags, information about shipments will be stored and tracked at different stages in the product lifecycle throughout the complete supply chain. By augmenting this track & trace information with sensor data regarding relevant properties such as temperature, humidity, velocities of movement etc. we can enable all intermediaries and the buyers of products to get an insight into a product’s history and to verify the quality of goods.

Especially when sufficient transparency across company borders is given, the tracking and tracing of composite products can potentially lead to more efficient quality management when it comes to exactly locating a faulty batch, production line or manufacturer, and meeting optimal quality improvement measures or precisely directed recall campaigns.

In the long run and in certain domains, we will see an increase in the utilization of sensor technologies in general, which allow for contributions to product safety far beyond the typical track & trace based approaches that are currently being implemented. Especially for certain product types such as perishable goods there are strong indications that measuring e.g. temperature or humidity on the way through the supply chains and altering delivery models accordingly can greatly enhance product quality. Likewise, in some areas, e.g. hazardous goods, it has already been demonstrated in research trials that embedded, communicating sensors can help prevent industrial accidents by giving feedback about storage and handling conditions.

Naturally, the ultimate goal of data exchange with the customer requires the previous installation of respective B2B exchange infrastructures based on global standards. Not-for-profit standards bodies such as EPCglobal are overseeing the development of an architecture of open standard interfaces for the necessary large scale B2B infrastructures, based on requirements from end users and with the active participation of several technology solution providers. The benefit of such open standards is to foster a competitive marketplace for solutions, in which the end-user can choose among interoperable solutions from multiple providers. In addition to this, we also need legislative bodies and institutions in order to establish trust and security among the respective businesses in the trade domain.

The implementation of RFID enabled data exchange infrastructures at a broad level will significantly and sustainably influence the importance and the future development of all related IT systems.

4.3 Gap Analysis

While the integration of RFID technologies with sensing infrastructures for product quality information has already been implemented at several pilot installations in the trade domain, these are mostly prototypical proof-of-concept studies, and in the future, we can even expect to see substantial development of hardware-related aspects such as production of small but reliable sensors with sufficient noise rejection, as well as lightweight, efficient and robust power supplies.

Commercially available, standardized sensing infrastructures that scale to the requirements of large supply chains and can be used throughout the complete product lifecycle are still to emerge. Likewise, cross-industry standards are not yet fully available.

Especially for large and open supply chains as they are frequently found in the trade domain there is a strong demand for interoperability between the various IT systems of the respective stakeholders. This includes both the various hardware standards regarding readers and tags as well as the heterogeneity of software systems up to the enterprise resource planning level. The different standards and legislations on frequency bands impose an additional challenge, as it may even be necessary to support different bands in parallel.

However, even if suitable components are developed and industry advances towards their standardization goals, the way these building blocks are used requires harmonization as well. This is evidenced by the fact that today, specialized or more generic solution platforms emerge to be used “out of the box” or with remarkably less customization demands than even a few years before, their main target areas are still stand-alone businesses or simple relationships; complex business-to-business information exchange with properly guaranteed data security and transaction consistency are, as of today, rare.

While many prerequisites (data models, transaction protocols etc.) are already present or could be developed with today’s premises, their combination, standardization and establishment of best practices in communication across company borders still requires much effort and field experience.

4.4 Resulting Research Targets

In order to close the identified gaps and realize the RFID solutions vision, we need to advance the state of the art in several technological areas as well as solve standardization issues.

Regarding several of the security aspects that are a precondition to establishing cross-organizational RFID enabled businesses (e.g. who is allowed to access which event data, how is counterfeiting being addressed etc.), there is probably a need for respective legislations and also for appropriate security technologies to be at the heart of the IT systems for interorganizational information exchange, to support authentication and enforce access control policies, as well as assuring the integrity and non-repudiation of the information that is exchanged.

As with many other application domains, the costs for the IT infrastructures, but mostly for the tags themselves, need to be reduced in order to move from pallet level tagging to smaller quantities of packaging and down to the item level in the long term. Related to this is research on novel tag technologies that work well with different materials such as metal or textiles and in general more work on the next generation of RFID tags that include or integrate sensing technologies and embedded computer platforms to implement the "smartness" necessary for certain advanced business processes.

If we look into more detail on these research targets and cluster or group them accordingly, we find the following detailed structure:

- Hardware-related improvements needed in:
  - Reliability of tags (number of failures still quite large, even if automatic data acquisition compensates for human errors)
  - Sensor technology (weight, robustness to adverse environmental conditions, noise rejection)
  - Embedded computing systems (particle computer, communication boards)
  - Power supply (battery) technology (capacity/size ratio, robustness)
  - Applicability of tags with conductive or noise emitting materials
- Improvement needed in low-level communication and tag data storage:
  - Frequency band and air interface standardization across frequency allocation regions (implies either legislative efforts or development of multi-frequency solutions)
  - Development of encryption solutions and standards for cases where data stored on tags are considered confidential information hidden from unauthorized parties
- Development needed in tracking/management frameworks and business-to-business or end user communication:
  - Research, development and (where needed, scientifically founded) testing and standardization of data models and communication protocols for item-level B2B practice (even "ontologies" which would allow inference to assist decisions or everyday operation)
  - Research, development and testing of access control mechanisms, security policies and protocols with security/risk sharing guarantees for sharing of information among trusted partners throughout the product lifecycle, including operations where less trusted third parties are involved as intermediaries

5 Payment

Payment applications have many interesting new technologies and development directions. Closed-end payment schemes, interoperability of ticketing and payment instruments, mobile payment applications, more stable security solutions, electronic purse and e-cash are just a few ones to be mentioned. From this list we selected electronic cash as the research subject in focus, because it has the highest relevance due to its economic impact and its strong reliance on contactless technology.

5.1 State of the art

Europe still relies on the independent, national payment systems, a situation which is not expected to change any time soon. The introduction of EURO in 12 European countries was a major step forward. However the depth of integration probably stops at this stage with further improvements only to be expected from the enlargements of the EURO zone with some of the new EU members.

With this higher level of interoperability achieved on a pan-European level, substantial expenses could be saved for the general public as well as for industry and services. The avoidance of currency exchange and the associated risks improved operating efficiency and contributed to a higher level of transparency, resulted in increased competition and the establishment of a truly European market.

Technology on the other side did not keep pace with this development. Cash is still king. The vast majority of payments both in terms of transaction numbers and value are still performed with cash. The decrease of cash usage is minimal and barely discernible especially in the case of low value payments.

In a payment system or instrument there are four aspects that matter: speed, security, expense and general acceptance/usage. Cash is performing very poorly compared to other possible solutions in all of the first three aspects, but it is unbeatable in the fourth, but most important aspect. General acceptance and usage is the most important characteristic of any payment method and none of the newly introduced and emerging solutions could even come close to cash in this aspect.

There were recently a number of initiatives by banks to introduce alternative payment instruments like mobile payment and electronic purse, but none of them succeeded so far; none became a generally accepted payment method. (Part of the reason of failure was that proprietary solutions were pursued where the necessary network effect could not be achieved and also often the technology used was inappropriate, like in case of stored value payments.) In the last 50 years the payment card was the only really successful, innovative solution that achieved widespread acceptance and adoption, and even its penetration only really accelerated during the past decade.

New offerings of closed loop payment schemes and prepaid cards operated by new 3rd party service providers try to capitalize on the inability of the incumbent financial service providers to satisfy the new requirements but this road only leads to further segmentation of the market and deterioration of economics.

5.2 Vision

To reduce the role of cash in small value payment transactions / full substitution is not realistic/ we partially need to rely on new technology, combined with adequate regulations, supported by favourable financial conditions, standardisation and active marketing. E-cash has to be introduced. E-cash is such an electronic payment method, where the actual monetary value is stored on a chip in a plastic card (or mobile handset) and can also be used in off-line transactions.

Europe would not be a pioneer in such moves of substituting traditional paper money. In the Far-East – especially Japan, Korea, Hong Kong - electronic money is already widely used, with purses installed into mobile devices or on contacless bank cards. The US also started on a similar path (contactless payment cards for small value transactions) with about 20 million cards already in circulation with over 45 thousand acceptance points and also successful completion of the first mobile trials.

Europe has a more difficult task because of its fragmented financial system, but can also learn from the experience of the early adopters.

The future of European small value payments, payments that cover most of our everyday purchases, should be based on a combination of state of the art technologies. The solution is an open payment scheme based on a contactless proximity application that is combined with remote mobile communication and PKI based security.

The new payment instrument is an offline purse that stores electronic value and acts as a kind of stored value account issued by banks. The purse can be loaded remotely from existing bank accounts resulting in full integration into the present financial infrastructure. The e-cash would be denominated in EUR ensuring overall acceptance across the whole EURO zone. The new e-cash or payment purse has to be a generally accepted, official payment instrument.

The issuing organisations, regulators would ensure that the money can be used and is generally accepted and that existing acquiring and clearing infrastructures can be used. This capability would take care of the most important usage barrier. The contactless feature of the application will ensure speed and convenience.

To date, many of the new approaches failed because users were unfamiliar with the way of operation of the new solutions and inconvenient usability features and frequent failures practically prevented customers from trying the new methods.

The speed of payment plays directly into the bottom line of merchants and makes a huge difference in the customer service of the shoppers.

The remote communication feature will provide direct access to one's bank account allowing customers to always recharge their purses whenever necessary, wherever they are. The purse can be implemented within specially designed mobile handsets – based on NFC technology – but may also be simple plastic cards, or may have any other type of form. The mobile handset housing the purse or a PC with an internet connection would just provide the necessary communication channel with the back office system of the partner financial institution for the top-up function. In the non-phone based embodiments, the contactless interface would also be the access channel of the application.

The third important component of the new payment instrument is the PKI based security architecture. The use of encryption and digital signature does not only provide a very high level of security much tighter than that of existing solutions but also enables offline P2P money transfer and definition of funds which are earmarked for special purposes. Such special, dedicated funds could be assigned to people under a certain age if limitations are in place regarding their consumption of specific products and services. The same feature can be used if money is provided to someone for a special purpose and not for general use. (buy a book not candy, social support not to be spent on booze)

The security architecture will also be used to ensure protection of sensitive personal information and to prevent misuse of user or transaction data.

To build an acceptance network with relatively low cost and high density mobile handsets with contactless interface will also be used as acceptance devices. With such an architecture plain everyday mobile phones, or more specialised devices for the merchants can be used as payment purses as well as POS terminals supporting all kinds of transactions, even P2P ones, between any two parties.

Besides being cheaper and more economic than the traditional paper money, the new e-cash would have additional benefits, like increased security – would comply with anti money laundering regulations – like contribution to the whitening of the economy, and to health and environment protection.

5.3 Gap Analysis

From technology point of view and in theory, everyone knows that cash is outdated, expensive and modern technology could provide better, more convenient means for payment. However habits are hard to change unless there are great motivations for the change.

If the role of cash is to be reduced, all involved parties need to act together and have to be committed to follow a common strategy, which will not be a simple and short task.

First the political will is necessary that indeed the move from cash to e-money is desired, with all its benefits and initial difficulties.

Financial service providers, merchants and even the regulators need to work together from design, through development and implementation to introduction and evaluation to be able to provide a technologically feasible, convenient, economically viable payment instrument that can be used universally across a number of countries, for a large variety of services and products at most merchants, for any values below a relatively high limit.

The first step for the introduction of a European wide service is the agreement on the standards used covering everything from technology, through security to consumer protection and liability issues. Where possible this work should be leveraging already existing international and European standards.

To ensure that the migration will happen regulators and authorities have to convince the public that the move from cash to electronic money is in their best interest too. To achieve the goals positive and negative motivation needs to be used.

The public needs to understand that the use of cash is not free of charge and there is no better way to make it obvious than the introduction of charges for cash payments. At the same time it also has to be ensured that using e-cash will be free of charge for both customers and merchants.

Cash is not widely used by the state and other state or government related organisations but whenever it should occur, cash should be substituted by the new e-money, to force their partners to move to electronic channels.

The regulators have to enforce that all – most – merchants accept e-cash as a new form of an official payment instrument. In order to make such a move viable all necessary regulations need to be in place that makes e-cash at least as convenient and more secure than traditional cash. Taking usability and security aspects into account, value driven security solutions should be introduced starting with unauthorized transactions for micro payments and the use of chip and PIN for larger amounts.

Merchants need to accept the new payment forms which may necessitate investment from their side. They need assurance that this investment has a good return and as such guarantee cannot be provided they need incentives to carry out the necessary changes.

Financial service providers will have to invest as well, and face the problem of running parallel business lines – as cash will not disappear completely – which initially inevitably will deteriorate their economics. The banks need the commitment of the authorities that the process of migration will not be stopped even if initial results are controversial and that there is real political commitment behind a successful migration.

Steady commitment does not however contradict to the expectation that all valid concerns that arise from the initial operation will need to be properly addressed and changes should be introduced into the program if found necessary.

As contactless technology will be the basis of the new e-money, the introduction of similar services, like ticketing, IDs should also be promoted, to familiarize users with the technology in general. In an ideal case, payment and ticketing applications that are interoperable across organizations and national boundaries could lead to rapid adoption of the service. To further strengthen the cross utilisation capabilities between the various services standardisation efforts like ITSO need to be analysed and adopted as much as possible.

The introduction of an interoperable, generally accepted European wide new payment instrument, that of e-cash, is primarily a political decision, but research can provide the necessary input and ammunition for such a decision and can provide a road-map for the successful implementation.

5.4 Resulting Research Targets

Research will not bring the necessary decisions and will not introduce e-cash, but can provide the necessary foundation for such a move.

Technology research:

- Cash survives wars and natural disasters. There are notes in museums which were printed hundreds of years ago. Chipcards carry electromagnetic charges which according to present technology can just disappear in a relatively short period of time – over a few years. Technology needs to be developed that extends the lifetime of this storage medium.
- Chipcards are not protected enough against unwanted electromagnetic impulses. The protection of the content of the cards need to be improved.
- Contactless P2P protocols need to be defined, that ensure the necessary speed and information content and to facilitate the direct cash exchange between individuals.
- The use of mobile handsets as an e-purse and contactless POS terminal has quite a few technical issues that need to be solved: These include the management of the secure elements and the selection of the applications to be used.
- There are open unsolved technical challenges in the underlying basic technology too. The power consumption of the chips need to be optimized, and also solutions need be found for the power-off mode of mobile handsets when the chips still need to be .

Standardisation:

- Various aspects of the new technology need to be standardized: basic underlying technology, security solutions, protocols, legal rules, business rules, customer service and protection issues, etc.

Usability research:

- Using cash in payment transactions is a natural interaction for the people over the age 8-9 until we die. The use of cards in payment transactions is becoming quite a common activity too, but there are large groups in the population who for whatever reason never use cards and have strong objections and aversion to cards. If a brand new payment method is introduced, the reaction of the public needs to be anticipated and understood very well, which requires large scale research actions.
- The touch paradigm of contactless payment seems to be very simple at first sight. However the complex process flow of interaction has to be analysed in details to make sure that

there are no such hidden obstacles that would make, or present the new payment process too complex, too complicated for whatever reason.

- Using a mobile handset for anything other than making a call or sending an SMS may seem to be too complex for many. However one of the most obvious form factors, providing most benefits and value added functions, for the e-purse is the mobile phone. The user interaction has to be elaborated in such a way that best combines the familiarity of using a mobile phone with the simplicity of the contactless application.

Security research:

- Security is always a key issue when payment is involved. Financial service providers have very high security requirements in terms of payment operation. The requirements, the possible technical solutions and the financial implications need to be analyzed and the most acceptable model needs to be elaborated. The solutions should include both storage and communication functions.
- When the security requirements are defined the certification procedures need to be defined too, as the e-money will have a rather diversified infrastructure with its elements dynamically changing and prepared by various vendors.
- The use of PKI and the processing and control of off-line P2P transaction has such new challenges that require extensive security studies and the specification of new procedures.

Business and logistics:

- The introduction of a combined remote and proximity payment solution based on mobile and contactless communication results in major changes in the present value chain. There will be new actors whose roles need to be identified and there will be also new functions which need to be assigned to existing or new players.
- Key architecture requirements are to be defined and the roadmap for the service introduction elaborated.
- Business models need to be developed to determine the profitability of the new service structure. It has to be seen how the service can be made more economic – a lot more economic – than the present cash based regime and still how each involved partner can realize its expected margin. The challenge of the model is to ensure the necessary ROI, when benefits are almost exclusively derived from the savings achieved, as the service in principle should be free of charge for the users.

Economics:

- It is expected that the substitution of cash in small value payments by e-cash would result in substantial savings on macro economic level. These assumptions need to be validated and the complex outcome of such a major change described as accurately and as concretely as possible.
- Introduction of a new payment instrument that would at least partially substitute cash in small value payments will have diverse socio-economic effects over the whole population. The tendencies and possible changes need to be identified, analysed and the necessary responses have to be prepared. The evaluation of some existing non-European programs would provide guidance in this work however cultural, social and financial differences need to be very well understood.
- The use of the new payment instruments will have a complex effect also on macro economic level. The potential scenarios and necessary responses will have to be elaborated.

6 Conclusion

In this paper, we have considered the current state of RFID application in four important business-oriented application areas. We described potential benefits of an intensified use of RFID tags in these areas, and are coming up with an analysis of the causes that prevent this intensification. Eventually, this analysis should help researchers and industry to direct their efforts to advance RFID technology itself and its application. In order to identify the most pressing problems that promise the most advancement, if overcome, at a reasonable investment, we tried to judge the issues encountered in the four application fields according to additional criteria. The following table gives a structured overview of the issues, with those at the top that should be given priority in a research agenda.

First, it must be noted that a rating as it is done in this table is necessarily subjective and highly influenced by the priorities and working areas of the authors. Therefore, our conclusions drawn here should be taken by the reader as a supplement to provide a stronger basis of her or his own assessment. The issues are listed such that those with the highest impact on European industry are listed first. This reflects our commitment to the goals of the European research framework. The second criterion is the immaturity level, thus prioritizing those issues that need a stronger investment to yield results. However, it is easy to read the table the other way around and consider those issues first that require less investment for good results. This latter view would be favoured by short-term research projects or smaller consortia, while the former view is more shaped according to the characteristics of long-term projects carried out by larger consortia (with more funding capabilities).

CERP Working Paper on RFID Research Roadmap

<table>
<tr><th></th><th>Research topic</th><th>Logistics</th><th>Product safety</th><th>Manufacturing & Maintenance</th><th>Payment</th><th>Impact on European Industry</th><th colspan="2">Immaturity level</th><th>Required effort</th><th>Time to commercialization</th></tr>
<tr><td>1</td><td>Product life cycle related RFID enabled features & tag maintenance</td><td></td><td></td><td>✓</td><td></td><td>high</td><td>|||||||||</td><td>90%</td><td>high</td><td>5+ y</td></tr>
<tr><td>2</td><td>Distributed decision making</td><td>✓</td><td></td><td>✓</td><td></td><td>high</td><td>|||||||</td><td>70%</td><td>high</td><td>5+ y</td></tr>
<tr><td>3</td><td>Built-in security</td><td>✓</td><td></td><td>✓</td><td></td><td>high</td><td>|||||||</td><td>70%</td><td>high</td><td>5+ y</td></tr>
<tr><td>4</td><td>User acceptance and privacy</td><td></td><td></td><td></td><td>✓</td><td>high</td><td>|||||||</td><td>70%</td><td>medium</td><td>3-5 y</td></tr>
<tr><td>5</td><td>Complex interaction modelling & new RFID based interaction models</td><td>✓</td><td></td><td>✓</td><td></td><td>high</td><td>|||||||</td><td>70%</td><td>high</td><td>3-5 y</td></tr>
<tr><td>6</td><td>Standardized data model for B2B exchange</td><td></td><td>✓</td><td></td><td>✓</td><td>high</td><td>||||||</td><td>60%</td><td>medium</td><td>3-5 y</td></tr>
<tr><td>7</td><td>Application integration</td><td>✓</td><td></td><td></td><td>✓</td><td>high</td><td>|||||</td><td>50%</td><td>medium</td><td>3-5 y</td></tr>
<tr><td>8</td><td>Reading reliability</td><td></td><td>✓</td><td></td><td></td><td>high</td><td>||||</td><td>40%</td><td>medium</td><td>1-3 y</td></tr>
<tr><td>9</td><td>Protection of tags against extreme phenomena (e.g. EMP)</td><td></td><td></td><td></td><td>✓</td><td>med.</td><td>|||||||||</td><td>90%</td><td>high</td><td>5+ y</td></tr>
<tr><td>10</td><td>Advanced Sensor Systems</td><td>✓</td><td></td><td>✓</td><td></td><td>med.</td><td>|||||||</td><td>70%</td><td>high</td><td>3-5 y</td></tr>
<tr><td>11</td><td>"Smart" tags (i.e. integrated displays, actuators)</td><td>✓</td><td></td><td>✓</td><td></td><td>med.</td><td>|||||||</td><td>70%</td><td>high</td><td>3-5 y</td></tr>
<tr><td>12</td><td>Operation on metallic and moist products</td><td>✓</td><td>✓</td><td>✓</td><td></td><td>med.</td><td>||||||</td><td>60%</td><td>medium</td><td>3-5 y</td></tr>
<tr><td>13</td><td>Access control and security policies for data exchange</td><td></td><td>✓</td><td></td><td>✓</td><td>med.</td><td>||||||</td><td>60%</td><td>medium</td><td>3-5 y</td></tr>
<tr><td>14</td><td>Large range readability</td><td>✓</td><td></td><td></td><td></td><td>med.</td><td>|||||</td><td>50%</td><td>low</td><td>3-5 y</td></tr>
<tr><td>15</td><td>Operation in harsh environments (e.g. extreme temperature)</td><td>✓</td><td></td><td>✓</td><td></td><td>med.</td><td>|||||</td><td>50%</td><td>medium</td><td>3-5 y</td></tr>
<tr><td>16</td><td>Secure storage of tag data</td><td></td><td></td><td></td><td>✓</td><td>med.</td><td>||||</td><td>40%</td><td>low</td><td>1-3 y</td></tr>
<tr><td>17</td><td>Tag robustness</td><td>✓</td><td></td><td>✓</td><td>✓</td><td>med.</td><td>|||</td><td>30%</td><td>low</td><td>3-5 y</td></tr>
<tr><td>18</td><td>Improved reader performance (reads/second, range)</td><td>✓</td><td></td><td></td><td></td><td>med.</td><td>||</td><td>20%</td><td>medium</td><td>1-3 y</td></tr>
<tr><td>19</td><td>User interaction</td><td></td><td></td><td></td><td>✓</td><td>low</td><td>|||||||</td><td>70%</td><td>medium</td><td>1-3 y</td></tr>
<tr><td>20</td><td>Confidentiality of tag data</td><td></td><td>✓</td><td></td><td></td><td>low</td><td>|||</td><td>30%</td><td>low</td><td>1-3 y</td></tr>
</table>

To consider some examples, let's pick the issue at the top of the list: product life cycle related RFID enabled features and tag maintenance. This issue refers to the capability of RFID technology to support a product throughout its complete life cycle. It is easy to imagine that for all the stages that a product goes through, and for its potentially long lifetime, a single tag may not be capable to support all upcoming interaction needs. However, the "upgrading" of RFID tags is a somewhat neglected feature of RFID-enabled products. To have the technology and processes available to support it could have a high impact on industry, but we are certainly far from having them readily available, and creating them would require a significant effort.

Let's also look at another issue, reading reliability, which would be the most promising short-term research goal according to this table. It's an important feature mainly in product safety, where tags are often read in uncontrolled environments. It might be a valuable research goal for a smaller group as the required effort is not overwhelming, and its commercial potential could be realized in a short term.

Many of the open problems listed are correlated, for example reading reliability and operation in harsh environments, and many of them could withstand a solution due to fundamental physical or economic reasons. To maximize the benefits, this should certainly be taken into consideration when selecting research topics. The challenges have been laid out, ready to be taken on by whoever brave enough!