Secure Document and Asset Tracking

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Abstract: **In contract electronics manufacturing, assets and their supporting documents are considered not only valuable intellectual property but also confidential, e.g. due to the military or high value aerospace products they support. Managing transaction records, controlled access and location at all times is of great importance, not only to limit risk but to follow mandatory protocols. In this study a Radio Frequency Identification (RFID) system capable of addressing the criteria described is presented. Both the hardware architecture used along with its limitations and performance in a harsh environment and the software based on a service oriented approach are discussed. The system is evaluated by means of discrete event simulation for different use-case scenarios. Test results show that although the system is capable of recording transactions, a 100% detection rate cannot be guaranteed if the documents are kept inside a metallic cabinet. This proves to be a consequence not of the number of tagged documents present but ofthe surrounding environment. Despite the system's limitations, which were taken into account during discrete event simulations, a reduction in cost partly due to a reduction in management time of 59% for the manager and 45% for the staff was observed.**

Index terms: **tracking, RFID, system architecture, discrete event simulation**

I. INTRODUCTION

Several studies show that despite the advantages in ease of access, transfer and processing of information allowed by digital formats migration to a paper-less office is far from being achieved [1, 2], factors including ease of use, mobility, and association between the object and its information prevent the migration to a paper-less office [3-6].

Certain domains in which the information held by the documents is security sensitive migration to a paper-less office is also prevented by legislation, a domain where this is the case is Electronics Contract Manufacturing (ECM). Not only ECM manufacturers must use printed formats they must also adhere to restrictions on the access, location and integrity of the documents.

As noncompliance to the set rules has economic consequences CEM manufacturers implement manual administrativeprocesses that enforce control and traceability for document transactions which demand considerable time and effort.

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Thanks to its capabilities for providing up to item level identification and state (i.e. knowledge of the location and time) Radio Frequency Identification (RFID) use for application scenarios where traceability and control are requirements is increasing (e.g. supply chain [7], logistics [8], manufacturing control [9], asset management [10, 11]).

Despite the benefits it promises and the successful trial applications reported in literature adoption of RFID is still small due to barriers such as: (i). Performance limitations in application environments, (ii). Rigid software architectures usable only for a single application, (iii). Lack of benefits assessing models. This paper addresses these barriers for the case of an RFID supported management system for security sensitive document and assets. The developed system prevents noncompliance to location, access and integrity rules and maintains transaction records. The rest of the paper is organized as follows. Section 0 summarizes the state of the art for RFID based asset management. Process re-engineering from the AS IS model to the To BE model is reported in Section IVIII. The proposed hardware architecture and its performance under operating conditions are presented in Section VIV. Section VIV presents the architectural software approach followed and the elements contained in the architecture. A quantitative assessment obtained from Discrete Event Simulation (DES) for time and costsavings achieved with the use of the RFID based management system is presented in Section VI. Finally, conclusion are provided in Section VII.

II. RELATED WORK

The use of Auto-Identification technologies (e.g. RFID, barcode) as a mean to increase traceability and control over business processes is widely reported in literature.

McFarlane et al. [12], for instance, has shown how the automated identification and retrieval of information allowed by RFID leads to an increase in the observability of control processes.

The capability of RFID to allow supply chain traceability at an item level using the EPCglobal network architecture has been shown by Barchetti et al. [13]. Using Key Performance Indicators (KPI) and Critical Success Factors (CSF) Bucciero has shown the impact of item level traceability for the pharmaceutical supply chain[14]for the tool presented in [13].

Taking into consideration the effect of metals, liquids and reader antenna Catarinucci et al. present a performance comparison (i.e. read rate) between 8 commercial UHF tags and a custom designed tag for the conditions encountered in the pharmaceutical supply chain [15].

The use of RFID for management of printed documents has received considerable attention, especially for library

management applications. Using a commercial UHF RFID tag and a hand-held reader Bin et al. developed a shelf management system [16] thatallows identification ofmisplaced books on the selected shelf, despite using the RFID tag for more than a simple identifier (i.e. book information is stored in the tag's user memory) location rules are enforced using a centralized database. The potential applications for RFID library management (e.g. sorting, inventory, theft prevention, transactions, cost) have been described by Mohideen et al.[17] and Selamat and Majlis[18]. The effect of the book of the tag's performance has been addressed by Kim et al resulting in the design of a loop antenna capable of readings of up to 5 metres [19]. Limitations on the localization of documents using UHF RFID have been reported by Buzzi et al [20] using 3 types of commercial tags used for inventory and search purposes, results showed that while search for a specific document is possible inventory activities are only successful at distances lower than 5 centimetre.

The reported literature shows that UHF RFID can be used in application scenarios demanding traceability and control even in environments with critical operating conditions. However, use of these systems is still limited as a consequence of 3 barriers: (i). Performance limitations in application environments, (ii). Rigid software architectures usable only for a single application, (iii).Lack of benefits assessing models.

III. PROCESS RE-EINGINEERING

A. AS-ISmodel

Given the confidentiality requirements (e.g. regarding design, access to components, operations and related documentation) demanded by aerospace, automotive and military markets CEM manufacturers must follow business processes that accomplish: (i). Controlled access to security sensitive documents and assets, (ii). Historical records for current and previous document and asset possessors, (iii). Inventory of held documents and assets.

An overview of such business processes is shown inFig. 1using CIMOSA constructs [21] (i.e. *Domain processes (DP), Business processes (BP), Enterprise activities (EA)*). The CIMOSA reference architecture was chosen because of its flexibility to describe development and manufacturing processes in a standardized way [22].

Secure document and asset management can be divided into 3 main processes (i.e. Domain Processes):

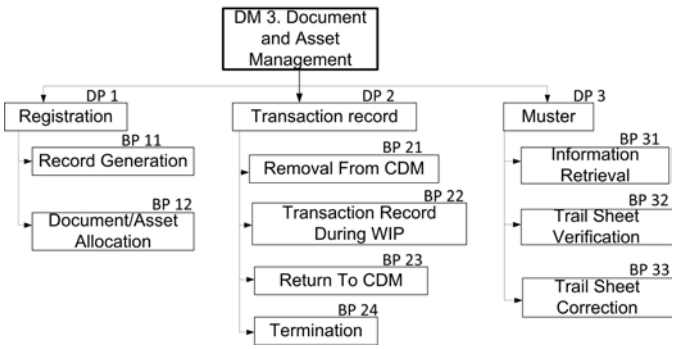


Fig. 1. CIMOSA overview of the AS-IS business model.

- Registration *(DP1)*: When new documents or groups of related documents (i.e. Drawing packs) arrive 1 of 2 employees from the Customer Data Management (CDM) department creates an entry for the document in an Excel table and prints one transaction trail sheet for the each storage location where the document or drawing pack can be stored *(BP11)*, currently there are 5 authorized locations.
  Once the document is inventoried if the document is not required for Work in Progress (WIP) it is placed by CDM staff in a secure cabinet located in the CDM office. Printed trail sheets for the document or drawing pack are placed at all storage locations and the transaction is stored manually both in the document's trail sheet at CDM and in an Excel table *(BP12)*.
- Transaction record *(DP2)*: When the document is required for WIP it is booked by 1 of 23 employees who possess the highest security clearance (i.e. *keyholders*). When removed from the CDM the keyholder must manually update the trail sheet for each of the documents or drawing packs removed *(BP21)*.
  During WIP if another employee needs the document the key holder is responsible for checking that the employee has a valid security clearance (i.e. required level and non-expired) to access the document. If this is the case the transaction must be manually recorded at the document's trail sheet kept at the storage location *(BP22)*. Only key holders are authorized to hand over possession of the document, once the employee has finished using the document he returns it to the key holder who assigned to him. When the document is not being used it cannot be placed in a different location that one of the authorized storage locations, it is the key holder's responsibility to enforce this and document it on the trail sheet *(BP22)*. When the document is not required for WIP anymore it is placed at the CDM storage location and its trail sheet is updated *(BP23)*. Finally, if no more customer orders needing the document are expected the document is either returned to the customer, destroyed or declassified whichever option is taken the transaction is recorded at the CDM trail sheet, at this point transaction records from all trail sheets are transcribed by a CDM staff member to an Excel table *(BP24)*.
- Muster *(DP3)*: The accuracy of the transaction records is tested at random times by a government agency. In order to ensure that the records are correct CDM staff will verify where the documents are using all the storage location trail sheets. An inventory of the documents in CDM and WIP is gathered from Excel tables *(BP31)*. CDM staff visually confirms that the current owner and location for the document correspond to the last dated record in the trail sheets *(BP32)*. When owner and last record do not coincide CDM staff must contact previous document owners

to determine where the trail was lost and update the transaction records accordingly *(BP33)*.

Currently the CEM has an average of 1000 documents in its possession, each one subject to an average of 60 transactions during the processing of a customer's order (i.e. design, manufacture and testing of PCA assemblies). Although the current procedures have been successful complying with the safety requirements, there is considerable risk that reliance on employee's good behaviour and manual transcription can lead to non-compliance with stated rules.

B. Process re-engineering: To Be model

By allowing real time enforcement of security rules (i.e. clearance, location, integrity) and automated record of transactions the proposed RFID based management aims to reduce the risks involved in the AS-IS model.
An overview of the re-engineered processes is shown in Fig. 2 using CIMOSA constructs.

- Registration *(DP1)*: After receiving a new document CDM staff member updates the document inventory using the RFID tool front end *(BP11)*. Instead of being stored in an Excel table this information is held in a relational database. In order to identify each document an RFID tag placed on the document is programmed with a unique identifier *(BP11)*. Clearance level, security rules and storage location information are also stored using the RFID tag's user memory.
  Until the document is placed into a storage area its trail sheet, held as a different table in the relational database, will show CDM staff as its current owner. When placing the document in the CDM office secure cabinet the employee must present its identification card containing an RFID tag programmed with a unique identifier, clearance level, clearance expiration date, forename and surname information and then place the documents being placed in the cabinet *(BP12)*. The transaction for each of the documents is automatically stored in its trail sheet.
- Transaction record *(DP2)*: Before removing a document the keyholder must identify himself using his ID card, after selecting the documents to be retrieved security clearance are checked and the transaction is authorized or denied. If the transaction is authorized the documents are presented to an RFID reader and their trail sheets are updated *(BP21)*. If on the contrary the authorization is denied a message is sent to CDM staff and a record of the failed transaction which includes the employee and documents involved is stored in a database table.
  When an employee needs a document during WIP both the keyholder and the employee must identify themselves and present the documents to be exchanged. Using the information stored in the RFID tags and the transaction records the system makes sure security rules are being followed. If the transaction is not authorized a record of the failed transaction is stored and a message is sent to CDM staff. When transactions are authorized the tool updates the corresponding trail sheets *(BP 22)*.
  When documents are returned to a key holder or storage location *(BP22)*, to CDM *(BP23)* or are terminated *(BP24)* trail sheets are updated accordingly using the identifiers from the documents and employees involved in the transactions.
- Muster *(DP3)*: Inventory of the held documents in CDM and WIP is achieved using a reporting tool that retrieves information from the relational database *(BP31)*. Instead of a visual verification for the correspondence between the documents and current owner the detected location for the RFID tags is used *(BP32)*. As the trail sheets are updated automatically no corrections to them is expected.
  In case of loss of a document its last owner can be retrieved from the trail sheets and its general whereabouts can be determined from the reader antenna that detects the tag document.
  An additional advantage that the RFID tool allows relates to the real time enforcement of security rules. Using information stored in the document's tag the tool determines the type of rule(s) the document is subject to *(BP33)*.
  When faced with a location rule (i.e. the document must be kept in a specific area) the reader's location is compared to the allowed locations for the

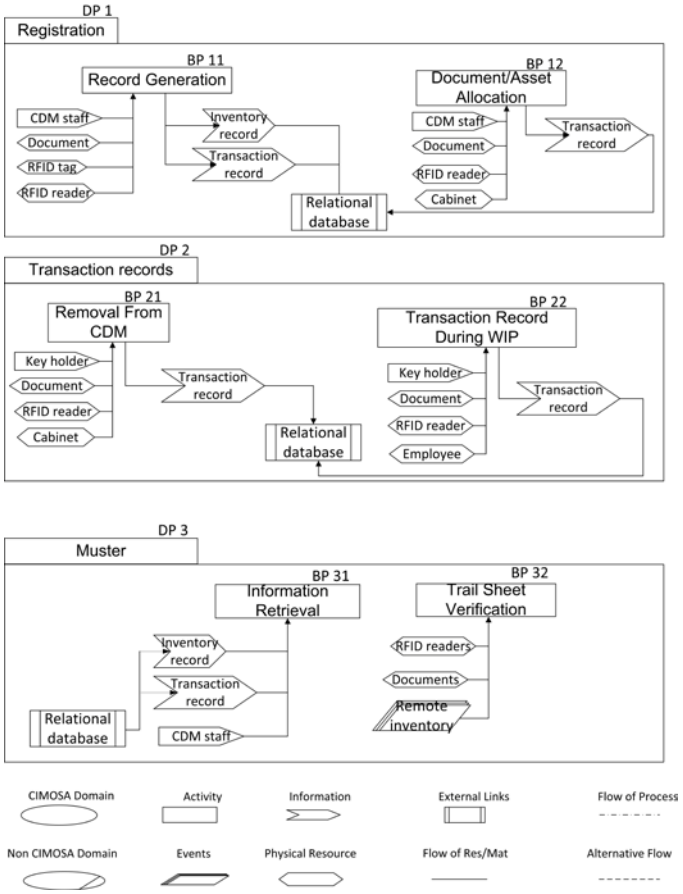


Fig. 2. CIMOSA overview of the TO-BE business model.

document. In case a violation of the rule is detected a message is sent to CDM staff and a record is made in a database table. A similar procedure is carried out when an integrity rule (i.e. documents must be kept together at all times) is encountered but instead of checking for allowed locations the tool checks for the presence of expected document in the same area.

IV. PROPOSED HARDWARE ARCHITECTURE

As mention previously RFID has been successfully used in application scenarios demanding traceability and control requirements. Unfortunately the performance of RFID tags is considerably affected by the presence of critical environment conditions [15, 23]. For the particular application addressed in this paper this critical environment conditions include the presence of metals, high number of tags in the same area and misalignment between the reader antenna and tag antenna.

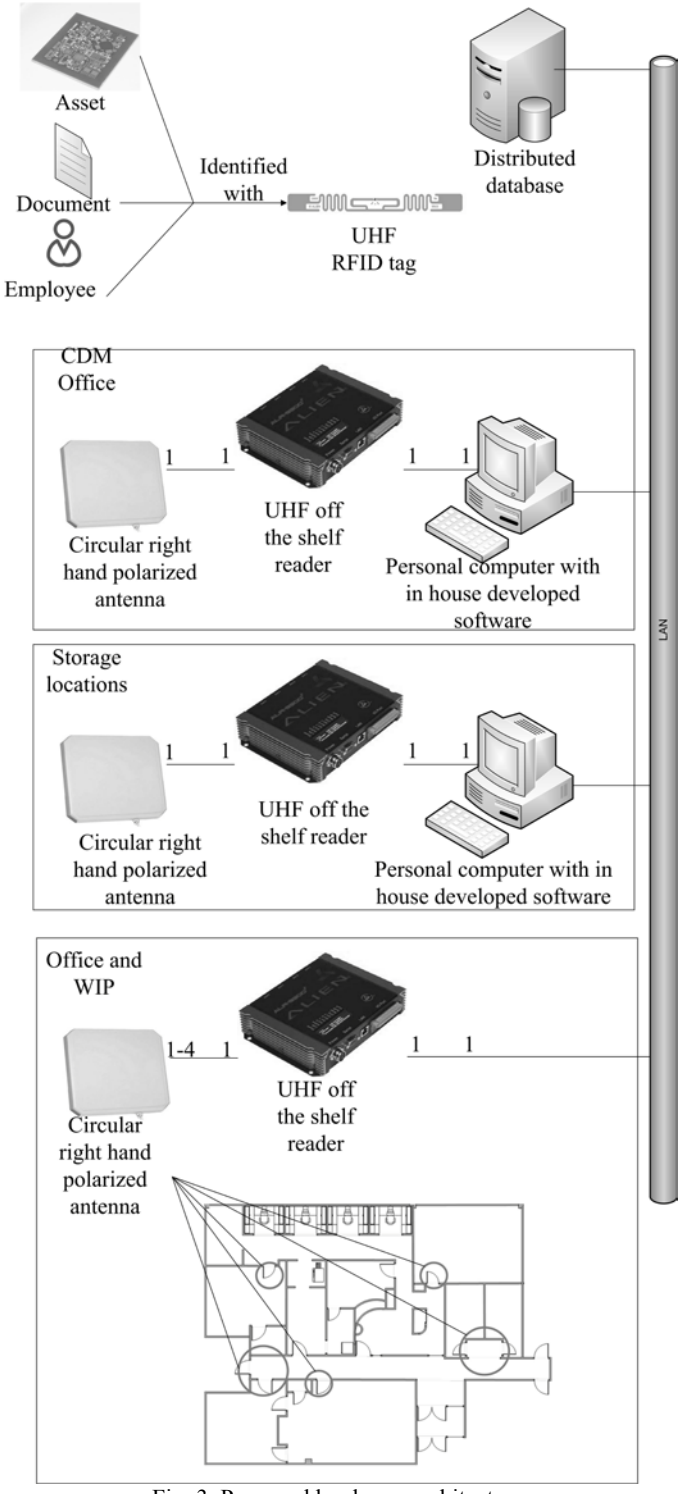


Fig. 3. Proposed hardware architecture.

A. Hardware architecture description

Currently there are 2 main RFID solutions being used for manufacturing applications, High Frequency (HF) and Ultra High Frequency (UHF). Choosing one or the other will have a direct influence on the performance characteristics (i.e. read range, data transmission rate, orientation and material sensitivity) expected. Offering a bigger read range (e.g. up to 10 metres) and considerable data rates (e.g. 400 tags/sec) UHF frequency is the preferred solution in supply chain applications [24]. Furthermore, being less sensitive to orientation between the reader antenna and tag antenna than HF [25], UHF is the solution chosen for the application addressed in this paper.

As shown inFig. 3 commercial off the shelf UHF tags (Alien ALN-964) are used to identify each document, asset and employee. During Registration *(DP1)* a commercial of the shelf UHF reader (Alien ALR-9900) connected to one circular right-hand polarized antenna (Alien ALR-8696-C) is used to program tags with document, asset or employee information respectively.

A distributed relational database is used to store inventory, transaction, security rules and system configuration information. Because the nature of the information to be held is fairly constant and is easily organized into defined schemas a non-relational database was not considered for this application [26, 27].

Each of the authorized storage locations, 5 safe cabinets in this case, has a UHF reader connected to a reader antenna. When the documents are placed, removed or assigned/returned to an employee the in-house developed software shows the procedure to follow, checks security rules are being enforced and stores the successful or unsuccessful transaction in the distributed database.

Each room door is fitted with a reader antenna connected to a UHF reader, depending on the dimensions of the room more than one antenna can be connected to the same reader. Information from the document, assets and employee tags detected by the reader is used to enforce security rules. In case of non-compliance the event is stored in the distributed database.

B. System performance limitations

B.1 Testing aims and procedure

It is known that RFID solution performance is affected by critical environment conditions. However, in order to establish the validity of the proposed solution beyond a theoretical concept its performance limitations must be established, this is the objective addressed with the testing carried out.

Test results are either presented as a percentage detection rate or Received Signal Strength (RSSI) magnitude whose values were provided by an Alien ALR-8800 connected to 2 circular right hand polarized antennas. The reported RSSI magnitudes are the average value for 30 samples and are characterized by a 95% confidence level. Testing was not carried in an anechoic chamber but in order to isolate the effect of environmental factors other than the ones of interest testing was carried under the same conditions. Although the RSSI value reported is only an indication of the received power and is referred to a normalization value high RSSI magnitudes guarantee reliable data transmission between the reader and the tag, for the reader used during the testing an RSSI value of 500 has shown to be threshold after which reliable data transmission is achieved.

It is also worth noting that because some of the testing is done using a specific type of cabinet the results presented here are by no means general. Nonetheless, the test results presented do show the performance limitations of the RFID based management tool presented.

As shown inFig. 4 three main aims were set for the testing (i.e. determine the effect of tag to tag interference, determine the influence of the metallic cabinet, determine the best reader antenna location). The issue of the influence of paper on RFID tag performance was not addressed due to it not being significant [28][29, 30].

Interference from the cabinet and best antenna location, were observed by detection of tagged documents inside the cabinet's drawers for all possible antenna locations in the drawer (see Fig. 4). Documents were tagged with RFID tags placed in the same location and care was taken to guarantee all documents were placed in the same orientation.

Tag to tag interference was observed by replacing the drawer with a cardboard drawer. Once again documents were placed in the same location and orientation (seeFig. 4)

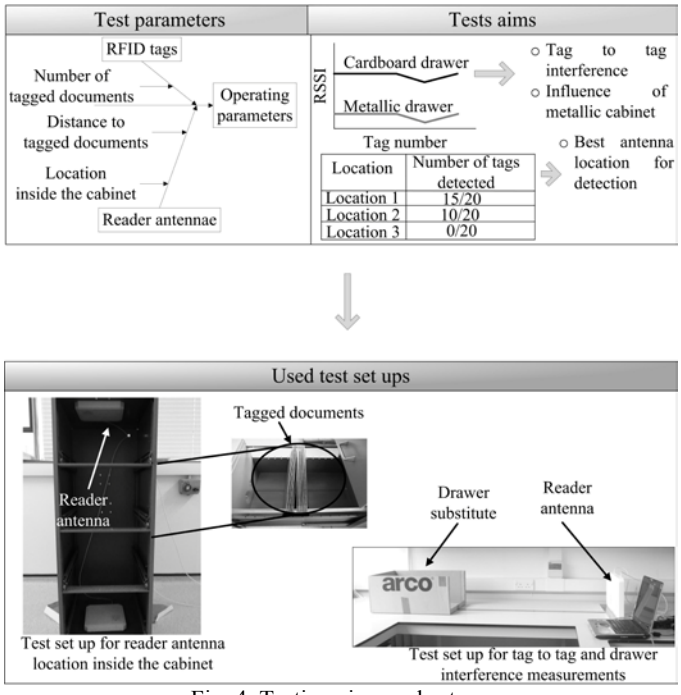


Fig. 4. Testing aims and set up.

B.2 Test results analysis

1. Reader antennae set up inside the cabinet

Muster tasks *(DP3)* demand a visual verification of the held documents and assets is a time consuming process, 2 weeks in average if no problem is found. Although this time can be reduced with the aid of a hand-held reader [31-33] a better approach would be to enable a remote inventory.

After placing two[34] reader antennas, number limited by cabinet's size constraints, at all possible locations in the cabinet a remote inventory was carried out, the results of which are shown in Fig. 5.

Despite there not being an antenna location set up capable of achieving 100% detection rate, some set ups do exhibit better performance than others. The reason for this performance variation seems to be the distance between the reader antenna and the documents. When the distance is large detection is low or non-existent and when the distance is low although 100% detection rate is still not achieved the worst encountered detection rate is 70%.

Given that the Muster tasks *(DP3)* demand a definitive knowledge of the document's current location, assumption of the same from the last stored location or transaction record is not an option. Although it would be possible to reduce the distance between the reader antenna and the documents by using smaller reader antennas, the lower output power (24.8 dBm) provided by them has achieved a detection rate of only 80% [35].

Under this circumstances the use of the developed system for inventory activities during the Muster *(DP3)* business process are limited to the accuracy of the transaction trail sheets.

2. Tag to tag influence on reader performance

Despite being capable of high data transmission rates, the effect tag to tag interference is a well-known issue in UHF RFID applications [34]. Given the amount of documents held inside a cabinet this is an issue that must be considered for

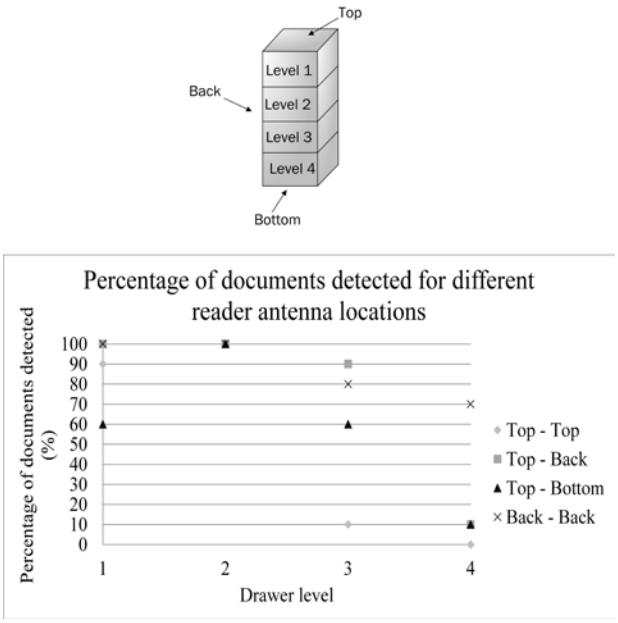


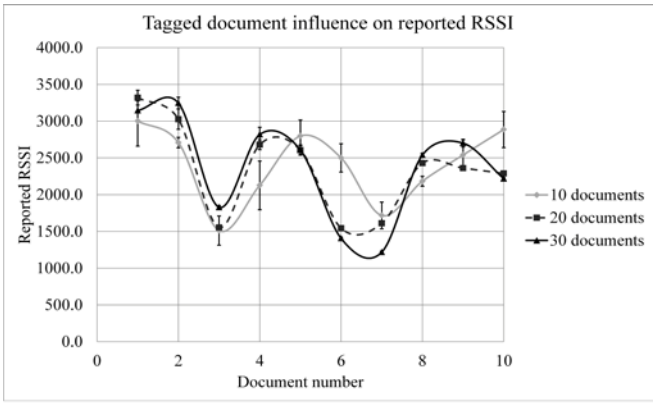
Fig. 5. Percentage of documents detected for different reader antenna locations.

this application scenario.

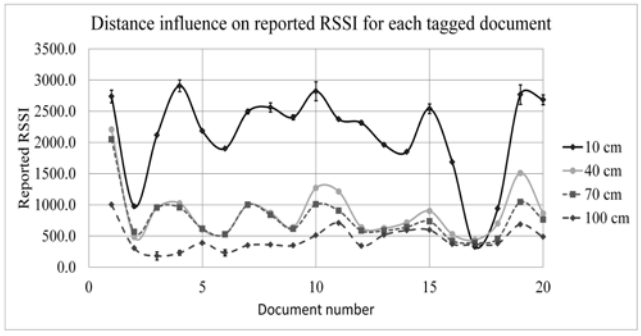
After removing the influence of the metallic drawer, by replacing it with a cardboard box, an increasing number of tagged documents were placed inside while the RSSI magnitude for each one was measured. The test was repeated at several distances between the reader antenna and the drawer to observe the variation of tag to tag influence with such distance.

Although the RSSI value does seem to vary as the number of tagged documents increases its magnitude does not seem to be significantly large to claim any effect from tag to tag interference (see Fig. 6.A). After conducting a two way ANOVA without replication of the RSSI magnitude no significant difference due to the number of tagged documents were found $F(2,18) = 0.59, p > 0.05$. The fact that irrespective of the number of tagged documents the RSSI magnitude follows a similar pattern (i.e. large positive or negative variations occur either on the same or around the same document) suggests that the influence of an object in the test location is responsible for the variations.

As shown in Fig. 6.B irrespective of the distance between the reader antenna and the tagged documents the RSSI magnitude follows a similar pattern which variation (i.e. difference between the RSSI magnitudes for two adjacent documents) decreases as the distance between the reader antenna and the tagged documents increases. As it has been proofed that the tag to tag interference is not significant results suggest that the influence of the object in the test location can be diminished just by altering the distance between the reader antenna and the documents.



A). Tag to tag influence on reported RSSI.



B). Distance influence on reported RSSI for each tagged document.

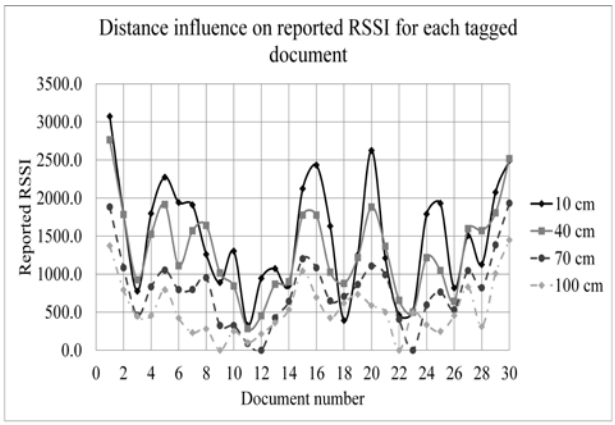
Fig. 6. Tag to tag influence on reader performance.

3. Drawer influence on reader performance

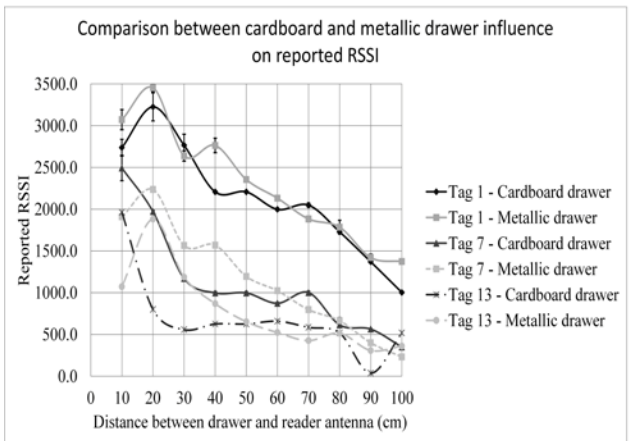
To determine drawer interference, a set of 20 tagged documents were placed inside a metallic drawer while the RSSI magnitude was measured for increasing distances between the reader antenna and the drawer.

As shown inFig. 7.A the RSSI magnitude exhibits considerable variation for all the tested distances. Similarly as observed for the tag to tag interference, the RSSI magnitude follows a similar pattern irrespective of the distance between the reader antenna and the documents. However, although the variation does decrease as the distance between the reader antenna and the documents increases the decrease seems to happen faster.

When the RSSI magnitude for the same tag in a cardboard and metallic drawer are compared(seeFig. 7.B) different trends are observed. When placed in a metallic drawer the RSSI magnitude after 30 cm exhibits a decreasing linear trend. However, for the same conditions when placed in a cardboard drawer the RSSI magnitude has a much smaller decrease and in cases centres around a magnitude. Such behaviour suggests that the metallic drawer can reduce the influence of surrounding objects if the reader antenna is placed facing



A). Distance influence on reported RSSI for each tagged document inside a metallic drawer.



B). Comparison between cardboard and metallic drawer influence on reported RSSI.

Fig. 7. Drawer influence on reader performance.

directly to the tagged documents.

V. SOFTWARE ARCHITECTURE

Although the developed system has been designed with a particular application in mind making the data structures (e.g. employee, document, asset) and business rules (e.g. clearance, location, integrity)unique to the application, traceability and control requirements are common to several other application domains. Developing an architecture that can be customized for different applications with a common core is desirable.

A. Service oriented architecture approach

Despite being successful in fulfilling set requirements, the usual software development process followed to create new applications is inefficient, expensive and not flexible as applications are designed for an immediate set of requirements [36, 37].

In order to enhance efficiency through reuse and agility software development makes use of different styles of architectural guidelines, Service Orientation being one of them. Architectures based on Service Orientation (SO) principles focus on a separation of concerns where solution logic is distributed in one of two layers: (i). A *business layer* containing business specific processes and knowledge, (ii) An *application layer* in charge of managing the computational resources used to support the business processes.[37]. The reasoning behind this separation being the independence between the functionality provided and how this functionality is achieved.

B. Software architecture description

Although the architecture followed for the development of the presented document and asset management tool is SOA, implementation is not achieved using Web Services (WS). Despite several applications using WS to implement SOA architectures[38-42], tying SOA to a specific technology goes against loose coupling and abstraction SO principles[37]. As shown inFig. 8 a collection of business and application tasks organized in classes, modules and software layers has been used for the development of the presented tool.

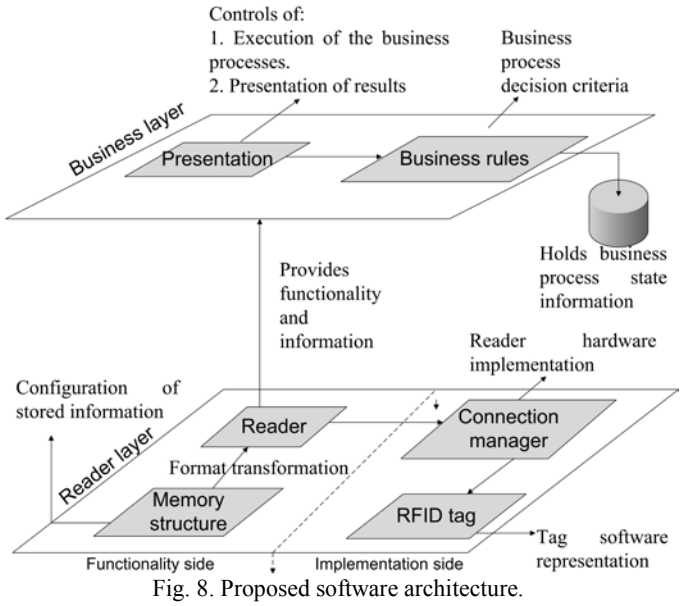


Fig. 8. Proposed software architecture.

As shown in Fig. 8records are kept in a *distributed database*, these records not only keep a registry of the documents/assets held but also of the business rules linked to them. The actual decision making process is carried out by the *Business rules* class in the *Presentation layer*. The front end (i.e. the display of the information in a relevant format according to the user) is responsibility of the *Presentation* class in the *Presentation layer*. Because both the specific business rules and information presentation are particular to the application they are part of the business specific logic of the solution as required by SOA characteristics. In case new business rules or users are required changes are done in the *Presentation* layer without having influence on how the required information is acquired.

By required information it is meant the properties of the document, asset or employee involved in the business process. In order to keep a relevant and business relevant data structure the length, type, and format of the information is defined in the *Memory Structure* module of the *Reader layer*. Besides providing the transformation from a business specific format to the approved format (hexadecimal) for storage in the RFID tag the *Reader* class in the *Reader layer* provides the functionality offered by the RFID reader, examples of such functionality are to read or write to user memory banks, search for specific Electronic Product Code (EPC) identifiers or generate a list of the RFID tags close to the reader. Being EPC or memory bank concepts that have no meaning to the user the *Memory structure* module transforms them into the business specific format before passing them to the *Presentation layer*. In case the required information at the *Presentation layer* changes it is the *Memory structure* that needs to be modified but how the information is stored in the RFID tag remains the same.

Although the functionality is provided by the *Reader* class the implementation is done at the *Connection manager* class. Despite having to provide the commands defined on the EPC Class-1 Gen 2 standards access to the functionality offered by each reader is done using proprietary Application Programming Interfaces (API) provided by each vendor. By maintaining a separation between the functionality and the implementation the integration of a new reader demands a new instance of the *Connection manager* class and not the development of a whole new application. Because the *Presentation layer* interacts only with the functionality contained in the *Reader* class the technology being used has no impact on this layer. An RFID system involves a reader and tags which software representation is contained in the *RFIDtag* class and represented tag related properties (e.g. EPC, memory bank).

Both the *Connection manager* and *RFID tag* classes are solution agnostic since it is at the *Reader* class level where the *Memory structure* module is used to give the information its business specific format. By maintaining this separation between business and application logic the *Readerlayer* can be used as an independent component provided that the *Memory structure* is defined accordingly for each new application. On the other hand, by maintaining the business

specific logic separate new applications within the same domain can be supported provided they follow the *Memory structure* defined.

VI. DEVELOPED SYSTEM EVALUATION

A quantitative evaluation of the benefits allowed by a system can be carried out using Activity Based Costing (ABC) [43]and Discrete Event Simulation (DES) [44] by comparing the costs incurred in the activities described in the AS-IS and TO-BE models.

Simulations using Arena (Version 13.0) were performed to establish the cost, time and efficiency for the AS-IS and TO-BE models. Simulations were based on a 9 hour day and a working month of 20 days. A total of 10 replicates were performed and both the system and statistics were initialized between them. All processes modelled were classified as non-value added (NVA) as document and asset management is an obligation rather than a service. The simulation time for each replicate was 12 months. Some of the most important simulation parameters are shown in Fig. 9, their values were determined from measurement carried out at the CEM site.

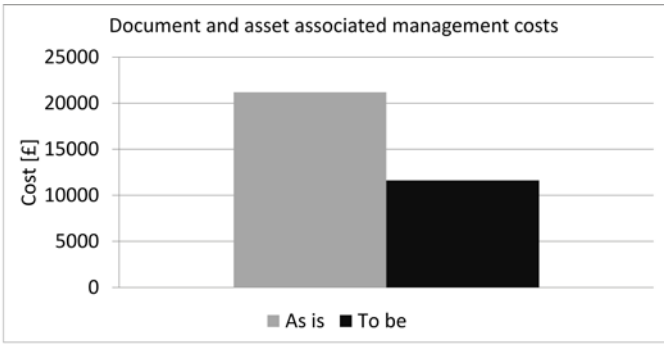
Implementation of the proposed system allows a reduction of nearly 45% in the cost associated to the document/asset management tasks (seeFig. 9). This represents a reduction of 42% in cost for the management activities involved for a single document/asset and 39% for drawing packs. With an average of 1000 documents this figures are significant.

The results show that economic benefits can be achieved by the implementation of the proposed system but do not reflect the increase in efficiency for the process. To do so the *wait time cost* (i.e. Cost for the time spent by an entity in queue before being processed at an activity) for the process was determined. The *wait time cost* reduction achieved for a single document is 20% and for a drawing pack is 14%.

A big portion of the cost involved in the activities can be attributed to the *CDM* staff and their involvement in the registration and record verification processes. The DES results showed that the time *CDM* staff would save with the implementation of the proposed system is 59% for the manager and 49% for the rest of the employees. Considering that the department is composed of only two employees, whose job is not limited to document/asset management, the biggest benefits can be achieved in this department.

TABLE I. SIMULATION INPUT PARAMETERS.

Activity	Resource required	Time required (min)
Document arrival	None	EXP(3), 5 documents per arrival
Document registration (No RFID)	CDM employee	TRIA(5,10,15) per document
Document registration (With RFID)	CDM employee	TRIA(5,10,15) per document
Digital trail sheet update (No RFID)	CDM employee	TRIA(10,15,20)
Digital trail sheet update (With RFID)	None	None



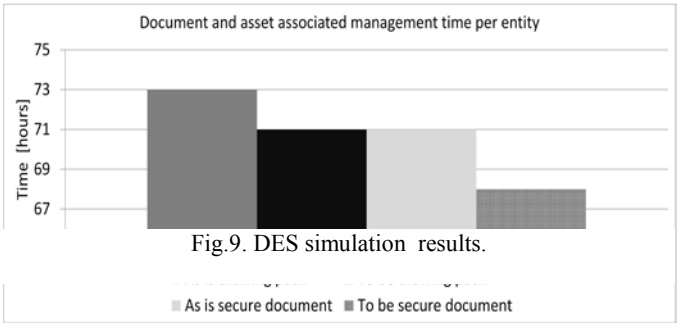


Fig.9. DES simulation results.

Although the implementation of the system allows a reduction in the cost and time involved in the document and asset management process, a greater benefit is the reduction in the probability of occurrence of a noncompliance event. Establishing the magnitude for the reduction in the probability of occurrence would require gathering data from the actual implementation of the system. However, it is clear that the real time enforcement of business rules and recording of transactions allow such probability of occurrence to be reduced.

VII. CONCLUSIONS

Despite the fact that digital formats have been around for several decades by now and that the advantages they present over printed ones are undeniable, the fact that the latter are still used makes it clear that in the future a combination of both formats will be used to support different business activities. As a result, further research on tools for management of printed formats is required.

A system which provides automated management of printed formats within the specific format of CEM, although not restricted to it, where strict business rules are enforced was presented in this paper. The system integrates both hardware and software architectures that have been tailored to address a particular problem.

The RFID based hardware architecture was tested under the harsh environmental conditions found in the application domain. It was found that although a large number of tagged documents are present the interference each has on the other is not significant, especially when compared with the effect that the environment has on the performance of the system. On the other hand, the presence of large metallic container such as drawers was found to have an effect dependant on the relative orientation between the tagged documents and the reader

antenna. These two observations suggest that even if RFID performance is affected by the surrounding environment reliable operation of the system is possible if chosen placements for the reader antennae favour direct facing between the tagged documents and the reader antennae. Although the capability of real time inventory of the stored documents within cabinets is desired, no antennae placement can guarantee a 100% detection rate.

By isolating the business logic in the *Presentation layer* changes in the business process are managed in either one of the two classes contained in this layer. The *Reader layer* which domain specific context is given by the proposed *Memory structure* module is solution independent and can be provided as an independent component that can be used either for business processes in the same domain or for new applications where traceability and/or controllability requirements are present. Although the architecture is tied to no specific implementation technology, RFID, loose coupling for the reader vendor is enforced by maintaining the separation between the functionality offered and its implementation.

The system was evaluated by means of comparison between DES models of the “As-Is” and “To-Be” business processes. Even though benefits of up to 60% on the time staff responsible for document management is involved in such process or 45% for the total cost demanded by the document management process, the greatest benefit which magnitude needs to be determined after the system’s implementation is the reduction in the probability of occurrence of a noncompliance event. By allowing real time enforcement of business rules and recording of transactions the system not only allows for a more efficient document management process but also address risk factors due to reliance on employee adherence to rules.

Although the presented system was developed for a particular application the same requirements and characteristics can be found in different domains. The limitations of RFID performance in harsh environments can be considered in such different domains. More importantly, the software architecture can be customized easily for such domains by modifying the business context specific *Memory structure* module. The proposed architecture is being used to support product lifecycle information management in the electronics supply chain [45] and material handling in the automotive industry [46].

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