A research agenda for Autonomous Business Process Management

Thomas Neubauer, Gernot Goluch, Bernhard Riedl
Secure Business Austria
neubauer, goluch, riedl@securityresearch.at

Abstract

Fast changing requirements, regarding different types of resources such as personnel or IT-systems, require companies to adapt their business processes in a very agile but yet sophisticated way. Most of today's companies fail in accomplishing this goal because of too static business process analysis and management approaches. The Autonomous Business Process Management methodology presented in this paper enables companies to self-adapt to changing requirements as they happen using emerging technologies and concepts, such as RFID, nanotechnology or Autonomous Computing.

1 Introduction

Today, most CEOs believe that their companies are not adaptive and agile enough to cater to changes in their current markets and at the same time pursue emerging opportunities [7]. As this study shows, CEOs a) urgently want to implement a competitive intelligence capability that allows the organization to react quickly and b) must anticipate and respond almost intuitively to changing customer needs. As the production sector slowly begins to deal with these issues appropriately (e.g. mass customization, on-demand production), companies in the service sector are often overstrained by trying to react to fast changing requirements. With the decreasing life cycle of change, the gap between determined requirements and a corporate response is increasing, because companies fail in keeping pace with the pressure of adapting their business processes and resources (e.g IT-systems or personnel) to fast changing business requirements. RFID technology holds great potential for efficiently mastering these challenges, but is just the beginning of a new era. The real potential could be realized in conjunction with complementary technologies such as sensors, nanotechnology and autonomous elements and their integration to a business process environment that allows the agile and dynamic management of corporations. Sensor technology enables RFID to track the status of objects, by monitoring e.g. temperature, pressure, movement or even the presence of bacteria. Nanotechnology can help make RFID smaller, so that it can be used more conveniently for a wider range of applications [6].

However, as current research primarily focuses on technical issues of these emerging technologies, RFID and autonomous computing require to radically rethink business and thus, demands fundamentally new methods for the efficient management of corporations. Companies understanding how to align their strategies, with regard to these new technologies, will have major competitive advantages because of their reduced reaction time to new business requirements. This paper introduces a research agenda for *Autonomous Business Process Management* that aims at developing a methodological framework for the agile and autonomous management of corporations. In this context, the word "agile" refers to the fact that today companies have to cope with fast changing requirements of the market and their customers. The word "autonomous" has a twofold meaning: Firstly, it refers to the fact that operative data is collected constantly by independent and self-managing devices. Secondly, this data stream is used to automatically allocate the optimal set of business processes and resources needed for the execution of these processes in real-time, according to the given corporate requirements and constraints. Different technologies and concepts are used to reach the goal of *Autonomous Business Process Management*: a) *RFID*, used as the main data and information gathering component in the first development cycles of the presented approach, b) the emerging *nanotechnology* as a successor of RFID and c) *autonomous computing* concepts to conquer rising system complexity. The approach presented in this paper aims at reducing the rising gap between market requirements and the ability of companies to fulfill theses requirements by allowing companies to self-adapt to changing requirements as they happen.

2 Related Work

This chapter evaluates related work in the research areas of Business Process Management, RFID, Nanotechnology

Second International Conference on Availability, Reliability and Security (ARES'07)
0-7695-2775-2/07 $20.00

as well as Autonomous Computing and identifies the major challenges regarding the efficient use and management of these technologies in the context of Autonomous Business Process Management.

2.1 Radio Frequency Identification

Radio Frequency Identification (RFID) has gained increasing attention from research and industry over the past years. This emerging technology allows the contactless tracking and tracing of physical objects. On the one hand, the use of RFID promises to reduce costs and streamline business processes by improving efficiency as well as effectiveness. On the other hand, the upcoming RFID-technology forces companies to make use of the new opportunities in order to stay competitive. AMR Research [2] asked nearly 500 companies about their plans related to RFID-technology. A third of them are evaluating the use of RFID in 2006, whereas a quarter of the questioned participants are currently running pilot-projects. The range of applications varies from "Track and Trace", inventory management, asset tracking to quality control. As the price of RFID-Transponders, detectors and related middleware decreased to a level where more and more applications become reasonable, the RFID market is growing fast. Analysts predict tremendous growth for RFID in supply chain management during the next several years. For example, Venture Development Corporation expects the global shipments of RFID systems in manufacturing, logistics, and retail markets to reach $4 billion in 2007, up from $1.25 billion in 2004. The market size of ubiquitous network society enablers is estimated to grow to $7 billion for 2008, and by 2015, the market may reach $24 billion, according to several estimates [6].

Rainer Kerth, senior architect for IBM's RFID-division, says that the true return on investment on RFID will come when the technology is integrated within an enterprise's business process architecture. In fact, RFID could be considered one of the essential building blocks for a smoothly integrated service-oriented architecture (SOA). "The business process is, in fact, the one component in the overall RFID-infrastructure where you can actually generate return on investment significant value beyond the fact you just captured RFID-data" Kerth says. As detailed process descriptions are as essential as continuous maintenance and process advancement to be able to operate anticipatory, RFID can help to understand existing business processes. RFID-technology allows to adapt or merge existing analysis methods and especially to create new ones. Business process analysis using RFID could be done in less time, consuming fewer resources but with more measured parameters, such as density, weight or temperature. Today, it is industry standard to use random sampling to track and trace items, tools, or documents through a process. Further methods include workflow analysis [1], benchmarking, failure mode and effects analysis [17], checklists, workshops or interviews.

2.2 Nanotechnology

Although nanotechnology is just at the beginning of its development, the buzz surrounding nanotechnology is comparable to that at the dawn of the digital revolution, which changed the face of how business operates today. In near future, appliance of nanotechnology will raise an enormous demand for the development of approaches and methods for the integration of these devices into daily business. In the long run, nanotechnology is expected to adopt many tasks that are currently fulfilled by RFID-tags, but will also bring up new opportunities [20]. Therefore we focus on this emerging technology in our approach, due to the great opportunities regarding monitor and sensor possibilities of business process entities. Nanotechnology is an umbrella term that covers many areas of research dealing with objects that are measured in nanometers. As a result nanotechnology is a hybrid science combining engineering and chemistry, which concentrates on the design, synthesis, characterization, as well as application of materials and devices on the nanoscale. In contrast to the Internet, which applied new technologies to many existing processes and businesses, researchers and practitioners agree that nanotechnology is about creating entirely new materials, products and systems (and therefore markets), as well as making existing products faster, stronger and better [20]. Nanotechnology is expected to have huge effects on many industries. This emerging technology is considered to be the basis of $1 trillion worth of products in the United States alone and will create anywhere from 800,000 to 2 million new jobs by 2015 [20]. As nanotechnology steadily enters evermore aspects of our life, it is becoming a foundation for the development of new materials as well as the development for new methods of computing [18]. Future scientific and technical needs for research and development at the nanoscale will have to concentrate on the following topics [5]: (a) nanotools to explore, analyze and manipulate at the nanoscale, (b) molecular assembly processes to construct novel materials and devise from nanoscale building blocks, (c) *new concepts for information technology*, (d) technologies to interface biological and synthetic systems and (e) the creation of a new knowledge base that will lead to major innovations in biological science and medicine. Focusing on information technology research in the field of system's integration principles and the development of design rules enabling the setup of complex architectures compatible with scalable technologies will be from vital and indispensable value [5].

2.3 Autonomous Systems

Pease [13] outlines a scenario for the application of Autonomous Networked Systems (ANTS) in 10-15 years, which will lead to the usage of self-managing and self-adapting mobile machines, able to handle specific tasks all by themselves. Moreover, he describes several techniques, which will be used by those machines, including RFID and nanotechnology, all combined within an autonomous system. Not addressed in this vision, and similar ones in the research field of autonomous networking systems, is the overall process of managing such systems by using business processes for the purpose of efficiently reaching a defined business goal, respectively the efficient management of data and information produced by such systems for the automatic definition and improvement of these business processes. Due to the increasing demand on dependable and effective computer systems, IBM proposed, inspired by the human body's autonomous nervous system, the Autonomous Computing concept as a valuable new approach in 2001 [10]: Indirect messages are sent to organs by autonomous controls at a sub conscious level, which regulate several "parameters", like breathing, temperature or heart rate, without any conscious thought. Implications for complex systems, such as computer systems, are the following: organized computing components building a network providing us what we need without any conscious mental or even physical input. Autonomous computing is an emerging area of study and a grand challenge for the entire IT community. Some components of this technology are already up and running, but complete autonomous systems do not exist yet. Autonomous computing is a radical change in the way businesses, academia and even the government design, develop, manage and maintain computer systems. Autonomous computing calls for a whole new area of study and a whole new way of conducting business.

IBM states several key challenges in the research field of Autonomous Computing [10]. "System Identity" covers the problem of systems knowing their boundaries extend, enabling them to make transactions with other systems, e.g. it is vital for designing fully autonomous systems to answer questions like: "How will we design our systems to define and redefine themselves in dynamic environments?" The building of consistent interfaces and points of control, while allowing the system to act in a heterogeneous environment, is another major research area subsumed under the keyword "Interface Design". Finding a systematic approach, which enables us to unite a constellation of autonomous components into a federated system, is probably one of the most thrilling research tasks for the next period in Autonomous Computing. Research issues, such as "Standards" and "Adaptive Algorithms", should enable system designers and architects to equip their systems to deal with changing environments and transactions. Following Asprey, there are five main research questions, respectively problems in the field of Autonomous Computing [4]. The first question listed is "Understanding and controlling emergent behavior" of system components, followed by the problem of "Learning in multi-agent systems". Models for "Negotiation and optimization" are needed for interaction between autonomous elements and for self-optimization. Solutions for the research problems "Architectures and networks" and "Programming languages and computational models" in the field of Autonomous Computing are required to make autonomous systems work with high performance and accuracy.

2.4 Challenges on the way towards Autonomous Business Process Management

As mentioned before, today's companies heavily depend on IT systems. Currently, Autonomous Computing focuses on solving technical issue of corporate IT-systems. However, the main challenge that demands the definition of fundamentally new methods and approaches is the consideration of the corporate business processes as an intermediate layer between business and IT. Therefore, known problems from the field of Autonomous Computing must be elaborated and adapted to the wider research field of business process management to generate a holistic approach and the following challenges have to be solved on the way towards realizing this vision:

- To stay competitive, processes have to be adapted and optimized for the use with RFID. Therefore it is necessary to understand the existing processes and to analyze the work flow of daily operations in the most realistic way. Traditional business process analysis that comprises the manual analysis and modeling of business processes is cost intensive and time-consuming. Studies show that up to 60% of workflow projects are used just for the definition of workflow models [9]. Moreover, traditional methods are error-prone, because experience and know-how serve as the basis. The automatic definition of process models provides better results regarding the criteria: completeness, minimality and specificity.

- According to Asprey [4], one of the grand research challenges of the 21st century in the field of information technology is to conquer system complexity. The increasing complexity of IT systems combined with a shortage of skilled IT professionals leads towards an inevitable need for a change in today's computer systems. Companies nowadays spend estimated 33% - 50% of their total cost of ownership for recovery

from or preparation for failures and 80% of their IT investments on administration, minor improvements and maintenance [12].

- The simultaneous explosion of information and integration of technology into everyday's life brought on new demands for how people manage and maintain computer systems. Demand is already outpacing supply when it comes to managing complex and even simple computer systems. Unfilled IT-jobs in the United States number in the hundreds of thousands. Even in uncertain economic times, demand for skilled IT workers is expected to increase by over 100 percent in the next six years.

- There are important technical, security and privacy-related challenges for enabling technologies such as RFID and RFID-supported sensors. RFID is by design easy to intercept, therefore, cryptographic safeguards are needed to guarantee confidentiality. Interoperability and standardization are required to ensure secure and reliable technological platforms in developing a stable network society. While the opportunities are immense, the scope and magnitude of potential threats and misuse grow correspondingly. In light of technical developments in RFID, there is an increasing need to ensure data protection and privacy. Even consumer boycotts were organized against companies planning the introduction of RFID, regarding concerns that such information-tracking will infringe on personal privacy and civil liberties. Information may also be misused (e.g. in "identity theft" fraud schemes), while concepts such as "ubiquitous surveillance" and the tracking of employees is soon becoming reality.

3 Autonomous Business Process Management - Research Agenda

The primary aim of our research agenda is the development of a new methodology for the agile and autonomous management of corporations. *Autonomous Business Process Management* (ABPM) starts from leading edge results in business process management, Autonomous Computing, RFID and nanotechnology. Therefore, the presented approach firstly aims at developing a method for RFID-driven business process analysis (Figure 1, part 1). This new approach means a fundamental change in business process analysis, as the actual state of business processes will be defined using RFID. To allow the automatic processing of data, collected during business process analysis, there is a need for further research regarding new methods and algorithms. Secondly, the project aims at developing a new methodology that allows the dynamic generation, autonomous adaptation and maintenance of business processes and the allocation of corresponding resources (such as IT-systems, personnel, ...) according to current corporate needs, restrictions and the corporate strategy (Figure 1, part 2). Exemplarily, in a hospital, several business process en-

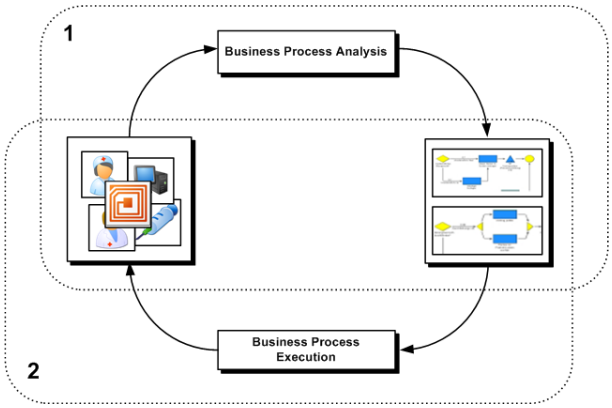

Figure 1. Autonomous Business Process Life Cycle

tities are tagged, respectively monitored, in real-time. The term "resources" refers to traditional resources, such as staff or computer systems, but also includes resources tagged with RFID, nanotechnology or autonomous devices such as ANTS. In the business process analysis phase, the gathered data is used to map the structure and business processes into the ABPM system. In the ongoing daily business, entities are monitored in real-time and gathered data is used as input for the ABPM system. At this point autonomous system concepts, such as self-adaptation, self-healing or self-optimization are used to optimize and adapt those business entities respectively corresponding processes. A sudden case of emergency for instance changes the need and availability of resources from one second to the other. At the same time the processes that are optimized to defined standard scenarios are obsolete and it is required to reallocate the available resources in dependence to the current corporate needs within seconds to allow the optimal reaction to the changed environment.

"Civilization advances by extending the number of important operations which we can perform without thinking about them." (Alfred North Whitehead, 1861-1947). This quote implies that millions of businesses, billions of humans that compose them, and trillions of devices that they depend upon all require the services of the IT industry to keep them running. The problem of system's complexity and the way different systems work together is creating a shortage of skilled IT workers to manage all the IT systems. This problem will grow exponentially, just as our dependences on technology will do. The solution may lie in automation,

or creating new capacities where important computing or business operations can run without the need of human intervention.

3.1 RFID-driven Business Process Analysis

RFID is not only capable of leading to new business processes, due to its ubiquitous nature, it can help to understand existing ones. A detailed process description is as essential as continuous maintenance and process advancement to be able to operate anticipatory. RFID-technology now allows to adapt or merge existing analysis methods or to create new ones. As we mentioned in the section before, a detailed workflow analysis could be done in less time with more adequate parameters. Today, it is standard to use random sampling to track and trace items, tools or documents through a process. By using RFID (or nanotechnology) it is possible to think about tracking all items through the workflow to measure the time they rest or the time they move from one station to another. The output of such an analysis could lead to shorter periods and it could improve process quality and transparency.

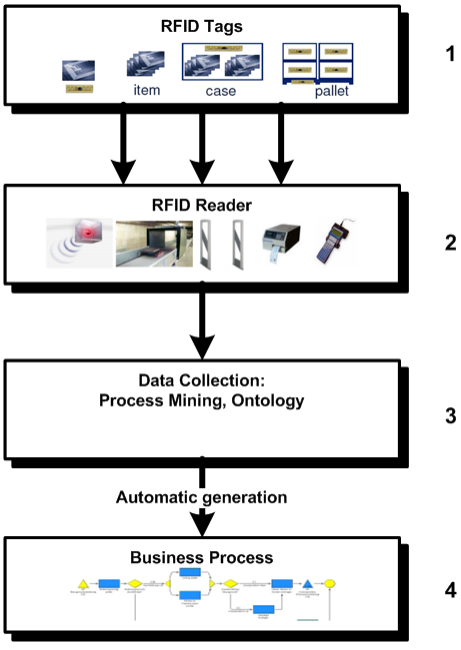

Figure 2. Autonomous Business Process Analysis

This approach provides an alternative to traditional business process analysis. Figure 2 shows the conceptual architecture of RFID-driven Business Process Analysis. The data of the relevant objects is collected using RFID tags (1) and RFID scanners (2). The gathered data is stored in a data collection (3) that serves as the basis for the automatic definition of the required business process (4). The major challenges for an efficient analysis of business processes by using RFID are:

- The definition of new methods and algorithms for installing the appropriate number and the adequate placement of readers within the organization's facility, as well as proper placement to avoid reader interference from other electro-magnetic radiation. Optimizing the placement of the RFID components is needed to create the appropriate kind of interactive environment in which RFID-related information can express its value [14].
- The definition of new methods and algorithms for efficient analysing, and interpreting data collected by using RFID for the generation of business processes and business process variants. These methods have to react in real-time to changing requirements and the agile environment.
- RFID allows tracking all items and resources of a workflow and measuring the time they remain standby or their processing time. The advantages of an automated analysis is a reduced use of resources (such as time and costs), as well as an improvement of process quality and transparency.

3.2 The Self-adapting Corporation

Figure 3 illustrates the way to the self-adapting (autonomous) corporation; thus passing several levels of business process management. Today's business process management techniques and tools comprise the basic level, requiring extensive highly skilled staff to analyze system or manually generated data leading to corresponding actions in the corporation, the managed level, where data, analysis and action is managed by corresponding tools, and the predictive level, enabling staff to work with already correlated data sets leading to recommended actions, of business process management. More sophisticated models such as agent based models [11, 22], touch the adaptive level of business process management by proposing system architectures which could be able to not only recommend but take actions concerning corporate business processes creation and optimization. Sterritt [19] identified several properties for building an autonomous system: An autonomous system has to adjust to changing circumstances (self-configuring), ensure effective recovery in case of faults (self-healing), be able to monitor and optimize its performance (self-optimizing), and defend against malicious attacks (self-protecting); thus leading to the main goal: a policy-driven self-managing system.

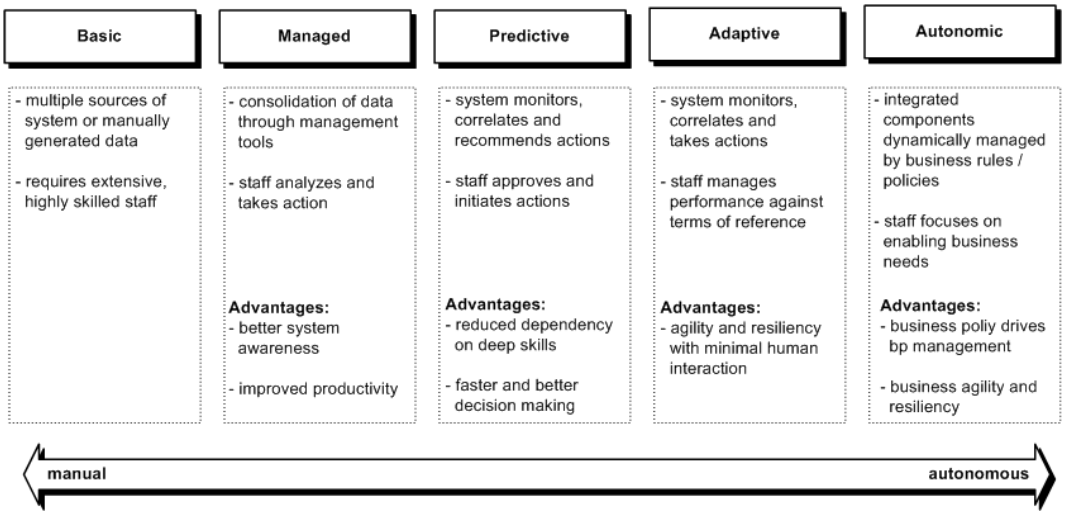

Figure 3. Manual to Autonomous Business Process Management

To comply with the objectives stated above specific attributes are necessary: The awareness of the system's internal state (self-aware), which has to be monitored (self-monitoring) and, if an adaptation has to be implemented, adjusted (self-adjusting), and external conditions (environment-aware) [19]. Sterritt and Bustard [19] outline two approaches for autonomous element's behavior and structure creation: through system engineering (a-priori done by domain experts) or adaptive learning (a-posteriori done by autonomous elements and corresponding rule sets). The key concept of any autonomous architecture respectively system is the autonomous element, which is defined as a component that is responsible for managing its own behavior in accordance with policies, which reflect the system's goals and how these goals should be accomplished.

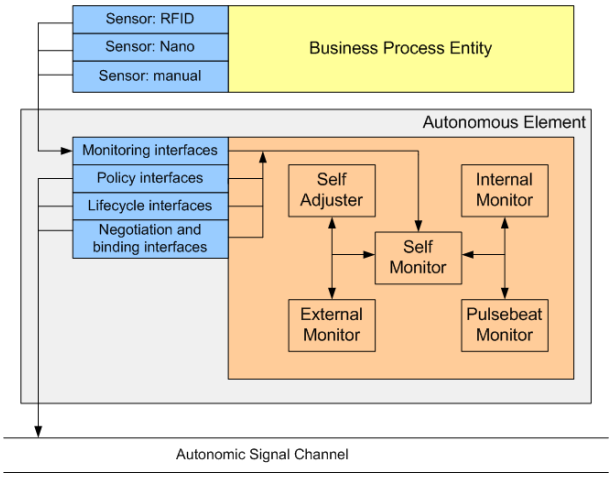

Figure 4. Autonomous Element in ABPM

Furthermore the autonomous element is responsible for the interaction with other autonomous elements to provide or consume computational service [21]. Sensors monitoring the behavior and comparing this with expected results, and effectors executing specific actions create a control loop [8]. In computer systems such an autonomous element (e.g. databases, web servers, etc.) consists of its main functionality (e.g. providing a database service) and specific implemented interfaces (e.g. a negotiation and binding interface) [21], which are used to implement the needed autonomous behavior. On the way towards Autonomous Computing systems today's power driven computing paradigm will need to transform to a data-driven paradigm. Granular and scattered computing devices will become more important than individual computers and response time instead of processor speed will be the number one benchmark for computing devices. Establishing a business process management system, respectively architecture, the autonomous level (compare figure 3) is our dedicated goal: Agile adaptation to current needs and restrictions of the corporate environment, enabled by the "real-time corporation" and automatic adaptation to given strategies, preferences and restrictions, will lead to the autonomous characteristics of self-adaptation, self-healing, self-protection and self-optimization of the corporation.

The "real-time" corporation consists of two main layers: the "real" corporate layer and the mapped computer simulated layer. Figure 4 visualizes these two layers, where the corporate layer includes the business process entities (e.g. an employee) and the corresponding sensor, and the mapped simulated layer comprises the corresponding autonomous elements, which provides functionality to reach the autonomous behavior of the whole composed (abstract) element (= business process entity and autonomous element). The autonomous element monitors the business pro-

cess entity via specific sensors (RFID, nano and/or manual), passing the data on to the self-monitor, which serves as central communication point. The external monitor analyzes and correlates this data and sends corresponding cognitions back to the self-monitor which passes it on to the self-adjuster. This module takes actions (e.g. a new service negotiation or optimization) according to specified business and system policies. The internal state of the element is monitored by the internal-monitor, which communicates corresponding analyzed data to the self-adjuster. The pulsebeat-monitor provides status information to other (authorized) elements via the autonomous signal channel. Beside the functionality of the self-adjuster stated above, all negotiations with other elements (superior or not) are handled by the elements negotiation module. Communication to other elements is established via well-defined interfaces comprising monitoring, policy, lifecycle, negotiation and binding activities.

3.3 Privacy and Trust

RFID tags offer information to every device which provides the necessary magnetic induction field to activate these tags. Hence an attacker, equipped with an adequate reader, could gain access to the data in the system and compromise the privacy e.g. of persons equipped with a RFID-tag. To avoid the scenario of plain-text access to information on our devices, we apply encryption of all data stored on RFID tags. Moreover, especially in the field of autonomous business process management where the combination of tags related with a timeline represents the actions employees set, it is necessary to appropriately handle the privacy issues that arise. Therefore, we propose an architecture that solves these privacy issues by concealing the collected data. We base our approach on a technique called pseudonymization (cf. [16]). Pseudonymization is an approach, where the identification data and the concealed data are stored separately in different databases. As the autonomous elements in our system represent people in the real world, it is necessary to assure the privacy of these people. By developing specific methods for the pseudonymization of the collected data we strive for granting the privacy of the participating persons. Furthermore, there are several potential attacks on a RFID-infrastructure: a) traditional hacking attacks, for example SQL- injections or buffer overflows, b) worms, which reproduce themselves by copying their content to another tag by compromising the middleware of the system and c) viruses are able to replicate without a proper network connection [15].

3.4 Benefits of the proposed approach

The return of investment (ROI) of using RFID depends on how corporations make use of this new technology. For example, if they only use RFID as a bar code replacement and do not adapt their underlying business process, the result will be suboptimal. Thus, companies are currently challenged to identify the potential of using RFID technologies. Many corporations argue that the ROI does not justify the initial investments for process re-engineering, the change of the IT-environment and integration. Others hesitate to make decisions without the existence of strong standards, or worry about privacy and social issues. In addition to these barriers, realizing the full potential of RFID within the organization's internal operations will require cost intensive integration with existing enterprise systems applications and likely business process redesign [3]. The expected benefits of the approach proposed in this paper are:

- RFID-driven business process analysis allows the fast and effective analysis of business processes. Compared to the use of traditional approaches for business process analysis, a significant reduction of cost and time can be expected because in traditional business process management projects about 60% of the effort are used for process analysis [9]. Moreover, problems of existing approaches such as faulty and biases data, can be reduced to a minimum.

- The reduction of administrative effort in terms of corporation system's stability and availability is another major expected benefit of the proposed approach. Additionally, a higher security level and fewer system or network errors are accomplished due to the autonomous system objectives self-healing and self-protection.

- Due to the proposed agile, respectively self-adapting autonomous business process management architecture, optimal adaptation of business processes and corresponding IT-systems to the corporate needs is accomplished. The proposed business process analysis and management approach guarantees simplified user experience enabled by a responsive real-time system.

- The proposed system enables faster reactions regarding unexpected events, which leads to cost reduction, and in the case of e-Health appliance even to saving of lives. Additionally, the vision of enabling self-optimizing business processes is realized by shifting available resources automatically from lower-order to higher-order business and negotiating, respectively adapting, trading relations between different business process entities.

- The proposed pseudonymization concept leads to a high and due to legal and social issues necessary, level of privacy and trust within the system.

4 Conclusions and Further Work

We proposed a methodology, respectively a research agenda, for the agile and autonomous management of corporations by introducing *Autonomous Business Process Management* that allows self-adaptation of corporations to changing requirements as they happen. Operative data is collected constantly by independent and self-managing devices such as RFID-tags, sensors or nanotechnology; thus enabling the ABPM system to automatically allocate the optimal set of business processes and resources needed for the execution of these processes in real-time, according to the given requirements and constraints. Additionally, a specific privacy and trust solution was developed, which is from high importance and vital interest for any appliance of the proposed approach. Future research will be geared towards the conceptual refinement of the presented methodology and in the alignment of the used technologies and concepts, such as RFID, nanotechnology and Autonomous Computing. Furthermore, one of the major research issues will be the implementation of a prototype for the automatic definition of business processes and the autonomic allocation of corporate resources according to this data and the given policies.

5 Acknowledgements

This work was performed at Secure Business Austria, a competence center that is funded by the Austrian Federal Ministry of Economics and Labor (BMWA) as well as by the provincial government of Vienna.

References

[1] R. Allen, "Workflow: An introduction," *WfMC External Relations Comitee*, 2005.

[2] AMR Research, http://www.amrresearch.com/, 2006.

[3] F. Asif and M. Mandviwalla, "Integrating the Supply Chain with RFID: A Technical and Business Analysis," *Communications of the Association for Information Systems*, vol. 15, pp. 393–426, 2005.

[4] W. Asprey, "Conquer System Complexity: Build Systems with Billions of Parts," in *CRA Conference on Grand Research Challenges in Computer Science and Engineering*, 2002, pp. 29–33.

[5] H. Brune, H. Ernst, A. Grunwald, W. Gruenwald, H. Hofmann, H. Krug, P. Janich, M. Mayor, W. Rathgeber, G. Schmid, U. Simon, V. Vogel and D. Wyrwa, *Nanotechnology*. Springer Berlin - Heidelberg, 2006.

[6] R. Das and P. Harrop, *The Internet of Things*. IDTechEx, Cambridge, 2001.

[7] IBM Business Consulting Services, "Companion guide to Your Turn: The Global CEO Study 2004"

[8] A. Ganek and T. A. Corbi, "The dawning of the autonomic computing era," *IBM Systems Journal*, vol. 42, pp. 5–18, 2003.

[9] J. Herbst and D. Karagiannis, "An Inductive Approach to the Acquisition and Adaptation of Workflow Models," in *IJCAI'99 Workshop on Intelligent Workflow and Process Management: The New Frontier for AI in Business*, 1999, pp. 52–57.

[10] P. Horn, "Autonomic computing: IBM's Perspective on the State of Information Technology," IBM Research, Tech. Rep., 2001.

[11] N. R. Jennings, P. Faratin, M. J. Johnson, T. J. Norman, and M. E. Wiegand, "Agent-based business process management." *International Journal of Cooperative Information Systems*, vol. 5, pp. 105–130, 1996.

[12] D. Patterson, "Availability and Maintainability, Performance: New Focus for a New Century, (FAST 02),," in *Keynote, USENIX Conference on File and Storage Technologies*, 2002.

[13] A. F. Pease, "Die ANTS kommen," *Pictures of the Future, Zeitschrift fuer Forschung und Innovation, Siemens*, pp. 80–83, 2006.

[14] T. Pering, R. Ballagas, and R. Want, "Spontaneous Marriages of Mobile Devices and Interactive Spaces." *Communications of the ACM*, vol. 48, pp. 53–59, 2005.

[15] M. R. Rieback, B. Crispo, and A. S. Tanenbaum, "RFID Malware," in *IEEE Security and Privacy*, 2006.

[16] B. Riedl, T. Neubauer, G. Goluch, O. Boehm, G. Reinauer and A. Krumboeck, "A secure architecture for the pseudonymization of medical data," *Proceedings of the Second International Conference on Availability, Reliability and Security ARES 2007*, IEEE CS, 2007.

[17] R. G. Rotondaro and C. L. de Oliveira, "Using failure mode effect analysis (FMEA) to improve service quality," *In Proceedings of the Twelfth Annual Conference of the Production and Operations management Society*, 2001.

[18] G. Rozenberg, J. Chen, and N. Jonoska, "Nanotechnology: Science and Computation," in *Natural Computing Series*. Springer Berlin - Heidelberg, 2006.

[19] R. Sterritt and D. Bustard, "Autonomic Computing - a means of achieving dependability?" in *Proceedings of the 10th IEEE International Conference and Workshop on the Engineering of Computer-Based Systems*, 2003, pp. 247–251.

[20] J. Uldrich and D. Newberry, "Next Big Thing Is Really Small: How Nanotechnology Will Change the Future of Your Business," 2006.

[21] S. White, J. Hanson, I. Whalley, D. Chess, J. Kephart, and T. J. Watson, "An architectural approach to autonomic computing," in Proceedings of the *International Conference on Autonomic Computing.*, 2004, pp. 2–9.

[22] M. J. Wooldridge and N. R. Jennings, "Intelligent Agents: Theory and Practice," *The Knowledge Engineering Review*, vol. 10, pp. 115–152, 1995.