RIGA TECHNICAL UNIVERSITY
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DEVELOPMENT OF CONCEPTION OF DECENTRALIZED DATA MANAGEMENT SYSTEM BASED ON INDIVIDUAL OBJECT PROPERTIES

Summary of Doctoral Thesis

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Riga 2012

UDK 004.65(043.2)
Zu 710 d

Zuravlovs V. Development of conception of decentralized data management system based on individual object properties. Summary of Doctoral Thesis. – R.:RTU Publishing House, 2012.- 48 p.

Printed in accordance with the decision of the board of Institute of Applied Computer Systems, Protocol No 79 of 21 September, 2012.

This work has been supported by the European Social Fund within the project «Support for the implementation of doctoral studies at Riga Technical University».

ISBN 978-9934-10-374-2

DOCTORAL THESIS
SUBMITTED FOR THE DOCTORAL DEGREE OF COMPUTER SYSTEMS
AT RIGA TECHNICAL UNIVERSITY

The defence of the thesis submitted for doctoral degree of computer systems will take place at an open session on December 19, 2012 at 14.30 in Meza Street 1/3, auditorium 202, Riga Technical University Faculty of Computer Science and Information Technology."

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APPROVAL

I confirm that I have developed this thesis submitted for the doctoral degree at Riga Technical University. This thesis has not been submitted for the doctoral degree in any other university.

Vadims Zuravlovs …………………………….(Signature)

Date: ………………………

The doctoral thesis is written in Latvian and includes introduction, 4 sections, conclusions, bibliography, 7 appendixes, 38 figures and 14 tables in the main text, 196 pages. The bibliography contains 264 references.

Saturs

Introduction

In modern information systems (IS), *physical object* is one of the basic units in such industries as logistics [Suh2005], maintenance services [Lai2011], smart buildings [Mon2007], real environment monitoring [Mon2007], etc. The IS traditional approach, when working with physical objects, is to centralize data storing and managing. According to traditional theory [Lah2005, Hei2005, Bau2005, Sar2010], monolithic data managing systems are among the most effective data storing and managing methods. This way of data managing has its risks, limitations, and problems [Dat2004].

In this thesis, an approach is developed for eliminating risks, limitations, and problems in *systems based on individual object properties (SBIOP)* – it is data management system conception specifically for SBIOP use.

The Relevance of the Subject

Globally, information and communication technologies are expanding very quickly. As new participants are constantly entering the market, the market rivalry is growing [KOM2004a]. Current economical conditions are forcing companies to use information and communication technologies more actively. The constantly increasing competition forces companies to look for new techniques in order to improve business productivity, lower costs, and thus optimize the use of company`s resources.

Now, built-in systems are 98% of all computer systems [Ten2000]. In a commission report for the Council, for European Parliament, the European Economic and Social Committee [KOM2007], the Seventh Framework Program (2007–2013), information and communication technologies, work program of the year 2007–2008, states four challenges: health service, video vehicle and mobility systems, micro-systems and nano-systems, organic electronics, and future networks. This suggests the attention should be paid to solutions that make use of built-in and portative system capabilities.

The usage of information and communication technologies in companies is found to be one of the success factors for improving European competitiveness. However, effective implementation of new business procedures and new business models in order to improve the potential of information and communication technology, is still a challenge, especially for millions of European small and medium-sized companies [KOM2004b]. Small and medium-sized companies, when competing with big enterprises and international corporations, need data management systems that provide such benefits as: *implementation of small solutions, options for gradual implementation and distribution of integration costs, autonomous* *operation*, etc. These benefits can be provided, by using modern built-in systems in combination with decentralized data management system approach.

Now, in European Union, including Latvia, equipment and software solutions are used, on the bases of which new data management system conceptions can be studied and created, in order to incorporate new level of IS. One such type of technologies is *radio frequency identification*. In [EPC2006], it is proven that this technology will really open doors to new stage of information community development, often referred to as “internet of things”, where not only computers and communication terminals are connected, but also other things from our every-day environment – clothing, consumer goods, etc. This aspect was the reason why in December 2006, European Council asked European Commission to review next internet generation and network problems in Council of Spring, 2008.

In European Union, protection of data privacy is an essential issue. Treaty on European Union, Article 6 stipulates that the Union is founded on the principles of liberty, democracy, respect for human rights and fundamental freedoms; and Article 30 states that for collecting, storing, processing, analyzing, and exchanging information in cooperation with police, terms of personal data protection should be observed. This implies that special attention should be paid to problems regarding data privacy, integrity, and accessibility.

The Goal of the Thesis

The goal of this thesis is to develop conception for decentralized data management systems based on object individual properties and to examine the possibilities of its practical application.

Tasks

To achieve the goal of the thesis, the following tasks were defined and solved:

- bearing in mind the main trends for modern information system development and specific needs of *systems based on object individual properties (SBIOP)*, to identify criteria for SBIOP and to perform analysis of best-known data management systems conceptions, meeting the set criteria;
- to determine technologies that can be used with SBIOP, to propose parameters for technology comparison, and to perform relevant technology analysis;
- to develop SBIOP conception and to verify conception`s compliance with the set criteria for SBIOP;
- to identify criteria that affect selection of technology suitable for SBIOP, to propose comparison method of effects, and on its basis, to identify the most suitable technologies for developed conception;
- to examine data privacy and security issues for the developed conception;

- to implement software elements of the developed conception, and to verify the possibilities of practical application for the conception.

Research Methods

The theoretical research was done based on analysis of the available scientific literature sources; the solving of set tasks was done via elements of systems theory, algebra, and set theory, real system operation simulation techniques, and software engineering methods.

Scientific Novelty of this Thesis is as follows:

- 8 criteria are identified, which *systems based on individual object properties* (*SBIOP*) should comply to.
- 9 monolithic and 5 decentralised classic data management systems have been studied and their suitability for the set SBIOP criteria has been rated. It is determined that none of the described data management systems meets all of the set SBIOP criteria, thus creating the need for developing decentralised data management system conception based on object individual properties.
- 16 technologies and technology modifications are identified that are typically used for SBIOP solutions, and three technology groups are proposed that categorize technologies based on SBIOP usage purposes. 8 criteria are proposed for technology comparison, based on common parameters of various technologies, and these criteria affect technology selection for SBIOP solution.
- Decentralised data management system conception based on object individual properties is developed, that meets the set SBIOP criteria; for the proposed conception, 3 basic principles, 3 object interaction scenarios, and 10 object property types are categorized. The proposed conception has the following benefits: decision making is done locally, on-site; diversity and uniqueness of physical objects are supported; higher data privacy level; abandoning the centralised data storing and managing infrastructure solution.
- Three main groups of impact criteria are identified and 20 technology criteria are categorised. For the basis or impact criteria, the method *CWCCRT* (acronym for *Calculation of Weight Coefficient Combination for Rating Technologies*) is created, in order to choose technology the most appropriate for a specific SBIOP solution.
- Data protection provision issue is examined for SBIOP conception application, and recommendations are proposed for minimising information security risks.

Practical Value of Research

Practical value of this thesis is the development of software elements that can be used for SBIOP solutions. Data storing and managing formats *RPML (Resource Physical Markup Language (XML) extension)* and *JSONR (JavaScript Object Notation for Resource (JSON) extension)* can be used in software for dealing with physical objects (e.g., logistics, manufacturing, etc.). The software created and described in this thesis, can be used for building, implementing, and modifying SBIOP solutions. Research results are mainly suitable for small and medium-sized companies that need such competitive benefits as implementation of small solutions, options for gradual implementation and distribution of integration costs, autonomous operation, etc.

Thesis Approbation

Thesis approbation was carried out in the following international conferences:

1. Informatics in the Scientific Knowledge 2012, ISK 2012, Varna, Bulgaria, 2012. July 27 –29.
2. Agents and Multiagents Systems for Enterprise Integration 2012, ZOCO 2012, Salamanca, Spain, March 29, 2012.
3. International Conference on Computer and Management 2012, CAMAN 2012, Vuhan, China, 2012, March 9 –11.
4. RTU 52. International scientific conference, Riga, Latvia, October 13, 2011.
5. 6th Electrical and control technologies, Kaunas, Lithuania, 2011, May 5 –6.
6. RTU 51. International scientific conference, Riga, Latvia, 2010, October 12 –16.
7. Applied Information and Communication technologies. The 4-th International Scientific Conference, Jelgava, Latvia, 2010, April 22 –23.
8. RTU 49. International scientific conference, Riga, Latvia, 2008, October 12 –14.
9. Informatics in the Scientific Knowledge 2008, ISK 2008, Varna, Bulgaria, 2008. June 26 –28.
10. Modeling of business, industrial and transport systems 2008, MBIT 2008, Riga, Latvia, 2008, May 7 –10.
11. RTU 48. International scientific conference, Riga, Latvia, 2007, October 11 –13.
12. RTU 47. International scientific conference, Riga, Latvia, 2006, October 12 –14.

Publications

Research results are presented in 11 publications that were written both by author of the thesis working individually, as well as with co-authors:

1. Zuravlyov V., Latisheva E., Lavendels J. Concept of Data Management Systems Based on Individual Object Properties // Proceedings of papers 'Informatics in the scientific knowledge 2012', Bulgaria, Varna, 27–29 June, 2012, pp. 269–279.
2. Zuravlyov V., Latisheva E. Research of Data Storage and Management Technology Applied to DARSIR Concept // Proceedings of papers 'Informatics in the scientific knowledge 2012', Bulgaria, Varna, 27–29 June, 2012, pp. 280–294.
3. Zuravlyov V., Matrosov A., Rutko D., Behavior Pattern Simulation of Freelance Marketplace, Workshop on Agents and Multi-agent systems for Enterprise Integration, ZOCO 2012, Salamanca, Spain, March, 2012.
4. Zuravlyov V., Matrosov A., Rutko D., Freelance resource management system optimization, The 2nd International Conference on Computer and Management, CAMAN 2012, Wuhan, China, March, 2012.
5. Zuravlyov V., Matrosov A. Multi-agent system built using RFID technology // Proceedings of the 6th international conference on electrical and control technologies, ISSN 1822-5934, Lithuania, Kaunas, 5–6 May, 2011. – pp. 15–20.
6. Zuravlyov V., Kryukov D., Kairish V. Security problems related to RFID-based concept usage and methods to counter them // Proceedings of the 6th international conference on electrical and control technologies, ISSN 1822-5934, Lithuania, Kaunas, 5–6 May, 2011. pp. 76–81.
7. Zuravlyov V., Latiseva E., Karish V. The Theoretical Basis and Practical Usage of the Simulation for Creating IT solutions for Data Management Systems // Proceedings of the international conference on Applied Computer Systems, ISSN 1407-7493, Latvia, Riga, 2011., pp. 138–144.
8. Zuravlyov V., Latisheva E. Various Aspects of RFID Technology and Their Use in Monitoring and Management of Traffic // Scientific Journal of RTU. 5. series., Computer Science. – 34. vol., Latvia, Riga, 2008, pp. 238–245.
9. Zuravlyov V. Various Aspects of 'Smart Laundry' Task Implementation, Using 'RFID' Technology // Proceedings of papers 'Informatics in the scientific knowledge 2008', Varna, Bulgaria, 26–28 June, 2008, pp. 150–156.
10. Zuravlyov V. Various Aspects of Simulation's Usage for Creation of Real Solutions with „DARSIR" Conception as Example // Proceedings of Conference 'Modeling of business, industrial and transport systems 2008; MBITS 2008', ISBN 978-9984-818-04-7, Latvia, Riga, 7–10 May, 2008, pp. 132–135.

11. Zuravlyov V. Main Principles of a New Concept of Designing Data Management Systems // Scientific Journal of RTU. 5. series., Computer Science. – 30. vol., Latvia, Riga, 2007, pp. 38–46.

The paper "*Behavior Pattern Simulation of Freelance Marketplace*" by author of the thesis, that he wrote in collaboration with Dmitry Rutko and Anton Matrosov, received award "*PAAMS '12 Award of Scientific Excellence*" in the international conference "*10th International Conference on Practical Applications of Agents and Multi-Agent Systems (PAAMS 12)*", in Salamanca, Spain.

Thesis Structure

The thesis consists of Introduction, 4 chapters, Conclusions, Bibliography, and 7 appendixes.

The introduction provides grounds for topicality of the performed research, formulation of thesis` goals and tasks, list of scientific methods used for developing this thesis, description of scientific novelty and practical significance of acquired results, as well as characterization of thesis approbation.

In the 1st chapter, criteria are proposed for systems based on individual object properties, and traditional monolithic and decentralized data management system conceptions are examined, in order to determine their compliance with these criteria. The best-known data management system conception limitations and benefits are identified that are taken into account in the further thesis for building data management system conception based on individual object properties.

In the 2nd chapter, technology comparison parameters are proposed in order to perform analysis on technologies used in systems based on individual object properties and to propose basis of parameter comparison. Results acquired in this chapter are used for applying selection methods to choose technologies necessary for information systems based on object individual properties.

In the 3rd chapter, conception is described for data management system based on individual object properties. Conception operation object types and object interaction scenarios are generally categorized, as well as object properties, and groups of rules, and conception verification is performed for system based on individual properties criteria proposed in 1st chapter.

In the 4th chapter, detailed examination for groups of object attributes and rules is done in order to prepare theoretical ground for their implementation in software. The most important conception technology selection criteria are proposed, based on which the technology selection method is created. Using this method, the most appropriate technologies are identified, judging by IS essential work conditions. Technology that had the best result after method application, is used for detailed analysis of security issues.

Results and conclusions of the thesis are summarized in the closing chapter.

Conception`s practical research are shown in the appendixes: DARSIR conception data exchange technical implementation, implementation of resource attribute group, technical implementation of resource rules, visual interactive simulation, conception verification with typical tasks, conception verification with atypical tasks, and implementation of new function.

1. Data Management System Analysis From Point of View of Data Storing and Managing

Today, if information processing is considered in the context of *information systems* (*IS*), first of all, *Data Management Systems* (*DMS*) are considered. DMS can be divided into two broad categories: *Monolithic Data Management Systems (MDMS)*, and *Decentralized Data Management Systems (DDMS)*. The principles and features of these two category systems are significantly different.

This chapter has three basic goals. The first – to define criteria for decentralized data management systems based on object individual properties. The second – to explore the best known DMS conceptions and assess their compliance with the set criteria. The third – from the range of data management system conceptions considered, to summarize principles and methods of best practice that have survived the test of time. The compiled results will be used for developing conception of systems based on object individual properties.

1.1. Systems Based on Individual Object Properties (SBIOP)

In this chapter, criteria are set for systems based on individual object properties. First of all, the main development trends of modern IS are examined, and description is given for systems based on individual object properties. On the basis of this information, criteria are defined for systems based on individual object properties. Finally, some typical examples of systems based on object individual properties are inspected, in order to verify practical application of set criteria.

Information System Design Trends

In order to define criteria for systems based on individual object properties, IS design principles should be defined. IS design principles are governed by various directions related to computer systems: data management systems, programming languages, technologies, and IS project management. For every direction, there is an enormous number of potential options.

By performing analysis on IS development trends, the end-user is able to choose the most suitable option.

During DMS research, the following information sources were analyzed: theory and future prospects of data management systems [Dat2004, Sim1995, etc]; operation principles of data management systems [Alt1980, Wid1996, etc.]; data management system manifests [Atk1990, Dat2000a, etc.]; individual data management system implementations [Gre2007, Row1987, etc.], and others.

By analyzing programming languages and related topics, the inspected issues include programming language theory [Boo1991, Eck2003, etc.], implementation of programming language and environment [AOS2011, Tel2011, etc.], database programming languages [ISO1999, Dat1997, etc.], data exchange protocols [Ber1992, Bay2010, etc.], markup languages [Cel1995, Cag2000, etc.], etc.

The IS development trends mentioned in these information sources are summarized. Basically, the result coincides with [Sim1995] research. The study states that there are four IS development trends, as summarized in Table 1.1.

Table 1.1

Basic Tendencies of IS Development (adapted from [Sim1995])

Nr.	Name	Description
1	*Distribution and decentralization of computing resource management*	With every year, computer systems are becoming smaller and more powerful. Using data communication equipment (local and wireless networks), information can be exchanged among devices. Almost all of the necessary operations users can perform locally, without connecting to the big servers.
2	*Heterogeneity of IS components*	Data are stored in various formats, data processing is provided by different types of software and hardware.
3	*Distribution of standards*	Consequences of the second trend are decreased by implementation of standards. Users should be free to choose hardware and software. That ensures free competition and simple IS distribution.
4	*Real-world modeling in information systems*	One of the major shortcomings in implementing IS is the difference between processes in IS and in the real-world. One example is the usage of *Object Oriented Model (OOM)*. OOM principles were suitable for programming and data management. In OOM, there is even closer link between designing a task and its implementation.

One of the key features that are relevant in the case of selecting DMS conception, is the principle of monolithic or decentralized data storage and management. Further sections provide overview of the data storage and management principles judging by their characteristics.

SBIOP Description

Systems based on individual object properties operate with physical objects. *Objects* are considered to be physical objects of the real-world, with their unique individual properties. *Properties* are the physical characteristics (attributes) of the object and operations with the object (rules).

The physical framework of an object is described using set theory notation. If F is a physical object:

$$F = \{A, N\},$$

where A is the set of object attributes that contains attributes 1 to i:

$$A = \{A1, A2,..., Ai\}$$

and N is a set of object rules that contains rules 1 to i:

$$N = \{N1, N2,..., Ni\}.$$

Defining Criteria for Systems Based on Individual Object Properties

When systems based on individual object properties are considered, the characterization of monolithic and decentralized data management systems partially coincides. It is expected that some part of required characterizations are not fully applicable with the help of traditional data management systems (see the graphic illustration in Figure 1.1).

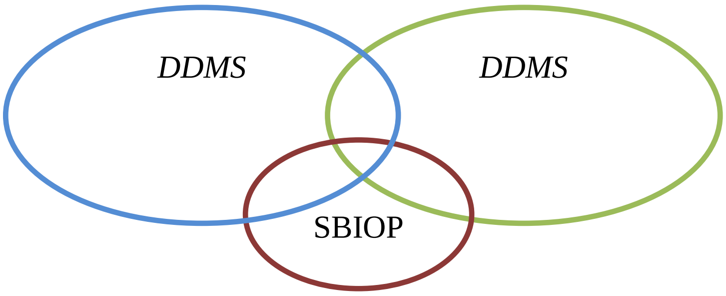

Figure 1.1 Overlapping of MDMS, DDMS, and SBIOP characteristics

The first task of this thesis is to set criteria for SBIOP range in order to verify compliance of MDMS and DDMS with these criteria. From IS development tendencies 1, 2, and 3 (see Table 1.1), criterion *(i)* regarding *distribution and decentralization of computing resource management*, and criterion *(ii)* regarding *implementation of standards* is derived. Whereas, IS development basic tendency 4 states that in IS, real-world modeling should be dealt with.

SBIOP is a system that operates with physical objects. One object differs from the other by its individual properties. They can be object`s physical properties and/or operations that are applied to the object. It results in the criterion *(iii)* regarding *support for heterogeneity of physical objects*. For determining individual properties of physical objects, human analyses the object. For analysis, he uses experience and information available on-site. Criterion *(iv)* is defined regarging *provision of local access to data*. If all the necessary information is available, decisions can be made on-site. Criterion *(v)* is provided regarding *autonomous operation*.

For large IS, MDMS are typically used (see [Sim1995] for details). Based on criterion *(v)* regarding *autonomous operation*, it can be concluded that IS system is divided into smaller independent solutions. Criterion *(vi)* is introduced regarding *economic justification for applying small solutions.* In a number of information sources (see [Pic2010, etc.] for details), it is recommended to build IS in small iterations, using agile software development principles. This recommendation defines/determines criterion *(vii)* regarding *gradual implementation costs*. Introduction justifies provision of data security and confidentiality, and based on that the criterion *(viii)* is introduced regarding *data confidentiality, integrity, and accessibility*.

All the criteria are summarized in Table 1.2.

Table 1.2

Set Criteria for Systems Based on Individual Object Properties

Nr.	Name	Description
I.	*Distribution and decentralization of computing resource management*	Centralized management can be abandoned, if there is sufficient local computing power for solution implementation.
II.	*Applying standards*	To provide users with free choice of hardware and software, support for up-to-date standards is necessary. Freedom of choice is especially required for equipment selection process. In the case of implementing new solution, the implementation costs are significantly lower if the existing hardware solution can be used.
III.	*Supporting diversity of physical objects*	The system should be able to operate with a large number of objects. Each object has its own individual properties. One object can have unique individual properties that are not suitable for other objects.

IV.	*Provision of local data access*	Acquiring information from sources that are not related to object itself, engages additional resources (data transmission to storage, taking data from storage, providing data exchange interface, organizing data storage space, facilitating data exchange via variety of storages, etc.). If data can be stored in a universal location (for example, within the physical object itself), the costs of data provision can be reduced significantly.
V.	*Autonomous operation*	If every element of DMS operation has access to local data that are necessary for decision-making, it can be said that autonomous operation is ensured.
VI.	*The economic benefits of implementing small solutions*	If the number of physical objects is low, there should be an economic justification for applying this particular principle of data management. When a small number of object interactions should be provided, large DMS solutions are not economically justified.
VII.	*Possibility of gradual implementation and distribution of implementation costs*	Criterion *(vi)* of small solutions, in turn, requires low implementation costs. Implementation of IS is usually needed to automate the manual work, and high implementation costs can reduce the economical advantages of IS implementation.
VIII.	*Ensuring data confidentiality, integrity, and accessibility*	Information security covers all information processes, both physical, as well as electronic, regardless of whether they involve people and technologies, or relationships with partners, customers, or third parties. This applies to all aspects of information and its protection across all information`s life-cycle in the organization

SBIOP Examples

In this section, examples of IS are described that meet the set SBIOP criteria (see Table 1.2), SBIOP examples are:

- Autonomous cooperative processes of logistics
- Cleaning, repairing, and maintenance services
- Smart buildings
- Monitoring, information, and control systems
- Controlling implementation of company`s internal policy

- Work process analysis
- Etc.

The first four of these SBIOP examples are described in detail. Each of the described examples has description of problems with references to external sources. Initially, the typical solutions of MDMS design principles are described. In addition, a way is proposed for building new IS based on SBIOP criteria.

1.2. Conceptions of Data Management Systems

In this thesis, *conception of data management system* is considered to be summarized views regarding this system and its processes, and it is considered to be one of the key steps for designing or modernizing IS. In other words, a conception is a general plan, main idea, the road system that describes solving of current task. In this thesis, the terms *data management system* and *data management system conception* are synonyms.

For describing data management systems, *Data Models (DM)* are most commonly used. The term DM was first introduced by *Edgar F. Codd* in his report [Cod1980]. It provides evidence that *relational model* is the first described DM. The first theoretical models were implemented based on existing working systems. Relational model it is the first DM that was first created as a theoretical model. Only on the basis of the relational model, the software implementation was done. Not all the DMS are described by models, in this thesis, there are implementation descriptions, also.

From MDMS set of DMs, four models can be distinguished: hierarchical model, network model, relational model, and object-oriented model. Nowadays, relational and object-oriented models are the most common directions of DM research. Other DMs are usually described, using these four basic models. All the other DMS can be built by using the four basic models, but typically, relational and object-oriented models are used. The DMS that have specific DMs, are described as DMs. Some are supposed to be extensions for relational model, they do not have a solid DM, and thus they are described as *databases*.

From set of DDMS, in this section five main types of DMS are described: *distributed databases*, *multi-agent systems*, *hypermedia databases*, *peer-to-peer databases*, and *sensor networks*. Distributed database combines basic characteristics of MDMS and DDMS, and provides centralized data management, but, nevertheless, decentralized data storage and management principles are also applied.

1.3. DMS Compliance with the Criteria for Systems Based on Object Individual Properties

In previous sections, the best-known DMS conceptions are described. This section summarizes information to verify compliance of the described DMS with the criteria of systems based on individual object properties. Every DMS can have many implementation variations. This chapter deals with typical implementations. The goal of this chapter is to verify compliance of DMS with the criteria of systems based on individual object properties that are summarized in Table 1.2. If none of the described DMS fully complies with the set criteria, there is a need for developing a DMS conception.

Monolithic Data Management Systems

Based on MDMS overview in Chapter 1.2, the MDMS compliance with systems based on individual object properties is verified. This verification provides compliance with set criteria that are described in Table 1.2.

Today, three of the described MDMS (*flat file model*, *hierarchical model*, and *network model*) have lost their relevance (fact from [Sim1995]). For these MDMS, analysis results are added to the data Table 1.3, but they do not need any comments.

There are criteria that cannot be achieved by MDMS, they are *(i) distribution and decentralization of computing resource management*, and *(iv) providing local access to data*. The traditional theory holds that MDMS manages data centrally, which is contrary to the criterion *(i)*. And for data access, it is necessary to connect to a centralized data storage, which does not meet criterion *(iv)*.

Today, all the popular MDMS meet criteria like *(ii) applying standards* and *(viii) ensuring data confidentiality, integrity, and accessibility*.

The criterion regarding *(iii) support for heterogeneity of physical objects* is fully complied with by *object-oriented model*. *Object relational model* complies with this criterion partially. All the other MDMS provide full compliance with this criterion, provided this MDMS can be applied with *object-oriented model*.

Compliance with criterion *(v) regarding autonomous operation* in the context of MDMS is unclear. For autonomous operation, data access should be provided locally, which is not granted. However, the DMS design principles themselves can be applied to autonomous operation, it depends on the specific implementation.

Two of these criteria are closely linked—they are *(vi) economical benefits of implementing small solutions* and *(vii) possibility of gradual implementation and distribution of implementation costs*. Provision of centralized data storage and management requires big initial investment. This is one of the reasons why criterion *(vi)* is usually not met. There may be exceptions—like MDMS for mobile devices and small databases. Implementing compliance with criterion *(vii)* requires common storage and management structure for solution`s initial data. One of the advantages is decreasing time for application developing cycle, provided the data storing format is not changed.

MDMS compliance with systems based on individual object properties is summarized in Table 1.3. In this table, for compliance with the criteria the following values are used: 0 – does not comply, 0/1 – complies partially, and 1 – complies.

Table 1.3

Compliance Comparison for MDMS Criteria

(I – distribution and decentralization of computing resource management II – applying standards; III – supporting the diversity of physical objects; IV – provision of local data access; V – autonomous operation; VI – the economic benefits of implementing small solutions; VII – possibility of gradual implementation and distribution of implementation costs; VIII – ensuring data confidentiality, integrity, and accessibility)

Criterion / ***MDMS***	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
Flat file model	0	0	0	0/1	0	0/1	0	0
Hierarchical model	0	0/1	0	0	0	0/1	0/1	0
Network model	0	0/1	0	0	0	0/1	0/1	0
Relational model	0	1	0	0	0/1	0/1	0/1	1
Object-oriented model	0	1	1	0	0/1	0/1	0/1	1
Object-relational model	0	1	0/1	0	0/1	0/1	0/1	1
Active databases	0	1	0/1	0	0/1	0/1	0/1	1
Data warehouses and other specific data management systems	0	1	0/1	0	0/1	0/1	0/1	1

Decentralized Data Management System

Based on DDMS description given in Chapter 1.2, DDMS compliance is verified with systems based on individual object properties. The verification was performed in order to provide compliance with criteria defined in Table 1.2.

Compliance with the first criterion *(i) regarding distribution and decentralization of computing resource management* is provided, based on decentralized data management principle itself. However, *distributed databases* and *sensor networks* comply with the criteria only partially. *Distributed databases* are characterized by MDMS and DDMS principles simultaneously. In *sensor networks* , every individual node receives task from adjacent nodes. It is possible that results are combined and processed in one node only.

Today, all the popular DDMS comply with criterion *(ii)* regarding *applying standards*. *Multi-agent systems* can fully meet the other criterion—criterion *(iii)* regarding *support for heterogeneity of physical objects*. It is possible for *distributed databases* and *hypermedia databases*, provided these DDMS are implemented with object-oriented approach.

The two criteria—*(iv) provision of local data access* and *(v) autonomous operation*—are closely linked. These criteria are fully met by *multi-agent systems*. *Distributed databases* can offer compliance, provided data exchange is done using nodes. All the nodes must be implemented with the help of DDMS principles. DDMS like *hypermedia databases* and *peer-to-peer databases* may comply with these criteria—it depends on the specific implementation. For *sensor network*, no data are stored. They are queried from the main node, and data transfer to this node is provided. If there is no link to the main node, the whole network is working without a goal.

The following two criteria can be considered together. They are *(vi) the economic benefits of implementing small solutions* and *(vii) possibility of gradual implementation and distribution of implementation costs*. For DDMS like *distributed databases, multi-agent systems,* and *hypermedia databases*, complete development cycle is necessary for implementing the full solution. This makes it difficult to implement small solutions, or large solutions should be introduced gradually. For *peer-to-peer databases* and *sensor networks*, the main software and hardware provisions already exist, so the applying is simpler. For example, for *a sensor network*, the basic elements are sensors that can be provided later on, supplementing the existing solution.

For DDMS, it is difficult to implement compliance to criterion *(viii) ensuring data confidentiality, integrity, and accessibility*. Only *distributed databases* meet this criterion, because of merging MDMS and DDMS principles. All the other DDMS have limitations regarding the usage of data security mechanisms, data integrity control, etc.

The compliance of DDMS with systems based on individual object properties is summarized in Table 1.4. The table uses the following values for meeting set criteria: 0 – does not comply, 0/1 – complies partially, and 1 – complies.

Table 1.4

Comparison of DDMS Compliance with Criteria

(I – distribution and decentralization of computing resource management; II – applying standards; III – supporting the diversity of physical objects; IV – provision of local data access; V – autonomous operation; VI – the economic benefits of implementing small solutions; VII – possibility of gradual implementation and distribution of implementation costs; VIII – ensuring data confidentiality, integrity, and accessibility)

DDMS / **Criterion**	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
Distributed databases	0/1	1	0/1	0/1	0/1	0/1	0/1	1
Multi-agent systems	1	1	1	1	1	0/1	0/1	0/1
Hypermedia databases	1	1	0/1	0/1	0/1	0/1	0/1	0/1
Peer-to-peer databases	1	1	0	0/1	0/1	1	1	0/1
Sensor network	0/1	1	0	0	0	1	1	0/1

1.4. Summary and Conclusions

The main theoretical result of this chapter is the identified SBIOP criteria. Analysis of best-known MDMS and DDMS conceptions are performed regarding their compliance with criteria. The main conclusions of this chapter are:

- It has been found that within the range of traditional MDMS and DDMS, none of them fully complies with the set SBIOP criteria. The closest among MDMS are *object-oriented model* and *active databases*. Among DDMS, those are *multi-agent systems*.
- The described DMS meet the set SBIOP criteria only partially. There was a need to develop a conception of decentralized data management system based on object individual properties, and this conception should meet criteria set for decentralized data management systems based on object individual properties.

2. Research of Technology Used by SBIOP

Every IS solution is based on particular technologies. This chapter aims to identify the technologies that are to be used for systems based on individual object properties. Based on the criteria defined by the new conception, parameters for comparing technologies are proposed that are required in order to meet the set SBIOP criteria. The proposed parameters with summarized values will be used for selecting technology best suited for the final solution.

2.1. Overview of Technology Identification Examples

Examples used are taken from systems based on individual object properties, as described in Chapter 1.1. Four examples were discussed, in order to determine the typical technologies that are used in systems based on individual object properties. These technologies will be discussed in more detail, to identify parameters that are important for the new conception. The following technologies are identified (given with usage descriptions):

- *Barcode* – this technology is used to identify physical objects, there are cases when, along with the identifier, additional information is stored about the object (e.g. lot number, manufacturer ID, etc.).

- *RFID* – this technology is used for the same purposes as the barcode technology. RFID is usually referred to as "*the next generation barcode technology*."

- *NFC* – modification of RFID technology, often used in built-in mobile devices, some of the most typical examples are quick-payments and user identification.

- *Local area network* – technology that is used for data transmission. For establishing a network, it is necessary to build a structure, but with the spreading of internet, the local area network technology is becoming more popular and accessible

- *Bluetooth, IrDA* – data transmission technologies, typically used for contacting mobile devices.

- *GSM, GPRS* – mobile communication standard and mobile data transmission service, used for data transmission, now widely accessible and used in locations where other transmission standards are not available.

- *Wi-Fi, WiMAX* – wireless data transmission technology, nowadays its infrastructure is widely used.

- *Satellites* – one of the most popular examples of this technology is GPS, that is suitable for positioning. Similar techniques that work on the same principles are Galileo, KOMPASS, GLONASS, and others.

2.2. Technologies

The conception for decentralized data management system based on individual object properties should meet criteria defined in Table 1.2. Technology description is done, based on technology comparison parameters that were set as the basis on these criteria. Based on these parameters, overview of technologies was performed.

2.2.1. Parameters for Comparing Technologies

Taking into account criteria like *(i) distribution and decentralization of computing resource management*, *(ii) applying standards*, *(iii) supporting the diversity of physical objects*, and *(v) autonomous operation*, it is proposed to divide all technologies into groups, judging by their usage options. The values of technology comparison parameter *(i)*, *groups of technologies* are listed in Table 2.1.

Table 2.1

Groups of technologies, by purpose of their use

No.	Name	Description
1.	*Technologies for object identification*	The main purpose for using the technologies of this group is to identify an object. It is usually a physical object. Included defined technologies are: barcode, RFID, NFC, and others.
2.	*Technologies for data*	These are technologies, the main purpose of which is to

	transmission	transmit data from one location to another. Included defined technologies are: Wi-Fi, WiMAX, Bluetooth, GPRS, IrDA, Satellites, etc.
3.	*Sensor-based technologies*	This group covers technologies that are typically used in conjunction with technologies of Group 1 and Group 2, and are needed to expand the functionality of standard technology. Typically, these are various types of sensors: *Global Positioning System*, *GPS*), thermometers, etc.

Criterion *(iv)* regarding *provision of local data access* should define technology comparison parameters regarding operation parameters of markup technologies: *(ii) working radius*, *(iii) data transfer rate*, *(iv) working frequency*, and *(v) the need of direct visibility*.

Two of the criteria—*(vi) the economic benefits of implementing small solutions* and *(vii) possibility of gradual implementation and distribution of implementation costs*—affect cost calculation. Because of this need, further technology comparison parameters are implemented – *(vi) costs of implementation* and *(vii) the complexity of technology actuating mechanism*. Special attention is paid to the problem *(viii) ensuring data confidentiality, integrity, and accessibility*. This criterion is reflected in technology comparison parameter *(viii) data protection*.

Set technology comparison parameters are described in Table 2.2.

Table 2.2

Parameters for Comparing Technologies

No.	**Name**	**Description**
I	*Group of technologies*	Three groups of technology usage are defined that refer to the purpose of use: *object identification* (Group 1), *data transmission* (Group 2), and *sensor-based technologies* (Group 3). One technology can simultaneously belong to several groups.
II	*Working radius*	The maximum working radius of technology between two devices.
III	*Data transfer rate*	How fast data can be transferred from one device to the other. In technologies used for identifying objects, the time required for identifying a single object is indicated.
IV	*Working frequency*	Most of technologies use a specific frequency. It is important

		to know them, since each country has its own limitations, and there are technologies the use of which is prohibited because of their used frequencies.
V	*The need of direct visibility*	One of the most important restrictions concerning technologies.
VI	*Costs of implementation*	Relative costs are given, expressed in relative units, where the first unit means costs of infrastructure, the second unit – costs of terminal part, and the third – costs of tags (for Group 1). The cost of a unit range from 0 to 9 (the higher, the more expensive).
VII	*Complexity of technology actuating mechanism*	It is the complexity of implementing principles of operation for technology`s device. For example, satellite technology is considered to be one of the most sophisticated technologies because satellites should be provided in order to actuate it. The values themselves are defined by technology description and judgements of the field`s experts.
VIII	*Data protection*	For data security and privacy, the level of support provided is defined. Two features are defined: *Software (SW)* and *Hardware (HW)*.

2.2.2. Comparison of Technology Parameters

Following the general overview of the technologies above, the essential SBIOP technology parameters are defined. For parameter analysis, the most often used technology varieties and versions are utilized. For example, the most popular version of Bluetooth technology today is Bluetooth 2.0. All this information is given in the form of a table (see Table 2.3).

Table 2.3

Comparison of Technology Parameters

(I – group of technologies; II – working radius (km); III – data transfer rate (data transfer rate, or obj/s); IV – working frequency; V – need of direct visibility; VI – costs of implementation (infrastructure/terminal/tag); VII – complexity of technology actuating mechanism; VIII – data protection)

Parameter / **Technology**	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
Barcode (Code128)	1.	0.01	0.3-0.5 obj/s	n/a	yes	3/1/0	no	SW
Barcode (DataMatrix)	1.	0.002	0.2-0.4 obj/s	n/a	yes	3/2/0	no	SW

Barcode (QR Code)	1.	0.002	0.2-0.4 obj/s	n/a	yes	3/2/0	no	SW
RFID (passive)	1.	0.0001 - 0.009	1-200 obj/s	LF, HF	pref.	4/2/1	no	SW, HW
RFID (semi active)	1.	0.001 – 0.035	1-200 obj/s	UHF, MF	pref.	4/2/3	no	SW, HW
RFID (active)	1.	0.035 – 0.1	1-200 obj/s	UHF, MF	pref.	4/2/5	mid	SW, HW
NFC	1 and 2	0.0015	424 KB/s	HF	pref.	4/1/1	no	SW, HW
LAN	2.	0.1	1 Gbit/s	HF	no	5/3/-	mid	SW, HW
Bluetooth	1 and 2	0.1	2 MB/s	HF	pref.	2/2/4	no	SW
IrDA	1 and 2	0.01	4 MB/s	LF	yes	2/2/4	no	SW
GSM	1 and 2	35	43.3 KB/s	UHF	no	7/3/5	yes	SW, HW
GPRS	2.	35	80 KB/s	UHF	no	7/3/5	yes	SW, HW
Wi-Fi	1 and 2	0.1	600 MB/s	MF	pref.	4/3/6	yes	SW, HW
WiMAX	1 and 2	50	70 MB/s	HF	pref.	5/3/7	yes	SW, HW
GPS	3.	global	n/a	UHF	yes	9/2/2	yes	n/a
Sensors	3.	0.001	n/a	n/a	yes	2/2/2	no	n/a

2.3. Summary and Conclusions

This chapter identifies technologies that are used in the case of SBIOP. The main theoretical results of this chapter are the proposed parameters for technology comparison that influence the further conception development. The information is summarized by performing technology comparison.

The main conclusions are as follows:

- By analyzing the four systems based on individual object properties (*autonomous cooperative processes of logistics; cleaning, repairing, and maintenance services, smart buildings, monitoring, information, and control systems*), 16 technologies and technology modifications are identified that can be used in systems based on individual object properties.

- None of the described technologies meets the criterion *(viii)* concerning *ensuring data confidentiality, integrity, and accessibility*. This criterion has to be supported in software level.
- Only Group 1 and 2 technologies can be used as basic technologies, while practically implementing DARSIR conception. The technologies of Group 3 can only be used as additional source of information.

3. Concept Description

Given the defined SBIOP criteria, this chapter provides conception of decentralized data management system based on object individual properties.

3.1. General Description of the Conception

Basic principles of decentralized data management system based on object individual properties were first published in [Zur2007]. This conception was named *Data And Rules Saved In Resource (DARSIR)*. Since in all the research the acronym DARSIR is mentioned in English (the complete list of author`s publications can be found in Introduction), this acronym is used here, as well.

In IS that is developed by applying principles of the DARSIR conception, data is not stored centrally but distributed among physical objects (IS members). This ensures abandoning of hardware required by the traditional database (e.g., server, network, etc.). This conception is appropriate when IS can be implemented with decentralized data storage and management principles.

DARSIR conception is based on the *object-oriented approach* in accordance to which one should examine the data that are used for system to fulfill its task. DARSIR considers resources to be such data. The object of DARSIR conception is called a *resource*. *Resource* is any living or non-living object that is involved in process of operating information system. Resource data are stored in *tags*. *Tag* is a part of technology used by the conception. Tag is attached to or built in the resource. For example, a tag of RFID technology is *RFID tag*. In barcode technology, it is *two-dimensional barcode*.

Resource structure can be described as follows:

$$B = \{S, D\},$$

where B is a tag,

$S = \{S_1, S_2, ..., S_i\}$ is a set of sensors,

and D is a document that reflects the data storage format.

Meanwhile, document D:

$$D = \{A, N\},$$

where $A = \{A_1, A_2,..., A_i\}$ is a set of resource attributes,

and $N = \{N_1, N_2,..., N_i\}$ is a set of resource rules.

In tag itself, link between sensors and document is implemented. Values received by sensor (for example, temperature in degrees of Celsius) can be operated (for example, received, processed, transferred, etc.), using rules defined in the document.

3.2. Internal Structure of Document

Document is a data description type, describing resource attributes and rules. As a basis for explaining document`s internal structure, an example from logistics is used.

Attributes

Attribute is presentation of object`s properties in a document. There are many varieties of attributes. To simplify the process of standardization, attributes can be classified—divided into *groups of attributes*. Provided that $A = \{A_1, A_2,..., A_i\}$ is a group of attributes, an individual group`s attribute can be described as follows:

$$A_i = \{NS, V, P\},$$

where NS is the name of attribute,

V is the value of attribute,

and $P = \{P_1, P_2,..., P_i\}$ is a set of attribute indication.

For example, container has physical parameters. The group of physical parameter attributes includes attributes that describe container`s height, width, volume, etc. The attribute that describes container`s height, has the name *con_height* (N), value *2.4* (V), and indication *m* (P). In this case, an indication shows that the value of the height in meters.

Rules

In the context of object-oriented approach, resource *rule* is a *method*. In object-oriented programming, methods are run by two big components: variables and methods. The rules of DARSIR conception can be described as follows:

$$N = \{M, PR, FN, T\},$$

where M are variables,

PR are procedures,

FN are functions,

and T is *trigger* – it is a set of operations that is stored within the resource and is run automatically if an event is previously defined.

Resource Groups

Economically, it is not justified to provide every resource with a hardware ability to physically interact with other resources.. IS has active and passive operation components. Given this principle, all the resources can be divided into two groups:

1. *Passive Resource (PR)* – these are resources that store data and are related to sensors (this type of resource stores internal data only).
2. *Active Resource (AR)* – resources that store data and have additional functionality. Active resources can be divided into:
   a. *Active Static Resource (ASR)* – information is being stored in static form (static instructions), and it can be changed only by other resources or devices.
   b. *Active Dynamic Resource (ADR)* – these not only store information, but also are able to directly influence other resources (for example, acquire information, run resource, etc.). The most common example here is an RFID scanner. If we assume that the resource is presented as an RFID tag, the RFID scanner is able to read and modify data found in the resources (RFID tags).

Starting DARSIR solution is provided by the ADR elements. ADR analogues can be found in MAS theory (see [Woo2001]),where they are called *agents*. Taking into account the technologies described in chapter 2, for ADR it is the *scanner* that in the case of DARSIR conception is the active element that provides internal functionality of resources, provided they are within the reception area.

3.3. Resource Interaction Scenarios

Resource interactions are provided through the active resources. ASR can store rules, but rules can be run only by ADR. ADR can be called a scanner. The scanner can interact with other resources provided these resources are located in the reception area. The aim of this section is to show three scenarios of resource interaction.

ADR basic characteristics is an autonomous operation with the ability to make decisions on-site, based on the available data. The simplest scenario is shown in Fig. 3.1.

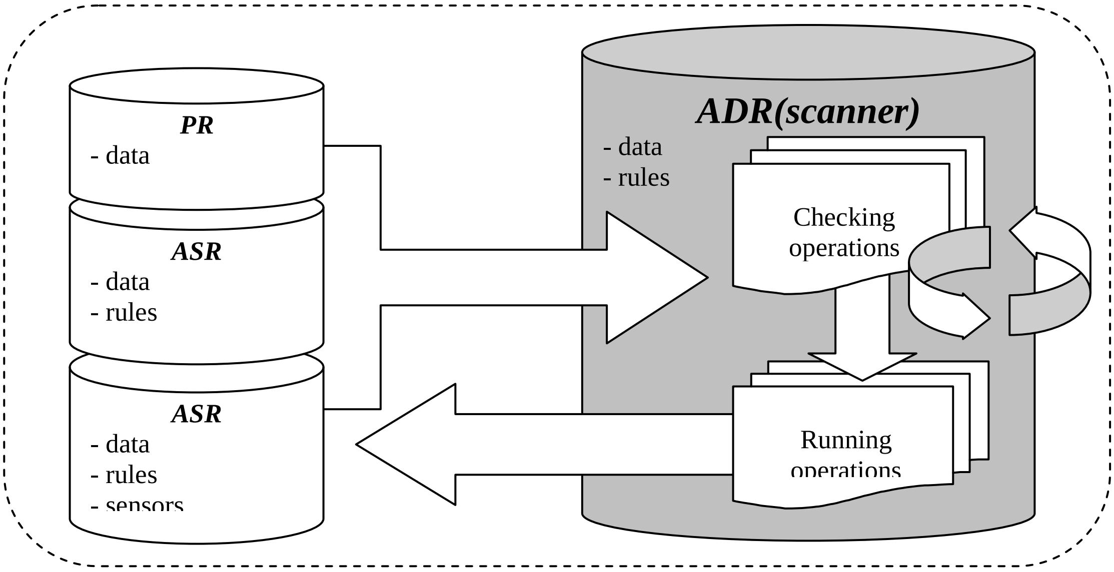

Figure 3.1 Scenario of single ADR interaction

ADR reads all the data and rules in its memory from Passive Resources (PR) and Active Static Resources (ASR) that are situated within its reading range. Attributes are received from PR. From ASR, rules can also be received. If ASR rules state that pre-defined activities should be fulfilled, then ADR performs them. If there are rules written within ADR, they are applied, also. One of the scenarios for ADR interaction is the basic solution for others, when two or more ADRs are situated in a shared area.

If there are two ADRs with the same or similar tasks, they themselves are expected to If there are two ADR with the same or similar tasks, it is expected that they themselves are working in parallel, and the interaction between them is not required. Scenario of two ADRs interacting simultaneously is shown in Fig. 3.2.

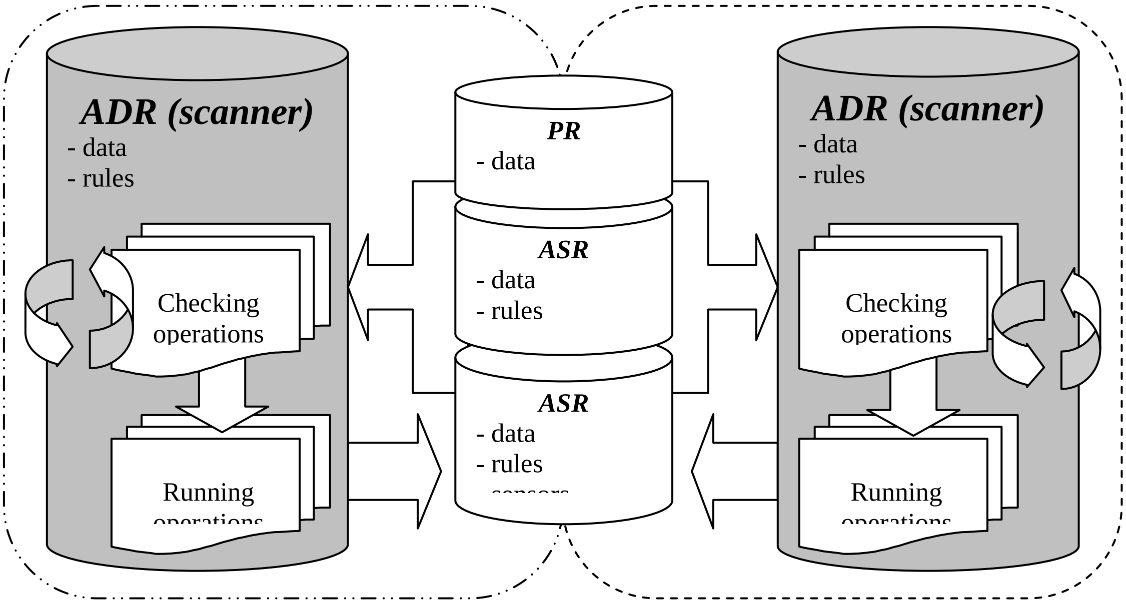

Figure 3.2. Scenario of two ADRs interacting simultaneously

Decentralized data management does not require direct ADR communication. All communications or other forms of interaction take place via the resources (usually PRs and ASRs). ADRs may supplement the resource with data and rules. A similar mechanism exists in the object-oriented approach. It is possible to create complex objects using constructors for composite objects. When these data become unnecessary, they can be deleted from the resource. For example, there is a container for moving boxes of the logistics process (see Fig. 3.3). The container has its own data (attributes and rules) the initial values of which are defined by the Manufacturer A. When logistics Company B starts using this container, this company adds its part of the data (new attributes and rules). One of the underlying processes of logistics can be implemented by another logistics Company C, which adds its data (attributes and rules) that are necessary for sharing information between members of Company C. When Company C completes its part of the job and returns the container to Company B, the data of Company C (attributes and rules) are no longer relevant and are deleted from the container.

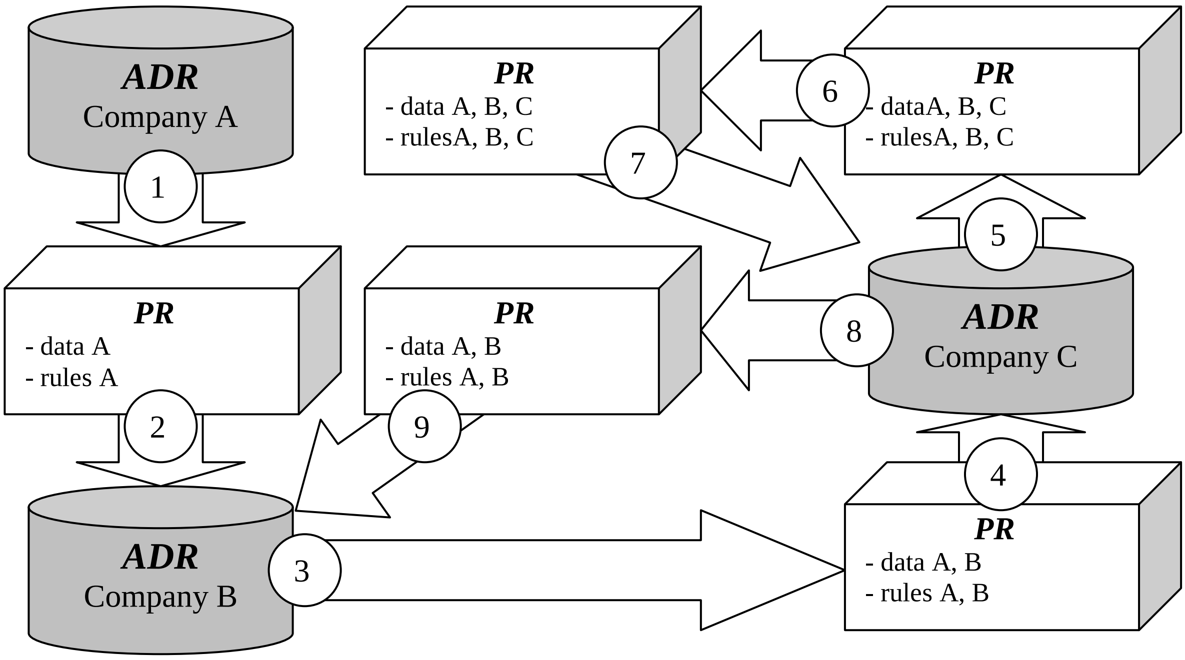

Figure 3. Scenario of consecutive interaction of various ADRs

3.4. Groups of Attributes and Rules

The resource is described in the DARSIR solution with attributes and rules. One attribute or rule can have several description schemes. One of the ways to streamline working with resources is to classify or standardize them. Within this section, attributes and rules are classified, dividing them into groups.

The arrangement of groups for attributes and rules is performed by their usage. Attributes and rules have the same groups, and they belong to the same groups. Every group of attributes have its particular rules attached that are necessary for starting attributes of this particular group. As the basis of grouping, RFID and barcode-based standards and principles were used, as well as research on the PML language [Bro2001a, Bro2001b etc.], adapting them to systems based on individual object properties.

The proposed group division is given in Table 3.1.

Table 3.1

Attribute and rule groups of DARSIR conception

Name	**Reason**
Resource identifier	Resource has a unique identifier by which to clearly distinguish one resource from a group of resources. There are various methods for identification of physical objects. Some of these methods are suitable for resource identification.
Individual properties	Resources have individual properties. The most common individual properties of resources are physical parameters (length, height, weight, etc.), material properties (plastic, metal, etc.), chemical composition (Calcium, Sodium, etc.), and so on. The way of operating with these properties is defined, and so is the possible application of the fundamental base units, such as length, mass, temperature, etc.
Relations	Resource has additional parameters that link the resource to other objects or places. Usually, it is the owner of the resource (e.g. an individual, organization, trademark, etc.) or resource location (e.g. a city, state, zip code, street address, building, room location, etc.).
Time	This is a part of the measurement system which is used to define the sequence of events, to compare their duration and the interval between events. For humans, the best suited periods are second, minute, hour, day, week, month, year, etc.
History	During the life of physical object, changes are happening. A mechanism is needed for storing history. History group is closely related to the time group. In the history attribute, time and state of the physical object is stored, which was recorded at the time.
Positioning	For resource, location can be defined. In sectors such as logistics, this is one of the most essential attributes. Positioning is divided into two broad categories: out-door and in-door.

Access rights	Because of data privacy and security requirements of DARSIR concept, access rights for resources should be regulated. For object-oriented approach, they are provided with the support of principles of encapsulation. Resources can be influenced by open rules (methods) and attributes. This group provides regulation of access rights.
Classification	A resource is a physical object with its unique individual properties. If there are a lot of resources, it is difficult to apply joint operations to them. One of the options for facilitating the handling of resources is resource classification and categorization. One should provide ability to create complex objects using constructors for composite objects.
Configuration	Resource may contain various other objects. A typical example is a container that contains boxes of goods. If the IS does not provide tags for all the resources, its information can be recorded in the basic resource. Thus, the information can be used in IS, but only through these groups.
Presentation	In the resource groups described above, automation was necessary for resource-related works. User must also provide information on resources that is not related to resource physical properties. Those are different types of data (text, video, audio, etc.) that are characterizing the resource and serving to inform the consumer of the resource about the properties of resource usage. Typical examples of resource presentation: user manual, warranty, advertisement (text, images, audio, video, etc.), and so on.

3.5. Conception Examination for Compliance to the Set Criteria

After describing the general DARSIR conception, it must be tested for compliance with the eight set SBIOP criteria.

Compliance to the first criterion *(i)* regarding *distribution and decentralization of computing resource management* is assured because DARSIR conception was developed on the base of DDMS operation principles. All the data refer to physical objects, and in every physical object the data are stored about the object itself. This

fact provides compliance with the criterion *(iv)* regarding *provision of local data access*. There is no need for other location for information storage.

One of the basic criteria that is based on modern solutions, is criterion *(ii)* regarding *applying standards*. Existing technologies and modern standards are described in Chapter 2, and they are used for developing DARSIR conception. Meeting the criterion *(iii) supporting the diversity of physical objects* is provided by storing data in modifications of current data exchange formats (for example, XML, JSON, and others).

For DARSIR conception, *active resources* (*AR*) are defined through which IT system can be divided into independent autonomous solutions. This is consistent with the criterion *(v)* regarding *autonomous operation*. Large systems can be divided into separate parts, and IT system can be implemented gradually. This offers benefits like dividing costs of implementation, gaining short-term economical effects. This is consistent with the criterion *(vii)* regarding *possibility of gradual implementation and distribution of implementation costs*. Using various technologies for DARSIR conception can provide benefits to utilize the existing technologies. Together with the above factors, this provides consistency with the criterion *(vi)* regarding *the economic benefits of implementing small solutions*.

On the last criterion *(viii)* regarding *ensuring data confidentiality, integrity, and accessibility*, additional research is needed. Consistency with this criterion can be partly achieved by specific technology characteristics (for example, see Table 2.3 in Paragraph 8 below). Compliance with criteria can be achieved through software, and in the further chapters, this process is described in detail.

3.6. Results and Conclusions

This chapter generally defines the basic elements of DARSIR conception (*resource*, *attribute*, *rule*, *document*), classifies and describes the three resource types (*PR*, *ASR*, and *ADR*), forms three scenarios of resource interactions (*single ADR (scanner) interaction*, *rival`s ADR interaction*, and *consecutive ADR interaction*) that are necessary for its creation. The individual properties of objects can be coordinated with system`s development, thus solving the issue about storing properties in the object itself. This, in turn, offers the ability to provide information from the object itself, in the moment of making decision that affects the object. The main conclusions are as follows:

- DARSIR conception is developed based on object-oriented approach, and it treats an object as a resource, the data of which is stored in a tag. The tag is attached to or built in the resource, and it contains set of sensors and document that represents data storing format, i.e., it provides structural storing of object properties (*attributes*) and methods (*rules*).
- *Attribute* is presentation of object`s properties in a document. Attributes have many variations, in order to simplify process of standardization, attributes should be divided

into *groups of attributes*. There are distinguished 10 groups of attributes and rules, which are organized by their usage.

- In the context of object-oriented approach, resource *rule* is a method, and a rule in DARSIR conception is represented by *variables*, *functions*, *procedures*, and *triggers*. A further research, mechanisms for implementation of rules should be developed.
- In the DARSIR conception, all the resources can be divided into *passive resources*, where data are stored and to which sensors are attached, and *active resources*, in which not only data are stored, but which also have resource functionality in accordance to which active resources are further divided into *active static resources* and *active dynamic resources*.
- Resource interaction is ensured through the *active resources*. Rules can be run only by an *active dynamic resource*, and it can be considered a scanner. The scanner can interact with other resources provided these resources are located in the reception area.
- Main Advantages of DARSIR Conception: *decisions can be made on-site*; *the diversity and uniqueness of physical objects is supported*; *data privacy level is increased*; *centralized data management and storing infrastructure can be abandoned*.
- The proposed DARSIR conception theoretically fully complies with the criteria set for object individual properties. Provided criterion *(viii)* regarding *ensuring data confidentiality, integrity, and accessibility* is examined in more detail, in the further chapters.

4. DARSIR Conception Implementation

Before the implementation, additional information should be acquired that may affect the implementation. Technology selection method should be defined required by this solution. Based on the impact criteria, the most appropriate technology should be defined and its typical implementation should be examined. Particular attention should be paid to the security and privacy issues.

4.1. Choosing Data Exchange and Storage Format

Data exchange formats are inspected to be used in conjunction with DARSIR conception. It was assumed that it is not effective to use database if the goal is to develop a decentralized DMS. For DARSIR conception, not only dates, but also functionality should be saved. The following data exchange formats were examined:

- *Delimiter-separated values* – it is text file for storing tabular data (numbers and text). Usually, method *CSV* (*Comma-Separated Values*) is used. This method is not meant for storing functionality.

- *eXtensible Markup Language (XML)* – one of the most popular formats for data exchange. It can be used.

- *JavaScript Object Notation (JSON)* – similar to XML language, can increase high-speed features, compared to XML. It can be used.

- *Protocol Buffers (PB)* – good, universal data exchange format, but the data exchange framework must be defined in advance. No flexibility, difficult to use.

For implementing DARSIR conception, two data exchange and storing formats are proposed and developed:

1. *Resource Physical Markup Language (RPML)* – it is an XML-type language that was developed specifically for DARSIR conception. First time this language definition and description is published in [Zur2007].

2. *JavaScript Object Notation for Resource, (JSONR)* – it is JSON-type language that was created particulary for DARSIR conception.

RPML and JSONR data exchange formats can be called DARSIR data exchange formats. In the thesis description, if the term DARSIR document is used, it is assumed it is RPML or JSONR data exchange format file.

4.2. Technology Selection

DARSIR conception can be used with different technologies. There is a need for a simple and reliable method for selecting the optimal technology solution, based on the solution`s needs. During solution analysis and development, new requirements can occur, but with this method one will be able to quickly assess their influence on technology selection.

The main criteria are examined that may influence this selection. Based on these criteria, a calculation method for technology selection is defined. For all the criteria, equal influence values are defined, and by default the technology most appropriate for DARSIR is chosen.

4.2.1. Impact Criteria

Impact criteria are divided into three groups:

1. *Physical parameters and the external environment* – one needs to define parameters that affect the mandatory implementation of the solution, i.e.: tag parameters (size, storage volume, ability to overwrite, etc.), scanner parameters (scanning rate, distance to the object), environmental conditions (temperature, humidity, etc.), etc.
2. *Costs* – total costs of running and maintaining the solution.
3. *Security and privacy* – implementing data protection methods of various kinds or combination of such methods.

4.2.2. Technology Selection Calculation Method

Specific technology is being chosen by assessing the need for IT solution. Usually, a compromise is found between options and costs. Technology criteria are defined, and every technology has its own parameter of technology type. For every type of technology parameter, a value is defined in the range from 0 to 1, the higher the parameter value, the better this parameter suits for DARSIR conception solution. For example, tag data storage volume, *linear barcode technology*. Its volume is 10 bytes and the value is 0.1 The volume for *two-dimensional barcodes* is 100 bytes and the value is 0.6 For *semi-active RFID tags*, the volume is 1,000,000 bytes and the value is 0.8

Another weight coefficient for technology parameters is defined, the permissible value range of which is 0 to 1. For example, when *barcode technology* is already used for a specific solution, the weight coefficient of technology type is 1. In cases when there is a need to calculate two-dimensional barcodes, the weight coefficient is 0.5, but RFID technology requires new costs, so the value is 0.1

For each technology, characteristics and limitations are defined. There are cases when essential technology limitations prevent from using certain technology. If the lowest possible value is set for an essential technology type parameter, then these limits are calculated during technology selection. For example, the tag data storage volume in the previous case. Let's suppose the IT solution requires 90 bytes of data volume, which corresponds to the value of 0.5 For *linear barcodes*, this value is 0.1, for *two-dimensional barcodes* it is 0.6, and for *semi-active RFID tags* it is 0.8 This means that all technologies correspond to the task, with the exception of *linear barcodes*.

CWCCRT (acronym for *Calculation of Weight Coefficient Combination for Rating Technologies*) is calculated according to the following formula:

$$CWCCRT = \sum_{i=1}^{n} a_i h(c_i, t_i) \quad , \tag{4.1a}$$

where n is the number of technologies, i is the number of technology type, a_i is the weight coefficient of technology type for ith technology, c_i is the type parameter of ith technology, t_i is threshold for acceptable values of ith technology type parameter, and h is the threshold function that acquires its value according to function:

$$h(c,t) = \begin{cases} c, \ ja \ c \geq t \\ +\infty, \ ja \ c < t. \end{cases} \tag{4.1b}$$

Coefficients of important parameters are called *Impact Factors (IF)*. DARSIR conception basically affects technologies for object identification (see Group 1 in Chapter 3.) IF of object identification technologies are combined in Table 4.1. – 4.3. In these tables, general information is provided, which means that every technology has various modifications, and for every modification, its own IFs can be defined.

Table 4.1

IF of physical parameters and external environmental technologies

(1 – data amount of tags, 2 – overwriting option, 3 – tag size; 4 – tag weight; 5 – atypical environmental conditions 6 – scanner reading rate; 7 – scanning distance; 8 – direct visibility of the scanning mode; 9 – scanner's multiple tag reading, 10 – technology recognition, distribution, and availability)

IC / **Technology**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Barcode (Code128)	0.2	0.1	0.9	0.9	0.9	0.4	0.3	0.1	0.1	0.8
Barcode (DataMatrix)	0.6	0.2	0.9	0.9	0.9	0.5	0.2	0.1	0.4	0.8
Barcode (QR Code)	0.6	0.2	0.9	0.9	0.9	0.5	0.2	0.1	0.4	0.8
RFID (passive)	0.6	0.1	0.9	0.9	0.9	0.7	0.6	0.7	0.9	0.8
RFID (semi active)	0.8	0.7	0.8	0.8	0.2	0.7	0.8	0.7	0.9	0.6
RFID (active)	0.9	0.9	0.2	0.5	0.1	0.5	0.9	0.8	0.7	0.4
NFC	0.6	0.5	0.9	0.9	0.7	0.7	0.6	0.7	0.4	0.6
Bluetooth	0.9	0.9	0.3	0.3	0.1	0.5	0.6	0.7	0.2	0.6
IrDA	0.9	0.9	0.3	0.3	0.1	0.5	0.6	0.3	0.2	0.5
GSM	0.8	0.6	0.3	0.3	0.1	0.3	0.8	0.7	0.7	0.8
Wi-Fi	0.9	0.7	0.2	0.2	0.1	0.3	0.7	0.7	0.6	0.9
WiMAX	0.9	0.9	0.2	0.2	0.1	0.2	0.9	0.7	0.6	0.5

Table 4.2

IF of technology costs

(1 – costs of technology implementation; 2 – costs of technology maintenance; 3 – scanner expenses; 4 – tag expenses; 5 – tag life-cycle)

IF / **Technology**	**1**	**2**	**3**	**4**	**5**
Barcode (Code128)	0.7	0.8	0.6	0.9	0.9
Barcode (DataMatrix)	0.7	0.8	0.7	0.9	0.9
Barcode (QR Code)	0.7	0.8	0.7	0.9	0.9
RFID (passive)	0.6	0.8	0.6	0.8	0.9
RFID (semi active)	0.5	0.7	0.6	0.7	0.7
RFID (active)	0.4	0.5	0.5	0.6	0.6
NFC	0.7	0.8	0.6	0.8	0.9
Bluetooth	0.5	0.5	0.6	0.6	0.4
IrDA	0.4	0.5	0.6	0.6	0.4
GSM	0.3	0.4	0.4	0.6	0.3
Wi-Fi	0.5	0.5	0.4	0.5	0.3
WiMAX	0.4	0.4	0.3	0.4	0.2

Table 4.3

IF of data security and privacy

(1 – built-in error detection features; 2 – built-in data recovery features; 3 – built-in features against unauthorized data use; 4 – identification methods; 5 – scanning accuracy

IF / **Technology**	**1**	**2**	**3**	**4**	**5**
Barcode (Code128)	0.4	0.1	0.1	0.9	0.2
Barcode (DataMatrix)	0.7	0.7	0.7	0.4	0.6
Barcode (QR Code)	0.7	0.7	0.7	0.4	0.6
RFID (passive)	0.4	0.1	0.5	0.9	0.7
RFID (semi active)	0.5	0.4	0.6	0.9	0.8
RFID (active)	0.6	0.6	0.7	0.9	0.8
NFC	0.4	0.1	0.5	0.9	0.7
Bluetooth	0.5	0.4	0.8	0.7	0.7
IrDA	0.5	0.4	0.8	0.7	0.7
GSM	0.5	0.3	0.7	0.6	0.8
Wi-Fi	0.5	0.2	0.8	0.7	0.7
WiMAX	0.5	0.2	0.8	0.7	0.7

Within one technology, devices of various manufacturers can be used, and they may have different parameters (technology values). By replacing one technology with another, CWCCRT is also affected. For example, barcode bar size is one criterion, while other criterion can be barcode data volume. If one increases requirements for data volume, usually it affects the size of barcode tags.

4.2.3. Calculation of One-Value for Impact Factors

IFs for technologies are defined, that affect systems based on individual object properties with the functionality for object identification. In subsequent research, it should be calculated which of the proposed technologies are the most suitable for DARSIR conception.

Suppose this task has an abstract solution that does not have any essential limitations, and all the IFs have the value of one. Let`s calculate for CWCCRT (using formula of 4.1) all the IFs that are defined for the 12 basic object identification technologies. The values of IFs are taken from Table 4.1 – 4.3.

In the first group of IFs, information about physical parameters and external environment is combined (see Table 4.1). The biggest CWCCRT with the value of 7.1 is aquired with the passive tags of RFID technology. Physical parameters (weight and size) of tags have the biggest advantage. Furthermore, it is possible to work with atypical environmental conditions, which cannot be fully provided by any other technology.

Table 4.2 summarizes the data regarding IF groups of technology costs. Judging by the CWCCRT calculation, the highest value is given to 2D barcodes (value of 4) and NFC (the value of 3.7). This result is obtained based on the long life-cycle of this technology and the low cost of tags.

In the third group of IFs, information regarding data security and providing confidentiality is summarized (see Table 4.3). The biggest CWCCRT with the value of 3.6 is acquired with the active tags of RFID technology. This result is based on the fact that RFID technology is more suitable to object identification than others.

According to CWCCRT calculations with one-value IF values, it is concluded that *2D barcode* and *RFID* technologies are the most suitable for DARSIR conception. However, RFID technology can have greater functionality, in comparison to the 2D barcode technology. For example, for barcodes, it is difficult to perform data overwriting options, the new tag must be printed over the previous one.

4.3. Overview of Safety Issues

DARSIR conception should provide compliance with the criterion *(viii)* regarding *data privacy, integrity, and accessibility* (see Table 1.2). First of all, technology security risks should be inspected. The RFID technology is used as the basis, and RFID technology`s specific attack taxonomy is examined. Analysis is performed regarding how topical are RFID technology information security problems for DARSIR conception. As a result, the current DARSIR conception security risks are acquired, and the new current risks are defined that are specific to DARSIR conception. The last step is to define basic measures for minimizing risks of RFID technologies for DARSIR conception.

4.3.1. Suitability of Information Security Problems Regarding DARSIR Conception

The main types of attacks performed in RFID systems are examined. Information from research [Tho2006] was used as the basis. ISs that are based on RFID technology, are usually dealing with centralized data management principles (for details see [Lah2005, Hei2005, Bau2005]). This is the main distinction in DARSIR conception risks, compared to the risks of a typical RFID technology implementation. Risks related to external data sources are not relevant to DARSIR conception. However, risks aiming at RFID tags (resources) are getting very dangerous.

The typical DARSIR conception implementation takes place in a closed system, so the risk of attack from internet or LAN is lower. Previously, RFID technology specific attack taxonomy was examined. Then, identified attacks on RFID technology and its suitability for DARSIR conception was considered.

At the end od this chapter, specific attack types are identified, that are characteristic to DARSIR conception.

- *Attack tag*. All the information (attributes and rules) is stored locally, in the resource itself. If the resource is not adequately protected (for example, the information is not encrypted), there is a possibility to add attack tag that inputs attack rules in the information system. When the attack rules are performed, it is possible to take control over some functions in the information system or acquire confidential information.
- *Forged tag*. In the resource (RFID tag), attributes can be stored that describe non-existent resource properties or damaged resource properties. For example, a pad can have attributes that describe pat size and weight. If this information is damaged, ir can cause technical problems, when this pad is getting transferred.

4.3.2. RFID Control for Reducing Information Security Risks

The data in RFID tags and system are not protected from many types of attacks, so the right security measures should be taken, in order to eliminate violations that cause system instability or its destruction. It must be remembered that there is no security measure that can prevent all potential attacks—its goal is to minimize threats or minimize the possible losses (influence) in case the attack happens.

Overall, twenty measures are offered for lowering security risks. For two risks that are specific to DARSIR conception (attack tag and forged tag), the next security measures for lowering risks are the following:

- *Attack tag.* In DARSIR conception, resource (RFID tag) itself stores rules that can change functionality of information system. A good system should be developed for communication between resources that store information about which functions can be performed with which resource (RFID tag). All attempts to perform illegal functions must be identified and eliminated, and reported to security team. The resources should also provide authentication option in information system. This can be done by using the methods above.

- *Forged tag.* This problem can be solved in at least two ways. The first method is data encryption using the standard methods. The second is the proposed information verification.

4.4. DARSIR Conception Practical Research

Within this thesis, theoretical research are described that resulted in developing DARSIR conception. In addition, practical DARSIR conception research was performed (the first one was [Zur2007]). JSONR and RPML language implementations were applied. First, the potential data types and their presentation formats were defined. Second, implementation of attribute groups and rule groups is shown. Based on this practical DARSIR conception implementation proposal, JSONR and RPML programming language implementation was developed. Particular attention was paid to data protection issue, and this research is published in report [Zur2011b].

The next step was software approbation in practical examples. It was studied how to build a software for implementing DARSIR solution; usage of a *visual interactive simulation* was proposed. As the major practical result, based on the theoretical argumentation in this chapter, "*DARSIR simulation tool*" has been built. Reference was made with comments in relation to using DARSIR conception on the basis of RFID technology. Results of the proposed approach are published in reports [Zur2011c, Zur2008c].

A typical task of this conception was proposed called "*Smart Laundry*" report [Zur2008b] – it is fully consistent with DARSIR conception requirements. DARSIR solution creation process is described from the compiling of solution requirements to the creation of solution in a mobile device. In addition, an atypical task was performed called "*Service Outsourcing Management System Design*". In this solution, only software is created, without using physical objects. Scope overview and research directions are formed. The operation principle of *multi-agent system* is used as the basis or this conception. Simulation is implemented with NetLogo [Wil1999] software. The two main results are reached. First – the DARSIR conception can also be applied for solutions that do not use physical objects. Second – research of creating new solutions can require creation of additional DARSIR conception attributes and rules. Results of this research is presented in reports [Zur2011a, Zur2012a, Zur2012b]. In addition to this research, practical verification of DARSIR conception was done with other tasks. For example, in report [Zur2008a], results are published from the task "*Road Traffic Monitoring and Management*".

4.5. Summary and Conclusions

This chapter addresses the current issues for introducing DARSIR conception. Special attention is paid to meeting the criterion *(viii)* (see Table 1.2) regarding *ensuring data* *confidentiality, integrity, and accessibility issues*. The practical studies of DARSIR conception are described with references to appendixes and international scientific reports. The main conclusions are as follows:

- For running *CWCCRT* (acronym for *Calculation of Weight Coefficient Combination for Rating Technologies*) method, twenty weight coefficient meanings are filled. CWCCRT is used with one-value impact criteria, and it is concluded that the most appropriate are *2D barcode* and *RFID* technologies.
- Within the range of examined technologies, RFID technology fits the best. It is concluded by applying CWCCRT method, provided that it is important to ensure the function for providing changes in resource attributes and rules during solution working process.
- By analyzing data security issues, two new types of attacks have been detected (attack tag and forged tag) that are specific to the DARSIR conception. Two recommendations are provided for implementing protection mechanisms, in order to reduce the risk of typical and newly discovered types of attacks.
- One of the options to provide users with an intuitive and easy to build IT solutions is implementation of simulation tools. An approach is proposed for creating IT solution directly from the simulation (for example, by using *visual interactive simulation*) thus proposing to simplify the process of creating an IT solution.
- After performing the atypical solution "*Service Outsourcing Management System Design*", the following results are received:
    - The DARSIR conception can also be applied to solutions that do not use physical objects.
    - Using universal methods, it is possible to build additional features for technologies that are used by DARSIR conception.
    - Research of creating new solutions can require creation of additional DARSIR conception attributes and rules.

The new theoretical results of this chapter are the research regarding addressing DARSIR conception`s security issues and the prepared theoretical materials for practical implementation of DARSIR conception. This includes groups of basic attributes and rules, CWCCRT method, etc.

Main Results and Conclusions

The goal of this thesis was to develop conception for decentralized systems based on individual object properties, and to test the properties of their implementation **on the basis of management system analysis and detection of their limitations and shortcomings**.

In order to achieve this goal, **the following tasks were fulfilled:**

- Criteria are identified for systems based on individual object properties (SBIOP). The most known conceptions of data management systems are studied and their compliance is evaluated in relation to the set SBIOP criteria. Within the range of data management system conceptions considered, principles and methods of best practice are summarized that have survived the test of time. The aggregated results are used for developing SBIOP conception.

- Technologies are determined that can be used for SBIOP. Based on criteria currently defined for SBIOP, parameters for comparing technologies are determined. The parameters are then used for determining the most appropriate technology to develop Information System (IS), based on the new conception.
- Using the determined SBIOP criteria, a conception for data management system based on individual object properties is offered. The main elements and scenarios of their interactions are described. Object properties are categorized, groups of attributes and rules are defined. Conception testing is performed for previously offered SBIOP criteria.
- Detailed study is performed for groups of attributes and rules, and the result is used during implementation of conception's practical application. The most essential IS solution technology selection criteria are set. Bearing in mind the criteria, a technology selection method is proposed. The method provides the ability to choose technologies best suited for the conception, based on relevant IS working conditions.
- A study of the developed conception`s privacy and security issues is performed. The typical attack methods are identified, detecting attack methods specific for the conception. Based on examination results, recommendations are given in order to minimize the information risks of the developed conception.
- Practical research for developed conception is performed, in order to verify practical applications for the software elements of the offered conception.

As a result of this research, the following criteria were identified for decentralised data management systems based on individual object properties:

- Distribution and decentralization of computing resource management;
- Applying standards;
- Supporting diversity of physical objects;
- Provision of local data access;
- Autonomous operation;
- Economical benefits of implementing small solutions;
- Opportunities for gradual implementation and expense distribution;
- Provision of data privacy, integrity, and accessibility.

By developing a data management conception that suits all the criteria mentioned, **the following new theoretical results are reached:**

- 8 criteria are identified, which *system based on individual object properties* (*SBIOP*) should comply to.

- 9 monolithic and 5 decentralised data management system conceptions have been studied and their suitability for set SBIOP criteria has been rated. It is concluded that none of the described data management systems meets all of the set SBIOP criteria, thus creating the need for developing decentralised data management system conception based on object individual properties.
- Data management systems` shortcomings, limitations, and benefits have been identified from the point of view of data storing and managing, and those are taken into consideration for building the new conception.
- 16 technologies and technology modifications are identified that are typically used for SBIOP solutions, and three technology groups are proposed that categorize technologies based on SBIOP usage purposes. 8 criteria are set for technology comparison, and these criteria affect technology selection for SBIOP solution.
- A conception DARSIR has been developed for decentralised data management systems based on individual object properties that satisfies the set SBIOP criteria. 3 basic types of objects are categorised for the proposed conception: *passive resources*, *active static resources*, and *active dynamic resources*. Three DARSIR conception resource interaction scenarios are suggested and described: interaction scenarios of *one ADR (scanner) interaction*, *parallel ADR interaction*, and *serial ADR interaction*. 10 groups for attributes and rules have been distinguished by their usage. The result is used for carrying out practical applications of DARSIR conception. The proposed conception has the following benefits: decision making is done locally, on-site; diversity and uniqueness of physical objects are supported; higher data privacy level; abandoning the centralised data storing and managing infrastructure solution.
- Three main groups of impact criteria are identified and 20 technology-affecting criteria are categorised, and as their basis, the method *CWCCRT* (acronym for *Calculation of Weight Coefficient Combination for Rating Technologies*) is created. The method CWCCRT was used to choose technology best suited for a specific solution. CWCCRT method has been used for 12 technologies from the group of object identification technologies. Via calculation with weight coefficients of equal worth, it is concluded that *RFID* and *barcode* technologies are suitable for DARSIR conception.
- It is concluded that none of the described technologies complies with the criterion concerning *ensuring data confidentiality, integrity, and accessibility* – this criterion has to be supported in software level. Additional research has been done, and the results are as follows:
    - 8 attack methods are determined that are relevant for implementing DARSIR conception on the basis of RFID technology, and two additional attack methods (*attack tag* and *forged tag*) are determined that are relevant to DARSIR conception, but the typical usage scenario of RFID technology does not significantly affect the solution.

  - 10 recommendations are proposed for lowering information security risks for DARSIR conception with RFID technology.
- Two new formats – *RPML* (on the basis of *XML* language) and *JSONR* (on the basis of *JSON* language) – are proposed, and those are used for applying DARSIR conception in practice.

The acquired theoretical results are implemented in a software complex, and two experiments are described in the thesis:

- A typical task of the conception – the DDMS solution, based on object individual properties, "Smart Laundry". A standard guide is provided for developing new solutions.
- A non-typical task of the conception – implementing software solution "Outsourcing Management System Based on Principles of Multi-Agent Systems". Two new groups of attributes are formed that are needed for practical application of the research. A guide for developing software solution is provided for a case the solution was not designed for, but can be applied, thus widening the range of solvable tasks.

The results of complex development and experimental testing of the software **brings to the following conclusions:**

- For *systems based on individual object properties (SBIOP)*, the following criteria are identified: *distribution and decentralization of computation resource management*; *applying standards; supporting diversity of physical objects*; *provision of local data access*; *autonomous operation*; *economical benefits of implementing small solutions*; *opportunities for gradual implementation and expense distribution*; *provision of data privacy, integrity, and accessibility*.
- The traditional data management systems only partially correspond to the list of SBIOP criteria. It was necessary to develop a conception for decentralized data management systems based on individual object properties that would satisfy the SBIOP criteria.
- The offered DARSIR conception fully complies with the list of SBIOP criteria.
- After applying CWCCRT (Calculation of Weight Coefficient Combination for Rating Technologies) method, it is concluded that from the identified SBIOP technologies and technology modifications the most suitable are:
  - RFID technology – if modification of information in the resource should be possible at any step of IS lifetime;
  - 2D barcode technology – if the information is static and will be changes very rarely in the IS lifetime.
- The basic benefits of DARSIR conception are: *decision making is done locally*; *diversity and uniqueness of physical objects are supported*; *higher data privacy level*; *abandoning the centralized data storing and managing infrastructure solution*.

Possible directions for future research:

1. Developing various solutions on the basis of the new conception, as well as offering new groups of attributes and rules for the conception as well as built-in functions, on the basis of these new solutions.
2. Offering and studying ways for developing practical solutions, based on the new conception.

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