RIGA TECHNICAL UNIVERSITY
Faculty of Computer Science and Information Technology
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DEVELOPMENT OF EDUCATION DEMAND AND OFFER INFORMATION MONITORING SYSTEM'S MODEL

Summary of the Doctoral Thesis

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DECLARATION OF ACADEMIC INTEGRITY

I hereby declare that the Doctoral Thesis submitted for the review to Riga Technical University for the promotion to the scientific degree of Doctor of Engineering Sciences is my own and does not contain any unacknowledged material from any source. I confirm that this Thesis has not been submitted to any other university for the promotion to other scientific degree.

Pēteris Rudzājs …….(signature)

Date: ……

The Doctoral Thesis has been written in Latvian. It includes 5 chapters, main results and conclusions, bibliography with 158 reference sources, 6 appendices, 49 figures and 14 tables in the main text. The volume of the Doctoral Thesis is 140 pages.

CONTENT

1. INTRODUCTION

A variety of information sources in the World Wide Web and inside the organizations contain valuable and reusable information. Nowadays there is a trend to use this information in automated information processing solutions, e. g., in gathering Web content, recommender systems, data mining and other solutions [1]. Information processing usually consists of activities that can be classified in four main groups, namely, information acquisition, analysis, decision making and decision implementation [2]. The automation of these activities can reduce their execution time, thus speeding up the achievement of information processing goals. However, in practice the full automation of activities is not always necessary or possible [3], thus leading to the situation where the activities have different automation levels in information processing [4]. Within the framework of the Doctoral Thesis, research is conducted in the context of education-related information processing and is devoted to systemic education demand and offer monitoring. The handling of this information for monitoring purpose requires technology based solutions for information acquisition, analysis and distribution among the stakeholders respecting the variability of options for implementing the information processing activities and automation levels.

1.1. Research Motivation

Due to different advancements (e. g., economic, business, science, standard development) the demand for knowledge, skills and competences on the job market and their offer at education institutions (education demand and offer further abbreviated as “edu d/o”) change relatively fast and foster the increase of the gap between the industry and education institutions (see upper part of Figure 1.1, which represents the connection between edu d/o), thus causing economic slowdown, unemployment and other problems [5]–[8]. To achieve and maintain edu d/o mutual correspondence, first the current status and its continuous changes should be identified, namely, edu d/o should be observed continuously. The observation can provide information relevant for aligning edu d/o. The alignment can take different forms, e. g., the adjustment of content of education institution courses in cooperation with industry representatives; and availability of information technology solutions for employers to identify continuous education possibilities in education institution for their employees.

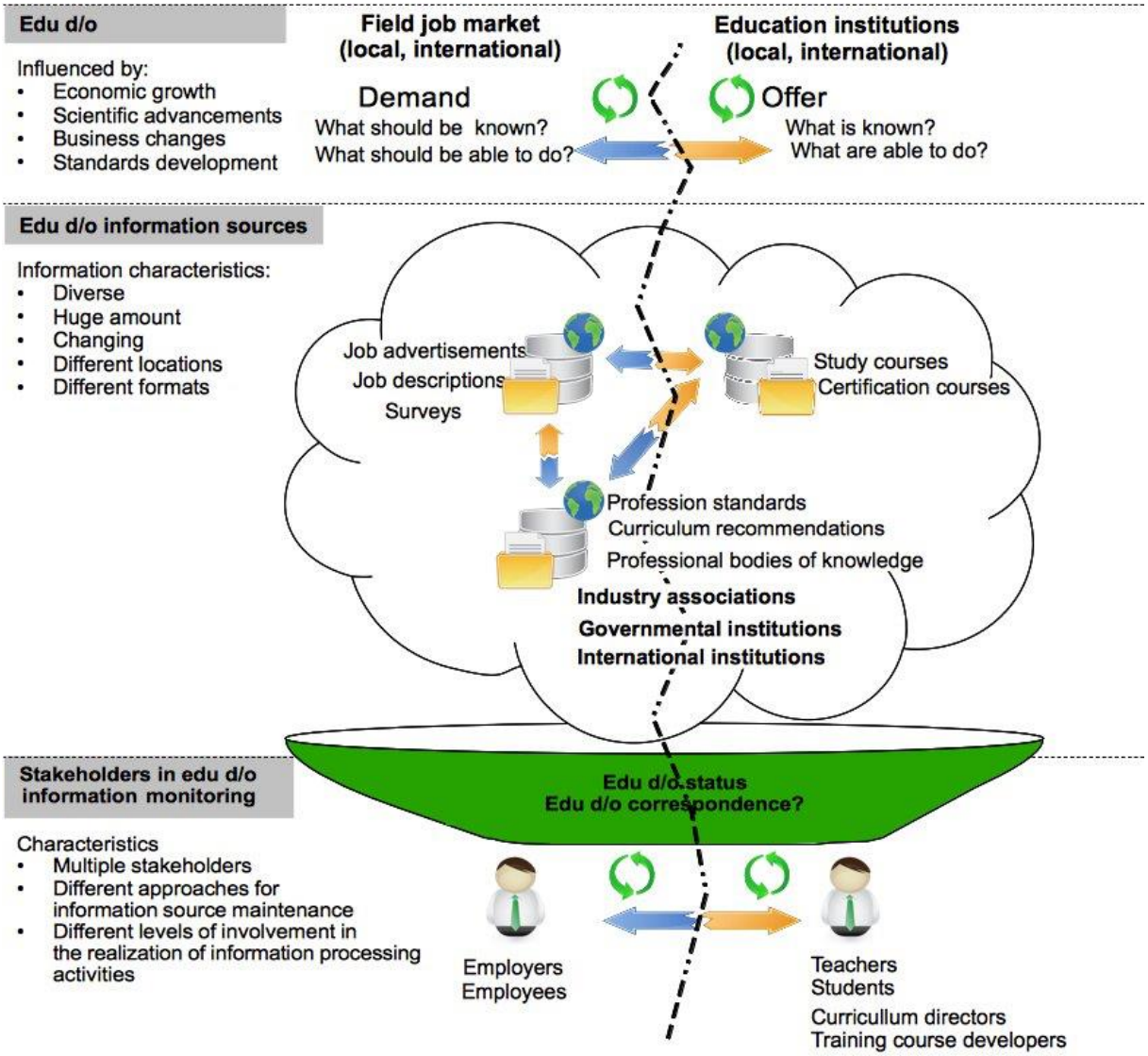

Figure 1.1. Problem domain of education demand and offer information processing.

There are various edu d/o information sources representing edu d/o information. By an information source the author of the Doctoral Thesis means anything that gives information about the area of interest, e. g., in the job market they are job advertisements, job descriptions, the results of surveys; at education institutions — various course descriptions; at other institutions they are profession standards, curriculum recommendations, professional bodies of knowledge. It is assumed that an information source is constituted by a document or a set of documents. Document is the representation of information, e. g., the curriculum gives information about courses included; thus, we say that the curriculum is constituted by a set of courses. However, the course description is the document representing, e. g., obtainable knowledge. Similarly we can say about job advertisements of a company that are the edu d/o information source constituted by a set of job advertisements (i. e., documents). In the above-

mentioned information sources, the amount of information is not only huge, but it is also continuously changing, available in different formats (usually knowledge, skills and competence information is encoded in various unstructured, semi-structured or structured textual documents) and distributed across such locations as the World Wide Web, databases and other types of documents inside the organizations [9]. The edu d/o information sources and the information characteristics are represented in the middle of Figure 1.1.

Due to the characteristics of edu d/o information, its processing is complicated and labor-intensive, thus hindering the systemic edu d/o information monitoring. As mentioned above, edu d/o information monitoring would provide valuable information to stakeholders both from education institutions (at universities — instructors, curriculum directors, and students; at other training institutions — course content developers and teachers) and from industrial organizations (employers and employees). Main stakeholders are represented in the lower part of Figure 1.1. Stakeholders in the edu d/o information monitoring can be involved in any information processing activity, e. g., they can provide edu d/o information sources, analyze them and distribute the results of analysis.

Currently, there is no systemic solution to edu d/o information monitoring enabling the monitoring of edu d/o information status and edu d/o information correspondence. By the *edu d/o information status* the author of the Doctoral Thesis means the edu d/o information represented in the edu d/o information source at particular moment of time, e. g., skills demanded in some or in a set of job advertisements in a particular field etc. The status of edu d/o information can be identified by analyzing edu d/o information sources. By the *edu d/o information correspondence* the author of the Doctoral Thesis means the mapping of edu d/o information represented in edu d/o information sources, e. g., the intersection of skills represented in job advertisements and course descriptions. Based on edu d/o information correspondence, we can reason about edu d/o correspondence. The edu d/o information characteristics and the intentions of different stakeholders regarding their involvement in the information processing activities and in the usage of analysis results should be respected when developing the systemic solution of edu d/o information monitoring. To systemically analyze edu d/o information status and correspondence, the documents of information sources should be made available to all the stakeholders involved in the monitoring. Due to the different approaches in maintaining edu d/o information sources, different implementations of the information acquisition should be available in edu d/o information monitoring. For example, course descriptions at universities usually are maintained and stored in the databases. That could facilitate automated acquisition of edu d/o information. As employers usually maintain their

job advertisements at Web sites, special mechanisms are required to make these descriptions available to other stakeholders in edu d/o information monitoring, e. g., descriptions could be provided by using user interfaces or by using specially designed Web crawlers [10]. Respectively, the implementation of information acquisition activity can vary for the one type of information source (e. g., database or Web site). In some cases, the human actor involvement might be necessary to input information, in other cases — information can be obtained and provided for further analysis purposes without the involvement of human actor (e. g., by using structured query language SQL or Web crawlers).

To characterize the human actor involvement in the implementation of information processing activity, the term *automation level* is used. In the Doctoral Thesis, the following automation levels are considered: manual, automatic, semi-automatic. *Manual* — an activity is performed by a human actor (perhaps, by using some general purpose office software, but not by the dedicated software application); *automatic* — an activity is performed by the dedicated software application without the involvement of a human actor; *semi-automatic* — an activity is performed by the dedicated software application, where some human actor involvement is necessary, e. g., a human actor should review and adjust the results obtained by software application.

1.2. Problem Statement

Based on the necessity to provide edu d/o correspondence and the lack of systemic solution for edu d/o information monitoring, two main goals of stakeholders in edu d/o information monitoring are defined, namely, *G1 — to systemically monitor the edu d/o information current status* and *G2 — to systemically monitor the edu d/o information correspondence*. As mentioned before, the edu d/o information characteristics and the intentions of different stakeholders regarding their involvement in information processing activities should be taken into consideration when developing a systemic solution to foster the achievement of the edu d/o information monitoring goals. Human actor and software involvement in edu d/o information processing pose the necessity to integrate in a unified system the solutions of the information processing activities with various levels of automation, thus fostering the achievement of the edu d/o information monitoring goals. To tackle the edu d/o information monitoring problem, the problem domain is explored and the appropriate system model for the edu d/o information monitoring is developed and evaluated. The system model in the Doctoral Thesis is represented as the system architecture, defining the structure, behavior and other views of the system [11], [12].

Goal and Objectives of the Doctoral Thesis

The goal of the Doctoral Thesis is to develop the model of edu d/o information monitoring system satisfying the requirements of processing edu d/o information with various characteristics, involvement of various stakeholders in the system, and satisfying the requirements for various implementation variants of activities with different levels of automation, thus fostering the achievement of stakeholder goals for edu d/o information status and correspondence monitoring.

In order to achieve the goal of the thesis, the following **objectives** have been set:

1. To explore current edu d/o information source management solutions for the information source maintenance, structured representation, retrieval and analysis.
2. To explore the structural characteristics of monitoring systems.
3. To explore the principles of service orientation, service systems and service composition suitable for the development of edu d/o information monitoring solution.
4. To explore the current means for representation of variability and its inclusion in the architecture of a system.
5. To define the requirements of systemic solution of edu d/o information monitoring based on the exploration of the problem domain (objectives 1–4).
6. To develop the model of edu d/o information monitoring system, which represents the variability of system functional structure and behavior.
7. To evaluate the usability of the model by developing concrete models of edu d/o information monitoring systems and their implementations in software prototypes.
8. To evaluate the utility of the model for the tackling of edu d/o information monitoring problem.

Research Object, Subject and Methods Used

The research object of the Doctoral Thesis is education information systems.

The research subject of the Doctoral Thesis is systemic support for edu d/o information monitoring.

The main result of the Doctoral Thesis is general edu d/o information monitoring system model. Design science research methodology is used for structuring the research reported in the Doctoral Thesis. Research is based on the analysis of literature, design and prototyping.

The approbation of research results has been carried out by evaluating the ability of the developed model to 1) represent the variability in edu d/o information monitoring, 2) satisfy the

requirements of edu d/o information monitoring, as well as 3) achieve the stakeholder goals G1 and G2.

Main Thesis Statements to Be Defended

S1 The edu d/o information monitoring system model, which ensures the related representation of system stakeholders and the services relevant for them, as well as the system structural and behavioral variability, is suitable to design edu d/o information monitoring systems.

S2 Based on the model mentioned in S1, it is possible to achieve the goals of stakeholders in edu d/o information monitoring.

1.3. Research Method

Design science research methodology [13] is used for structuring the research reported in the Doctoral Thesis. This methodology has been chosen because it suggests the development of technology oriented artifacts to solve social, organizational or business problems in the field of information systems [14]. In design science research, the artifacts are classified as constructs, models, methods and instantiations [14], [15]. The goal of research is the development of model of edu d/o information monitoring system, which contributes to the solution of edu d/o information monitoring problem, namely, the lack of systemic edu d/o information monitoring. This means, that the artifact is developed (model of edu d/o information monitoring system) to contribute to solving the problem of the lack of systemic edu d/o information monitoring.

According to the design science research methodology [13], the following activities are to be carried out: 1) problem identification and motivation, 2) definition of objectives of the solution, 3) design and development, 4) demonstration, 5) evaluation and 6) communication. Below, these activities are explained in relation to the Thesis (in the description of activities the text in brackets and in *italic* points to the corresponding objectives and chapters of the Thesis).

In the *first activity*:

1) The edu d/o information monitoring problem has been explored by identifying the main stakeholders of the problem and their goals (see *Section 1.1*), and by formulating the problem (corresponds to the goal of the Thesis stated in *Section 1.2*).
2) The problem domain has been explored by analyzing the literature *(Objectives 1–4; Chapter 2).*

For the formulation of the problem, the following template for the design science problems has been used [16] (p. 15):

Improve <a problem context> by <designing an artifact> that satisfies <some requirements> in order to <help stakeholders achieve some goals>

In the Thesis, there are the following corresponding elements:

- Problem context: systemic edu d/o information monitoring.
- Artifact: the model of edu d/o information monitoring system.
- Requirements to be satisfied: **Rq1** — the processing of edu d/o information with various characteristics, **Rq2** — the involvement of various stakeholders in the system, and **Rq3** — the need for various implementation variants of activities with different levels of automation.
- Stakeholder goals: G1 — systemic edu d/o information status monitoring and G2 — systemic edu d/o information correspondence monitoring.

In the *second activity*, the requirements of systemic edu d/o information monitoring solution have been defined based on the formulated problem and the exploration of the problem domain (*Objective 5; Section 3.2*).

In the third activity, the model of edu d/o information monitoring system (i. e., artifact) has been developed. Methods for the representation of variability of system functional structure and behavior have been developed to design the model (*Objective 6; Chapter 3*). These methods are a means (Wieringa [16] calls them "instruments") to develop the artifact. The prototypes that implement the model have also been developed (*Objective 7; Chapter 4)*. The prototype is a means to evaluate the model.

In the *fourth* and *fifth activity*, the designed model has been evaluated by demonstrating its prototype and evaluating the utility for edu d/o information monitoring (*Objective 8; Chapter 5*).

The *sixth activity* is devoted to communication of the research — the results of the Doctoral Thesis have been presented in 12 international conferences and have been published in 20 papers.

1.4. Scientific Novelty and Practical Significance of the Thesis

The main **scientific novelty** of the Thesis is the developed model of edu d/o information monitoring system, which satisfies requirements of processing edu d/o information sources with various characteristics, involvement of various stakeholders in the system, and satisfying requirements for various implementation variants of activities with different levels of automation, thus fostering the achievement of stakeholder goals for edu d/o information status and correspondence monitoring.

Theoretical Value

The aforementioned scientific novelty includes several **theoretical results** (a detailed list of results is provided in the chapter "Main Results and Conclusions"):

- Two-level system architecture and methods for representation of the system functional structure and behavior variability.
- Based on findings on existing edu d/o information source management solutions, adapted and implemented methods in edu d/o information monitoring domain for direct and mediated edu d/o information identification and source document mapping.
- Systematized overview on topics of classification of monitoring systems and service systems by means of literature analysis.

Practical Significance

Development of the Thesis has revealed the following practical results (a detailed list of results is provided in the chapter "Main Results and Conclusions"):

- Two edu d/o information monitoring system prototypes, namely, EduMON portal and KIVIS tool.
- Detected correspondences among documents of various edu d/o information sources in the information technology domain.

Approbation of the Obtained Results

The results of the Thesis have been presented in 12 international conferences:

- July 19–23, 2014. *2nd International Conference on the Human Side of Service Engineering*. Poland, Krakow.
- November 26–27, 2013. *1st IEEE Workshop on Advances in Information, Electronic and Electrical Engineering (AIEEE 2013)*. Latvia, Riga.
- September 23–25, 2013. *12th International Conference on Perspectives in Business Informatics Research*. Poland, Warsaw.
- June 19, 2013. *4th Workshop on Business and IT Alignment (BITA 2013) in conjunction with 16th International Conference on Business Information Systems (BIS 2013)*. Poland, Poznan.
- August 29–30, 2012. *21st International Conference on Information Systems Development (ISD2012)*. Italy, Prato.
- May 16–18, 2012. *6th International Conference on Research Challenges in Information Science (RCIS2012)*. Spain, Valencia.
- October 6, 2011. *10th International Conference on Perspectives in Business Informatics Research (BIR2011)*. Latvia, Riga.

- July 24–26, 2011. *International Conference on Intelligent Systems and Agents (ISA2011)*. Italy, Rome.
- February 23–28, 2011. *3rd International Conference on Information, Process, and Knowledge Management (eKNOW2011)*. Guadeloupe, Le Gosier.
- October 11–15, 2010. *51st International Scientific Conference of Riga Technical University*. Latvia, Riga.
- October 12–16, 2009. *50th International Scientific Conference of Riga Technical University*. Latvia, Riga.
- September 16–19, 2009. *18th International Conference on Information Systems Development (ISD2009)*. China, Nanchang.

The results have been presented in 20 international scientific papers:

- Rudzajs P. and Kirikova M. Conceptual Correspondence Monitoring: Multimode Information Logistics Approach // Complex Systems Informatics and Modeling Quarterly, vol. 1, no. 1, pp. 57–73, 2014.
- Rudzajs P. and Kirikova M. Variability Handling in Multi-Mode Service Composition // 2nd International Conference on the Human Side of Service Engineering, 2014, pp. 3–12.
- Rudzajs P. and Kirikova M. Service Functioning Mode in Variability Model // Lecture Notes in Business Information Processing (Advanced Information Systems Engineering Workshops), vol. 178, L. Iliadis, M. Papazoglou, and K. Pohl, Eds. Thessaloniki, Greece: Springer International Publishing, 2014, pp. 124–135. Indexed in: **SpringerLink, Scopus**.
- Rudzajs P., Kirikova M., Strazdina, R. Capabilities and Challenges of Contemporary Service Based Monitoring Systems // 12th International Conference on Perspectives in Business Informatics Research (BIR2013). Berlin: Springer-Verlag Berlin Heidelberg, 2013, pp. 278–289. Indexed in: **SpringerLink, Scopus, ISI Web of Science**.
- Rudzajs P., Kirikova M., Strazdina R. Configurative Alignment of Business and Application Services: A Work Systems Perspective // Proceedings of 4th Workshop on Business and IT Alignment (BITA 2013) in conjunction with 16th International Conference on Business Information Systems (BIS 2013). Berlin: Springer-Verlag Berlin Heidelberg, 2013, pp. 100–111. Indexed in: **SpringerLink**, **ISI Web of Science.**
- Kirikova M., Rudzajs P. Multimode Information Logistics for Conceptual Correspondence Monitoring // 11th International Conference on Perspectives in Business Informatics Research (BIR2012): 5th Workshop on Information Logistics and Knowledge Supply (ILOG 2012), 2012, pp. 31–42.
- Rudzajs P., Kirikova M. Towards Monitoring Correspondence between Education Demand and Offer // 21st International Conference on Information Systems

Development (ISD2012), 2012. Berlin: Springer, 2012, pp. 467–479. Indexed in: **SpringerLink**.

- Rudzājs P. Towards Automated Education Demand-Offer Information Monitoring: the Information extraction // 6st International Conference on Research Challenges in Information Science (RCIS2012), 2012, pp. 453–454. Indexed in: **IEEExplore, Scopus**.
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- Rudzajs P. Towards Automated Education Demand-Offer Information Monitoring: the Architecture // Selected Papers from Workshops and Doctoral Consortium of the International Conference on Perspectives in Business Informatics Research, BIR2011, 2011, pp. 252–265. Indexed in: **ISI Web of Science**, **Scopus**.
- Rudzajs P. Education Offer/Demand Compliance Monitoring Approach // 10th International Conference on Perspectives in Business Informatics Research, BIR2011, 2011, pp. 427–436.
- Birzniece I. and Rudzajs P. Machine Learning Based Study Course Comparison // IADIS Conference on Intelligent Systems and Agents (ISA 2011), 2011, pp. 107–111. Indexed in: **Scopus**.
- Rudzajs P., Buksa I. Business Process and Regulations: Approach to Linkage and Change Management // 10th International Conference on Perspectives in Business Informatics Research, 2011, pp. 96–109. Indexed in: **SpringerLink, ISI Web of Science, Scopus**.
- Rudzajs P., Kirikova M., Strazdina R., Sukovskis U. Learning Outcomes in the Mirror of Qualification Frameworks // Proceedings of the 3rd International Conference "Institutional Strategic Quality Management" (ISQM2011), 2011, pp. 247–354.
- Rudzajs P., Kirikova M., Strazdina R., Sukovskis U. Towards Managing Learning Outcomes in the Jungle of Qualification Standards // Proceedings of EQANIE-Conference "Learning Outcomes and Quality Management in Informatics Education", 2011, pp 1–7.
- Rudzajs P., Kirikova M. Enhancing Knowledge Flow by Mediated Mapping between Conceptual Structures // Third International Conference on Information, Process, and Knowledge Management, 2011, pp. 36–41. Indexed in: ThinkMind.
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- Strazdina R., Kirikova M., Penicina L., Rudzajs P. Knowledge Requirements Monitoring System: Advantages for Industry and University // Proceedings of the Second International Conference on Information, Process, and Knowledge Management (eKNOW 2010), 2010, IEEE Computer Society, pp. 120–125. Indexed in: **IEEExplore, ISI Web of Science, Scopus**.
- Rudzajs P., Kirikova M. IT Knowledge Requirements Identification in Organizational Networks: Cooperation between Industrial Organizations and Universities // International Conference on Information Systems Development (ISD2009), 2009, pp. 187–199. Indexed in: **SpringerLink, Scopus.**

1.5. Structure of the Doctoral Thesis

The Thesis consists of 5 chapters, main results and conclusions, bibliography and appendices.

The first, introduction, chapter concerns the problem to be solved, defines the goal, objectives, and describes the research method, main results and contents of the Thesis.

In the second chapter, the exploration results of edu d/o information monitoring problem domain are reported, which concern the existing solutions of edu d/o information source management, structural characteristics of monitoring systems in different fields, as well as reveal the principles of service orientation, service systems and service composition, which are suitable for the integration of edu d/o information source management solutions into a unified system. Current means for representation of variability of the information processing activities and their implementation variants and inclusion in the system architecture are also discussed.

The third chapter provides a detailed description of the developed model of edu d/o information monitoring system with its constituting sub-models, namely, 1) base service model, 2) base service flow model, 3) system functional structure variability model and 4) behavior variability model. For the development of models 3) and 4) special methods are developed and presented in the chapter.

In the fourth chapter, the description of developed models of edu d/o information monitoring systems for concrete systems and their software prototypes are provided.

The fifth chapter provides the evaluation results of edu d/o information monitoring system model. The ability of the model to represent the variability in edu d/o information monitoring system, the compliance of the model with edu d/o information monitoring requirements and the utility of the model for the stakeholders to achieve their edu d/o information monitoring goals are evaluated.

To conclude the Thesis, main theoretical and practical results as well as possible future research directions are summarized in the section of main results and conclusions.

The Thesis has 6 appendices:

1. Glossary of abbreviations used in the Thesis.
2. Summary of structural characteristics of various monitoring systems.
3. Summary of service system classification.
4. Abbreviations of services.
5. Description of software prototype configuration for mediated edu d/o information identification.
6. Results of the automatic edu d/o information identification in the selected set of documents.

2. PROBLEM DOMAIN OF EDUCATION DEMAND AND OFFER (EDU D/O) INFORMATION MONITORING

To find the existing means, which can be used for solving the actual edu d/o monitoring problem and for development of system model, the literature analysis has been carried out. The results of analysis are presented as follows: 1) existing solutions of edu d/o information source management, 2) monitoring systems, 3) services and service systems, and 4) handling of system variability. Such a structure has been selected with a goal to identify edu d/o information source management solutions, principles to integrate these solutions into a unified system, as well as to research the variability representation in the system architecture, thus forming a basis for the development of model of edu d/o information monitoring system.

2.1. Edu D/O Information Source Management Solutions

By the edu d/o information source management solutions the author of the Thesis means solutions for edu d/o information source maintenance, structured representation, retrieval and analysis. Important edu d/o information sources (see Section 1.1) are created, stored and distributed by different information source maintenance systems. For this purpose, information systems are used, e. g., study management systems for maintenance of study course descriptions [17], [18] and human resource management systems [19] as well as job advertisement portals (e. g., www.cv.lv) for maintenance of job descriptions and advertisements.

Apart from the maintenance of edu d/o information sources, the processing of these information sources should be performed. To automate the processing of these sources and to facilitate the common understanding between the stakeholders about the edu d/o information represented in these sources, it is important to use knowledge structures. Knowledge structures [20] systemize the concepts of some field (e. g., knowledge, skills and competences in the information technology field) and are a means to represent edu d/o information in a structured way, e. g., for structured representation of skills obtained in study courses and demanded in job advertisements. Knowledge structures are suitable for achieving information interoperability among stakeholders and can serve as a "unified language" [21], which is understood by stakeholders. This is especially important in edu d/o information monitoring to ensure unified and structured representation and processing of edu d/o information sources. The development and use of interoperability means are highly promoted by the institutions of the European Union [22], [23]. During the development of the Thesis [24]–[28], several knowledge structures for systemizing knowledge, skills and competences have been identified, e. g., "Computing Classification System" taxonomy provided by the Association for Computing Machinery

(ACM-CCS) [29], European Dictionary of Skills and Competencies (DISCO) [30], European e-Competence framework (e-CF) [31] and tools and technologies defined by the American Occupation Information Network program "O*NET" [32].

As the edu d/o information sources are distributed and maintained by their owners, solutions are necessary for gathering them in one location to enable further analysis for the achievement of stakeholder goals G1 and G2 stated in Section 1.2. Taking into account that most of edu d/o information sources are available on the Web, it is important to note the role of Web crawlers [10] for information retrieval. When information source documents are retrieved, usually an analysis is performed to extract the concepts of interest (e. g., persons, locations, events, skills etc. [33]) from these documents. The most popular platforms for this purpose are Apache Unstructured Information Management Architecture (UIMA) [34] and General Architecture for Text Engineering (GATE) [35], which are used in various solutions, e. g., for the extraction of competence information from the employee profiles inside an organization [36].

By exploring existing edu d/o information management solutions, it has been concluded:

1. Solutions operate in isolation from other solutions and they are not targeted for the edu d/o information monitoring.
2. Several edu d/o information sources can be used as basic information sources for edu d/o information monitoring.
3. Solutions for structured edu d/o information representation (i. e., knowledge structures) can be used as a means to identify the edu d/o information in information sources in a unified way and to map the information sources (i. e., identify correspondence), thus facilitating the achievement of stakeholder goals (G1 and G2).
4. As most of the edu d/o information source documents are available on the Web and their retrieval is a time-consuming process, the Web crawlers are suitable. Information sources are also available from databases, Web services and documents inside organizations. This variety of sources should be respected when developing the edu d/o information monitoring solution to facilitate the achievement of stakeholder goals G1 and G2.
5. The analysis of retrieved edu d/o information source documents is the task of text analysis. For this purpose, natural language processing methods are to be used. Several text analysis platforms are available, which can serve as a means to

automate the analysis of edu d/o information source documents. In the Thesis, the purpose of document analysis is to identify edu d/o information in text documents, thus facilitating the achievement of goal G1.

2.2. Monitoring Systems

For the systemic monitoring problem, the monitoring systems are used in practice. The main goal of the monitoring systems is to enable system users to observe a situation and its changes during the period of time [37]. Monitoring systems in education and other domains are studied in the Thesis with the goal to find foundation for the development of edu d/o information monitoring solution, namely, the potential system structure.

Currently, the monitoring systems designated for education domain are used mainly for education management solutions that ensure the monitoring of the execution of syllabi [38]–[40]. Monitoring systems are used in other domains as well, e. g., environment monitoring [41], health monitoring [42], mechanical system monitoring [43], information technology infrastructure monitoring [44], media monitoring [45], [46], business activity and process monitoring [47].

By exploring the monitoring systems in the fields listed above, it has been concluded that there are no structured frameworks for the description of monitoring systems, thus hindering the analysis of their structure and comparison with other monitoring systems. For the purpose of structured description of monitoring systems, a special framework has been developed by using several parameters identified by the analysis of literature. This framework initially was presented in the thesis author's publication [48] and author's supervised Bachelor Thesis [49].

Edu d/o information monitoring here is described by the developed framework (parameters are highlighted in *italic* in this paragraph). In the edu d/o information monitoring, the *object of monitoring* is textual edu d/o information sources, which contain unstructured, structured or semi-structured (*data rigidity*) textual format documents (*data source format*) generated by a human actor. *Monitoring aspect* is edu d/o information represented in documents. Data are provided by *virtual sensors* (software retrieves the data from data sources) or *physical sensors* (a human actor retrieves the data). By exploring media monitoring systems, it has been concluded that they process information sources with the characteristics similar to edu d/o information sources (e. g., diversity, changing nature, huge amount, and different formats and structure). This finding allows making the statement that the elements of *internal organization* of media monitoring systems can be applicable to the edu d/o information

monitoring, e. g., services [50]. In edu d/o information monitoring the following *monitoring sub-functions* are identified: information retrieval, analysis and distribution. Data reading from databases, Web crawling, data downloading and manual data entry into the system are the *monitoring methods* used in information retrieval sub-function. As mentioned in Section 2.1, edu d/o information source document analysis is a text analysis task; therefore, an information analysis sub-function includes natural language processing, namely, text analysis and concept based (i. e., using knowledge structures) information source processing and mapping. For the information distribution sub-function, similarly as in other monitoring systems, specialized user interfaces and portals with search and browsing facilities can be used. Due to the edu d/o information characteristics and other problems identified in the problem domain, human actors and software can be involved in the execution of monitoring sub-functions (*involved agents*).

Exploring the structure of monitoring systems, the use of the developed framework helped to identify structural characteristics of individual monitoring systems. Edu d/o information monitoring system should have the union of the characteristics of several types of monitoring systems, namely, *be able to retrieve data from different types of data sources*, because there are multiple edu d/o information sources and their characteristics; *be able to handle structured, unstructured and semi-structured data*, because edu d/o information resides in different textual format documents (unstructured, semi-structured and unstructured); *should include multiple elements and methods used in internal organization of monitoring system for data retrieval, analysis and distribution*, because different methods and elements are necessary to process edu d/o information sources and to achieve stakeholder goals (see G1 and G2 in Section 1.2); *both human actor and software should be involved in monitoring data retrieval, analysis and distribution,* because multiple stakeholders can be involved in the edu d/o information monitoring, thus posing requirements to mechanisms for situations when activities are performed by a human actor, software or both.

Currently, the monitoring systems designated for the education domain are used mainly for education management solutions that ensure the monitoring of the execution of syllabi. In the education field, there are no solutions for edu d/o information monitoring. The specific character of edu d/o information monitoring is that it requires the involvement of multiple stakeholders in monitoring activities that was rarely observed in the explored monitoring systems. Human involvement in the monitoring activities and the edu d/o information source characteristics pose the requirement to ensure a flexible edu d/o information monitoring solution suitable for situations when the activities are performed by a human, software or both. For this purpose services, service systems and system variability handling is explored.

2.3. Services and Service Systems

The solutions for edu d/o information source maintenance, retrieval and analysis can be viewed as services, which together with available resources (i. e., edu d/o information sources and knowledge structures) form the system, which fosters the achievement of the stakeholder goals. Therefore, in the development of edu d/o information monitoring the solutions can potentially be based on the paradigm of service system that is focused primarily on interaction between people, technology, other internal and external service systems, as well on the exchange of shared information between the stakeholders of service system to achieve common goal by service compositions [51]. The service is the base unit of service oriented solution and the service orientation principles are applied in its design [50]. By services in the broader sense one understands activities performed for the benefit of service system stakeholders [52]. However, in the Thesis the narrower sense is used — services are understood simply as modular functionality that can be accessed and combined with other functionalities [53]. If in the execution of the functionality software is involved, the term *automated service* is used. According to automation levels defined in Section 1.1, automated service can be with automation level "automatic" or "semi-automatic". If a human actor performs the functionality, the term *manual service* is used (automation level is "manual"). If the service is considered at the high abstraction level, then term abstract service is used, whereas at the low abstraction level — concrete service [54]. Concrete service is the implementation of abstract service. Automated services and manual services are types of concrete services.

In the edu d/o information monitoring, multiple edu d/o information source management solutions (see Section 2.1) are to be integrated in the unified system for the achievement of stakeholder goals. For this purpose the principles of service orientation, service systems and service composition are applicable. Edu d/o information source management solutions further are viewed as services, which together with available resources form the information intensive service system that fosters the achievement of the stakeholder goals by service compositions. The research on service composition mainly considers automated services that form the system, however taking into account the requirement to include multiple stakeholders in the edu d/o information monitoring with the necessity to consider the services with various automation levels, the method for such service composition is required. As service systems pose the variability of possible solutions, the next section reports the results of research on the representation of variability and its inclusion in the system architecture.

2.4. System Variability Handling

Many systems are designed with variability in mind, e. g., self-adaptive systems, open platforms, as well as service systems [55]. The possibility of multiple edu d/o information management solutions (i. e., services) and their combinations (i. e., service compositions) for the achievement of stakeholder goals raise the necessity for the system variability handling [56]. In the context of variability handling, current means for representation of variability [57] and its inclusion in the architecture of systems [58] are discussed. Variability in software engineering usually is defined as an ability for software or software artifact (e. g., service) to be changed for the specific context [59], [60]. As in the Thesis the information intensive [61] service system is considered, the variability is defined as an ability to change an information processing unit (i. e., service) to adapt to a specific context or an intention.

Based on studies on variability handling, it has been concluded that the feature models are widely used as a means to represent the system functional structure variability [57], [62]. Feature models are used as a means to manage system variability; to document and analyze the mandatory, non-mandatory and alternative features of the system (in the Thesis — services); to ease the communication of system features to the stakeholders, and for the system design [63], [64]. In the Thesis it has been concluded that for the system variability handling the architecture views are used, which are defined by viewpoints [12]. Therefore, it has been concluded that a feature model is suitable for representing the view of service system functional structure variability [65]. As the behavior of a service system is determined by service compositions, the service flows (i. e., the result of service composition) are suitable for representing the view of system behavior variability. These mentioned views of the system should be included in the model of edu d/o information monitoring system. As the feature model and the service flows currently do not support the representation of abstract services, concrete services and service automation levels, in the Thesis they cannot be used directly. Moreover, the methods for maintaining the alignment in the system architecture between the functional structure and behavior variability views are not available at present. In the Thesis, two methods are proposed, namely, the method for the design of the feature model extended with service types and automation levels and the method for the design of service flows extended with service types and automation levels based on the feature model.

3. GENERAL EDU D/O INFORMATION MONITORING SYSTEM (GEDUMON) MODEL

The proposed general edu d/o information monitoring system model is represented as system architecture. The system architecture is the conceptual model defining the structure, behavior and other views of the system [11]. The architecture description is the representation of the system allowing one to reason on the structure and behavior of the system. The developed general edu d/o information monitoring system model is represented by related sub-models. These sub-models satisfy the edu d/o information monitoring requirements (stated in Section 1.2) of the processing of edu d/o information with various characteristics, the involvement of various stakeholders in the system, and the need for implementation variants of activities with different levels of automation. Further in the text **G**eneral **Edu** d/o information **MON**itoring system is referred to as GEduMON. As the GEduMON model represents the structure of the system it is further referred to as system architecture, whereas the sub-models — as models included into the architecture.

GEduMON architecture is developed in two levels, namely, general architecture and detailed architecture are developed. General architecture defines the framework for the structure and behavior, whereas detailed architecture based on the general architecture defines the views of system functional structure and behavior variability. These views are necessary to specify the variability of service system (see Section 2.4).

GEduMON architecture is developed with the following steps (see Figure 3.1):

1. Development of base service model for the representation of architecture framework (see Section 3.1).
2. Development of base service flow model for representation of base service execution sequence based on base services and their requirements (see Section 3.2).
3. Development of architecture view for representation of variability of system functional structure based on a base service model and by using extended feature model (see Section 3.3).
4. Development of architecture view for representation of variability of system behavior based on the view of system functional structure and by using extended service flows (see Section 3.4).

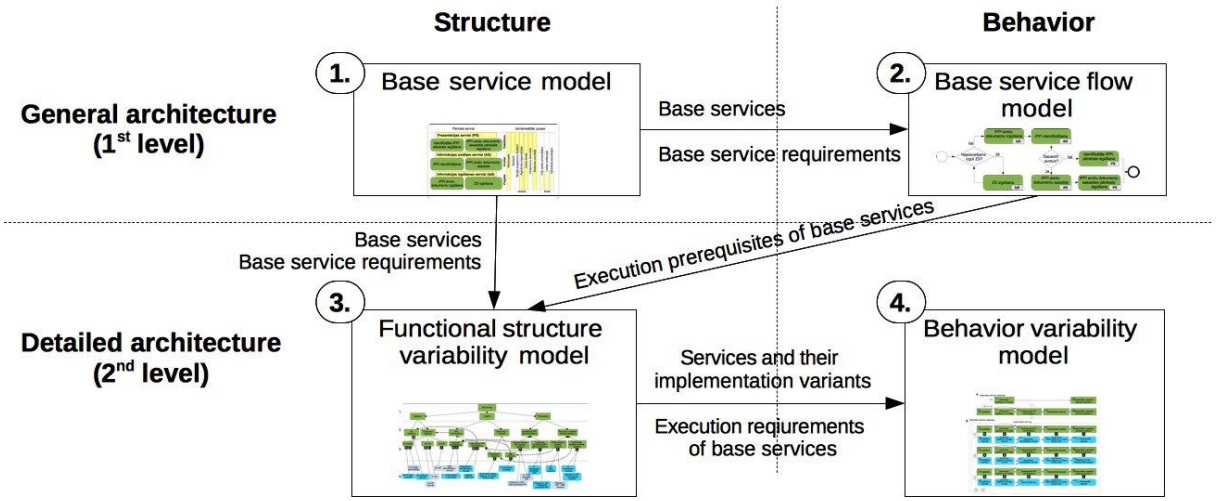


Figure 3.1. GEduMON architecture development steps.

The gradual development of base service model is represented in the Thesis author's publications [9], [24], [25], [28], [66], [67], whereas the variability aspects of system functional structure and behavior are initially discussed in the Thesis author's publications [68]–[72].

3.1. Base Service Model

This section describes the developed GEduMON base service model, which forms part of general GEduMON architecture. Model is developed based on the goals of stakeholders involved in edu d/o information monitoring and on the research on monitoring problem domain (see Chapters 1 and 2). Base service model represents the framework of system structure, namely, it represents services required for edu d/o information monitoring (see Figure 3.2).

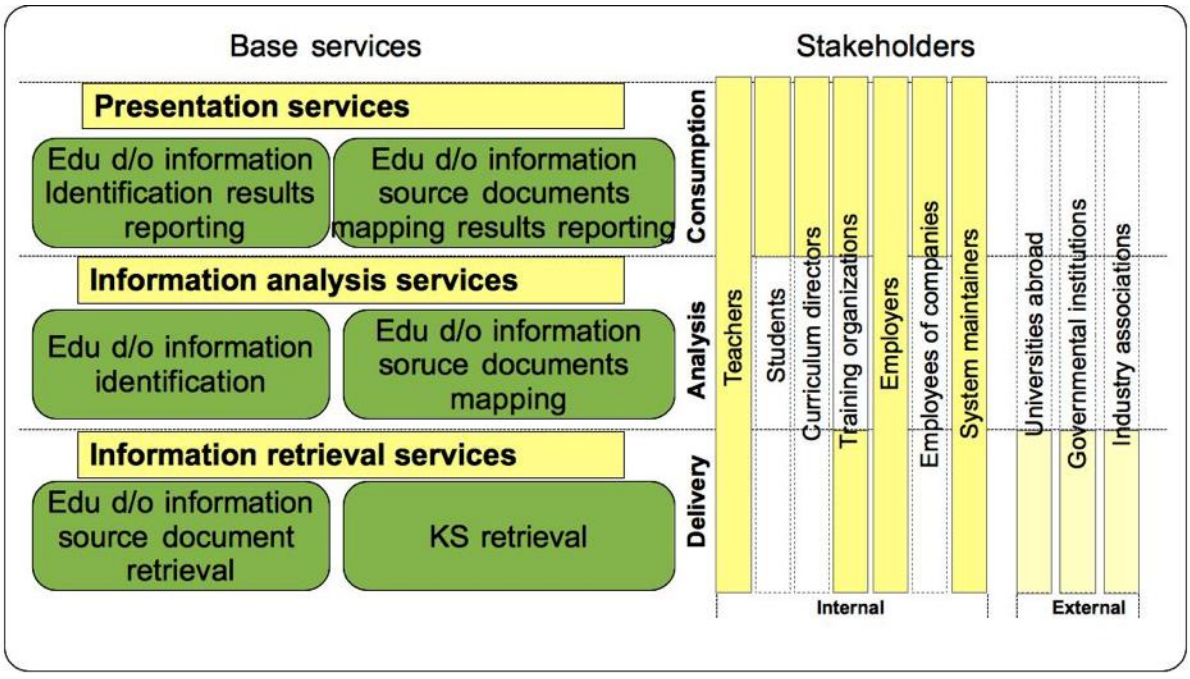


Figure 3.2. Base service model. Highlighted parts of the bars on the right side of figure indicate the stakeholder involvement in execution of delivery, analysis and consumption activities.

Base services are organized by main monitoring sub-functions (retrieval, analysis and distribution) as the service groups:

- **Information retrieval service group.** The services of this group are designated for delivering content to the system for analysis and distribution among the stakeholders and for services of other groups. Two base services are identified in this group, namely, edu d/o information source document retrieval service and knowledge structure (KS) retrieval service.
- **Information analysis service group**. The services in this group are designated for the identification of edu d/o information in documents and for mapping of edu d/o information source documents, thus facilitating the achievement of edu d/o information monitoring goals. The services in this group use the results of services of information retrieval service group.
- **Presentation service group.** The services in this group are designated for the representation of analysis results to the stakeholders in form of tables, graphs and images. Two base services are identified, namely, edu d/o information identification results reporting service and documents mapping results reporting service.

Base service requirements are specified to identify the mandatory, possible service variations and execution sequence. *Mandatory service* requirements define whether without the service the achievement of stakeholder goals is possible; *possible service variation* requirements define the possible variation of base services according to stakeholder goals and the results of edu d/o information monitoring problem domain; and *service execution* requirements define the execution prerequisites of base services and its variants.

The potential involvement of stakeholders in the execution of services is represented on the right side of Figure 3.2. We can see that larger involvement is in the consuming activity. However, to perform this activity, the retrieval and analysis activities should be performed. Stakeholder involvement in edu d/o information monitoring activities determines the involvement of stakeholders in EduMON base services, e. g., teacher involvement in the analysis activity, which means that teachers could be involved in the execution of EduMON base services for edu d/o information identification and edu d/o information source document mapping.

3.2. Base Service Flow Model

Based on requirements stated for base services, the base service flow model is constructed for achieving the stakeholder goals (see Figure 3.3). This model represents the system by abstracting from the variability of the system behavior.

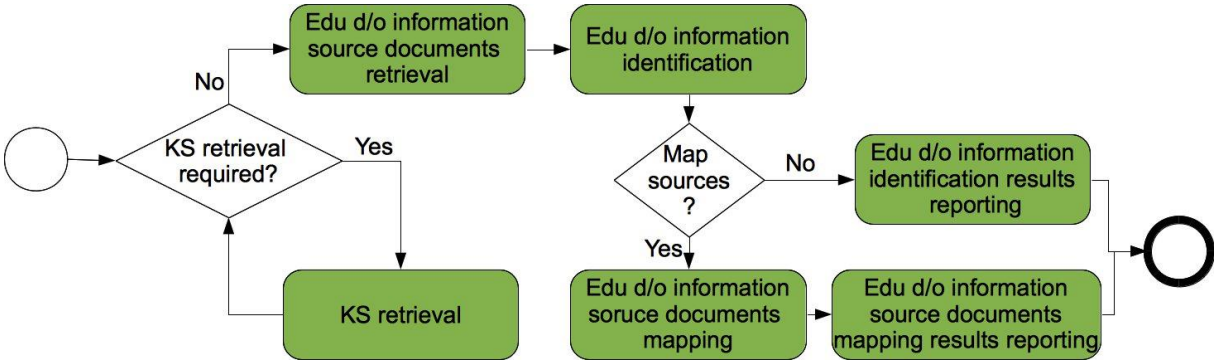


Figure 3.3. GEduMON base service flow model.

Each service in the flow model can be executed only if the necessary resources exist, namely, document or knowledge structure is available or the result of other required service is available. As variation requirements in the Thesis are defined for each base service, variability in the GEduMON base service flow is possible. Apart from the variants of each base service, variation in the implementation variants exists as well. This fact leads to the situation where the GEduMON base service flow can have multiple alternatives, which are determined by the flows of service implementations or concrete services. In order to define concrete service flows, view of variability of system functional structure in the architecture is defined, based on which the method for service composition is proposed (see Sections 3.3 and 3.4).

3.3. Functional Structure Variability Model

As explained in Section 2.4, the feature model cannot be directly used for the representation of variability in edu d/o information monitoring service system, because it does not support the representation of different service types and automation. Therefore, the extension of the feature model is proposed to represent the abstract services, namely, service groups (i. e., variation points) and their services (i. e., variants), as well as the concrete services or implementation variants of abstract services, which are characterized by automation levels.

Abstract services in the feature model are represented as variation points in rectangular boxes, whereas the concrete services are represented as rounded boxes (see Figure 3.4.). The variation point is the point in the system where the choice has to be made, which variant to use [60]. Variant is one of the options in the variation point. Concrete services implement abstract

services; therefore, they are called implementation variants of services. Abstract services are denoted as S_i, whereas concrete services as $S_i^{\{A,M,SA\}}$, where the upper index points to the service automation level. Both for abstract and concrete services the bottom index is used for identifying the number of service. An example of an extended feature model is given in Figure 3.4.

The main benefits of the feature model extended with service types and automation levels are the ability, even before service composition, to clearly identify services where the human actor involvement is necessary (namely, services with M and SA automation levels), and the ability, at the time of service composition, to identify the transition between services with different automation levels.

Using the extended feature model, viewpoint [65] for variability of system functional structure is defined. Based on this viewpoint the appropriate view of GEduMON is developed. Viewpoint also defines the relationships with other models in system architecture. In this case, the relationship with the GEduMON base service model is identified meaning that the abstract services of feature model should correspond to the EduMON base services and their variants. Feature Model Design (FMD) method is proposed for the alignment of base service model and extended feature model. FMD method uses the base services and their requirements defined in base service model to design feature model. The GEduMON feature model designed using FMD method is represented in Figure 3.4.

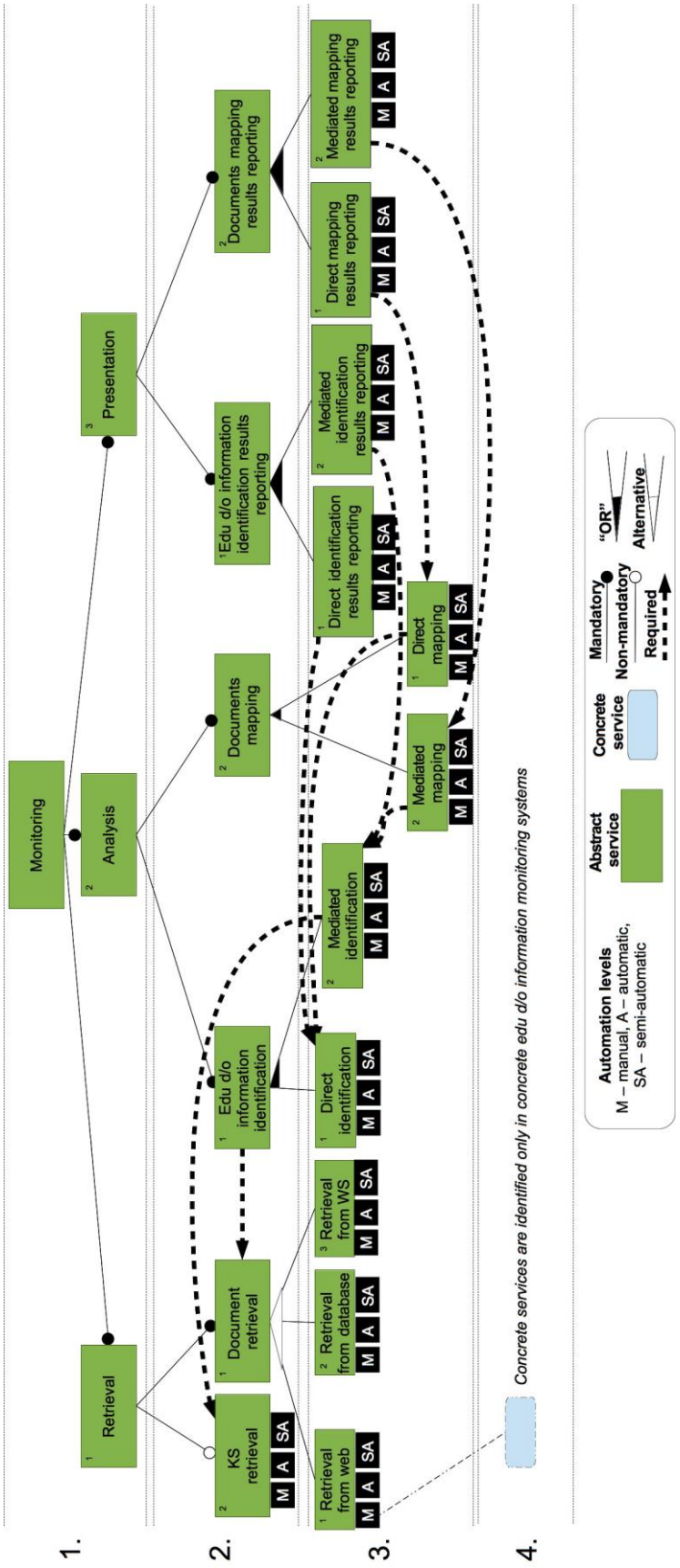


Figure 3.4. Feature model representing the view of GEduMON functional structure variability. The number of service is identified by concatenating the numbers of higher level services, e. g., direct edu d/o information identification service number is 2.1.1; thus, it is represented as $S_{2.1.1}$. 1. — service group level, 2. — base service level, 3. — base service variation level, 4. — implementation variant level.

3.4. Behavior Variability Model

Based on general GEduMON architecture, detailed architecture consisting of models of functional structure (see Section 3.3) and behavior variability is developed. This section presents the behavior variability model, the goal of which is to specify the system behavior variability in alignment with the functional structure variability model. The service flows extended with service types and automation levels are used to define the viewpoint and appropriate view for the variability of system behavior. In this viewpoint, the relationship with the GEduMON functional structure variability model is identified, i. e., the abstract services and concrete services of service flows should correspond to the abstract and concrete services, as well as to the relationships presented in GEduMON feature model. Intention Oriented Service Composition (IOSC) method is proposed for the alignment of system functional structure variability with the system behavior variability (method initially presented in the Thesis author's publication [71]). IOSC method is applicable for service composition (i. e., the arrangement of services in a service flow) using the extended feature model, namely, the abstract and concrete services and the relationships between them. To use this method, feature model based on extended feature model notation should be available (see Section 3.3). Concrete service flows for implementation of intention oriented service are the result of the IOSC method. The result of usage of IOSC method in the GEduMON allows us to analyze the system from the behavior variability viewpoint by providing an ability to compose flows of services with various automation levels. By analyzing service flows, we can directly identify the transitions and alignment of service interfaces, which is important when deciding on implementation of particular services and the transitions between them.

The next chapter discusses concrete implementations of the GEduMON model, namely, software prototypes of the EduMON portal and KIVIS tool. For this purpose, the GEduMON functional structure variability model is extended with concrete services and the IOSC method is used to construct the concrete service flows implementing intention oriented services, which constitute the system behavior variability model.

4. IMPLEMENTATION OF GEDUMON SERVICES

GEduMON model presented in the previous chapter is defined as two-level edu d/o information monitoring system architecture. System general architecture (1st level) is constituted of base service model and base service flow model. System detailed architecture (2nd level) is based on general architecture and is constituted of functional structure and behavior variability models. According to the developed GEduMON functional structure and behavior variability models, identified abstract services are implemented and integrated in a unified system, thus demonstrating the viability of services and promoting the tackling of edu d/o information monitoring problem. Two concrete implementations of the GEduMON model are proposed in the Thesis, namely, EduMON portal and KIVIS tool [24]. KIVIS tool was developed with the support of Lattelecom Technology Ltd. and Riga Technical University in the context of research project No. ZP-2009/15 "Development of the Method and the Prototype for the Normalization and Linkage of Computer-based Competence Descriptions". The participation of the company in the development of the tool also shows its interest in tackling the edu d/o information monitoring problem. The solutions adapted and implemented in services of EduMON portal and KIVIS tool for mediated edu d/o information identification and mediated mapping of information sources are discussed in more detail in the Thesis author's publications [24]–[27], [73].

Manual services are implemented as manually executable activities, results of which are made available for other services in the system by entering them in the database through user interface input forms or transforming them to the format acceptable to other services of the system. Automatic services are implemented as software components, integrated libraries or integrated services provided by other platforms.

The GEduMON functional structure variability model presented in Section 3.3 is extended with concrete EduMON services; thus, we obtain the EduMON functional structure variability model. This model is represented in Figure 4.1.

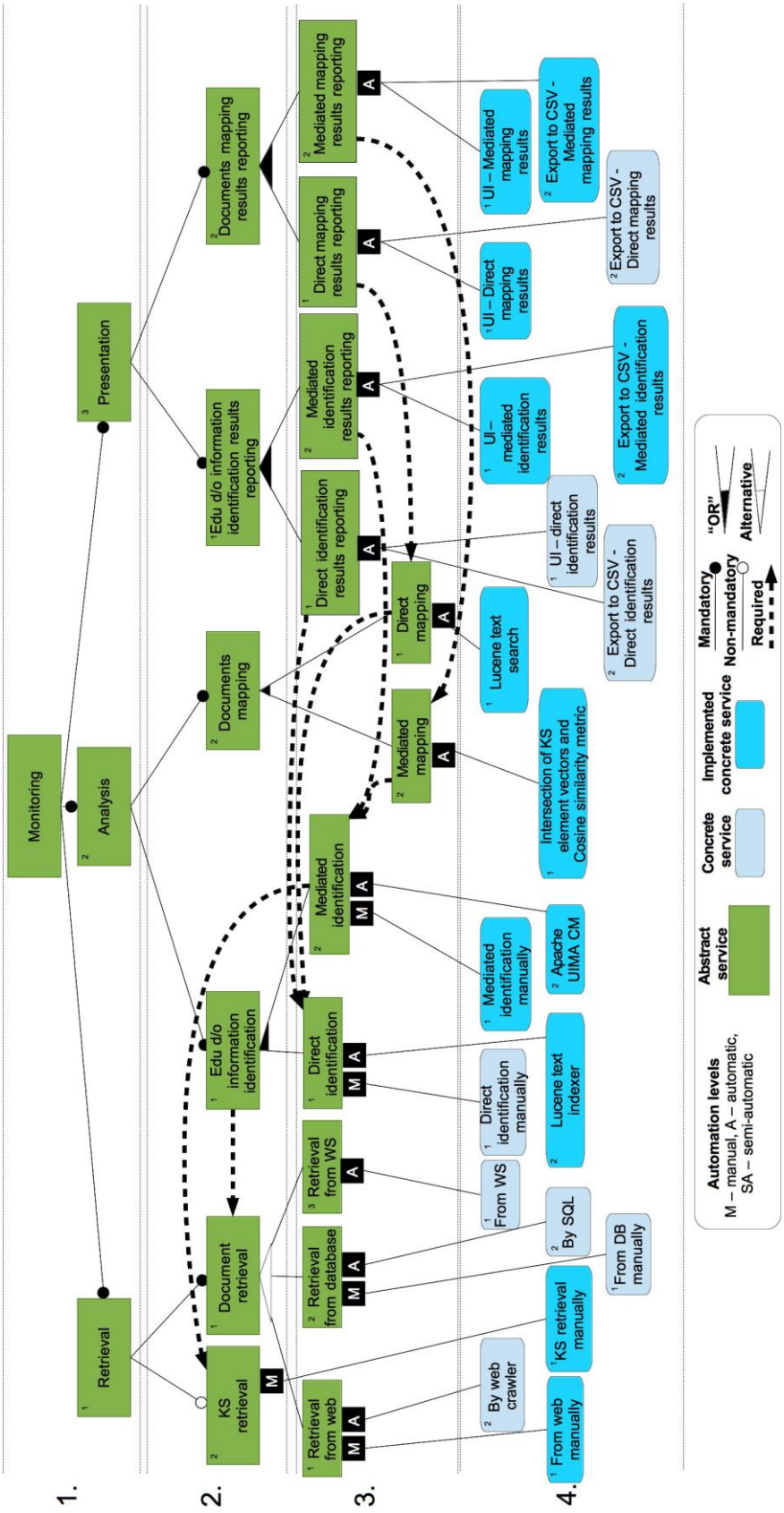


Figure 4.1. Feature model representing the view of EduMON functional structure variability. The number of service is identified by concatenating the numbers of higher level services, e. g., direct edu d/o information identification service number is 2.1.1; thus, it is represented as $S_{2.1.1}$. Implemented concrete services are highlighted.

EduMON behavior variability view is constituted with intention oriented services and intention oriented service flows that implement them. Intention oriented services are formulated using the abstract services from the system feature model, e. g., service $IS_{(1.1.1;\ 3.2.2)}$ (i. e., achieves the intention "retrieve documents from Web resources and get the report of edu d/o information source documents mediated mapping") is part of the EduMON behavior variability view (other intention oriented services should be represented in this view as well). To design the service flows implementing this intention oriented service, the EduMON feature model represented in Figure 4.1 is used and the IOSC method is employed. Illustrative example of the result of the use of IOSC method representing the service flows implementing intention oriented service $IS_{(1.1.1;\ 3.2.2)}$ is given in Figure 4.2.

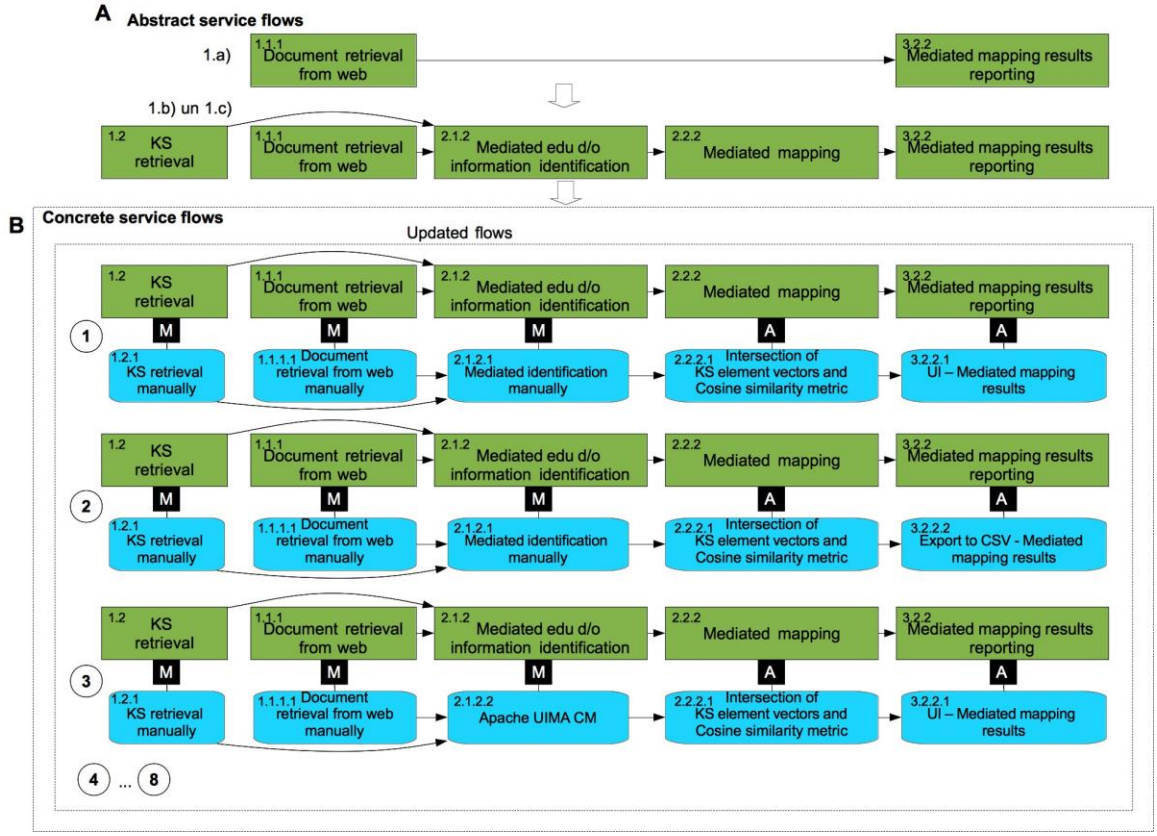


Figure 4.2. The result of IOSC method (example) representing the implementing service flows for intention oriented service $IS_{(1.1.1;\ 3.2.2)}$. Service flow models constitute the EduMON behavior variability view.

For the sake of simplicity, the options of service flows for implementing intention oriented service $IS_{(1.1.1,\ 3.2.2)}$ are formulated in the following way: (numbers on the left-hand side are just indicative and indicate the corresponding service flow in Figure 4.2; "•" — denotes service composition, "U" denotes the union of service flow options [74]):

$IS_{(1.1.1,\ 3.2.2)}$ = U (

1. •($S^{M}_{1.2.1}$, $S^{M}_{1.1.1.1}$, $S^{M}_{2.1.2.1}$, $S^{A}_{2.2.2.1}$, $S^{A}_{3.2.2.1}$),

2. •($S^{M}_{1.2.1}$, $S^{M}_{1.1.1.1}$, $S^{M}_{2.1.2.1}$, $S^{A}_{2.2.2.1}$, $S^{A}_{3.2.2.2}$),
3. •($S^{M}_{1.2.1}$, $S^{M}_{1.1.1.1}$, $S^{A}_{2.1.2.2}$, $S^{A}_{2.2.2.1}$, $S^{A}_{3.2.2.1}$),
4. •($S^{M}_{1.2.1}$, $S^{M}_{1.1.1.1}$, $S^{A}_{2.1.2.2}$, $S^{A}_{2.2.2.1}$, $S^{A}_{3.2.2.2}$),
5. •($S^{M}_{1.2.1}$, $S^{A}_{1.1.1.2}$, $S^{M}_{2.1.2.1}$, $S^{A}_{2.2.2.1}$, $S^{A}_{3.2.2.1}$),
6. •($S^{M}_{1.2.1}$, $S^{A}_{1.1.1.2}$, $S^{M}_{2.1.2.1}$, $S^{A}_{2.2.2.1}$, $S^{A}_{3.2.2.2}$),
7. •($S^{M}_{1.2.1}$, $S^{A}_{1.1.1.2}$, $S^{A}_{2.1.2.2}$, $S^{A}_{2.2.2.1}$, $S^{A}_{3.2.2.1}$),
8. •($S^{M}_{1.2.1}$, $S^{A}_{1.1.1.2}$, $S^{A}_{2.1.2.2}$, $S^{A}_{2.2.2.1}$, $S^{A}_{3.2.2.2}$));

EduMON portal provides execution of service flows where the following services are included (numbers of services correspond to the numbers of services represented in Figure 4.1):

- Service $S^{M}_{1.1.1.1}$ for manual edu d/o information source document retrieval from the Web. Human actor executes the service by visiting edu d/o information source and retrieving its documents. After the retrieval, the documents are saved, e. g., in the text files. To ensure the availability of the results of this service to other services in the EduMON, a user interface input form is implemented for entering them in the EduMON database.
- Service $S^{M}_{1.2.1}$ for manual knowledge structure retrieval. Human actor executes the service by visiting the Web or other resources, where the knowledge structure of interest is available and retrieving this knowledge structure. After the retrieval, the knowledge structure is saved, e. g., in the text file. To ensure the availability of the results of this service to other services, in the EduMON special transition among the services is implemented, namely, the knowledge structure is transformed to the format acceptable to other services.
- Service $S^{A}_{2.1.2.2}$ for mediated edu d/o information identification by using the Apache UIMA platform. Service is executed by the Apache UIMA ConcepMapper [75] text analysis engine with the adapted configuration to enable the identification of knowledge structure elements in the documents. As a result of mediated edu d/o information identification, the vector of knowledge structure elements (those represented in the document) is created. Initially, the principle of this service is described in the Thesis author's publications [27], [73].
- Service $S^{A}_{2.1.1.2}$ for direct edu d/o information identification by a text indexer and service $S^{A}_{2.2.1.1}$ for direct edu d/o information source document mapping by text search. These services use text indexing and search software library Lucene [76]. This library is integrated into the EduMON portal and it is used to perform the analysis of the edu d/o

information source documents and to create the text index and then to perform the search (i. e., document mapping) within this index.

- Service $S^{A}_{2.2.2.1}$ for mediated edu d/o information source document mapping by using the vectors of knowledge structure elements and *Cosine* [77] similarity metric. Initially, the grounding principle of this service is described in the Thesis author's publication [24].
- Presentation services for reporting:
  - Services $S^{A}_{3.1.2.1}$ and $S^{A}_{3.1.2.2}$ for mediated edu d/o information identification results reporting by a user interface (UI) and by exporting to a CSV format file.
  - Service $S^{A}_{3.2.1.1}$ for direct edu d/o information source document mapping results reporting by a UI.
  - Services $S^{A}_{3.2.2.1}$ and $S^{A}_{3.2.2.2}$ for mediated edu d/o information source document mapping results reporting by a UI and by exporting to a CSV format file.

Similarly to EduMON, the KIVIS tool functional structure variability and behavior variability models are obtainable by updating the GEduMON functional structure variability model and behavior variability model with the concrete KIVIS services. KIVIS tool provides execution of service flows where the following services are included (methods employed in services and the execution results of services are initially described in the Thesis author's publications [24]–[26]):

- Service for manual edu d/o information source document retrieval from the Web and service for manual knowledge structure retrieval. The operating principles of these services are similar to the corresponding EduMON services.
- Service for manual mediated edu d/o information identification.
- Service for automatic mediated edu d/o information source document mapping by using the vectors of knowledge structure elements.
- Presentation services for mediated edu d/o information identification and document mapping results reporting by a UI.

These developed detailed architecture models and corresponding software prototypes (EduMON portal and KIVIS tool) are used as instruments to evaluate the usability of GEduMON model for the development of edu d/o information monitoring systems as well as its practical utility.

5. EVALUATION OF GEDUMON MODEL

According to the design science research methodology, the developed GEduMON model is the artifact (see Section 1.3). Several analytical, experimental, testing and descriptive methods are used for the evaluation of artifacts [14]. The two of descriptive methods, namely, informed arguments and scenarios, are used to evaluate the GEduMON model in the Thesis. Information about the structure of GEduMON model is used to make arguments about its suitability to the tackling of edu d/o information monitoring problem. The model quality criteria [78] "conformity with requirements" and "usability" are used as the basis for evaluating the GEduMON model. The criterion "conformity with requirements" in the Thesis is understood as the completeness and consistency of the model, which is evaluated as the ability of the model to represent the variability in edu d/o information monitoring and alignment of GEduMON general and detailed architecture (see Section 5.1). In turn, the criterion "usability" is understood as the suitability of model for the design and development of edu d/o information monitoring systems, namely, for the design and development of EduMON portal and KIVIS tool (see Section 5.2). Apart from the artifact conformity with requirements and usability, its practical utility is evaluated with scenarios, namely, the EduMON portal usage scenarios are designed demonstrating its utility (see Section 5.3). The EduMON portal is a means to evaluate the practical utility of GEduMON model.

5.1. Completeness and Consistency of GEduMON Model

The construction of GEduMON architecture is performed at two abstraction levels, namely, general and detailed architecture are developed (see Chapter 3). System general architecture is constituted of base service model and base service flow model. System detailed architecture is constituted of functional structure and behavior variability models. The means for variability representation and the implementation variants of abstract services are justified with the research on edu d/o information monitoring problem domain, namely, the research on edu d/o information source management solutions, monitoring systems, service systems and system variability handling. The proposed GEduMON model allows representing the variability both in the system functional structure and in the behavior variability models. Variability in the functional structure variability model is represented using the feature model extended in the Thesis. Extended feature model provides the possibility to represent the variability of abstract services as well as implementation variants of abstract services and their automation levels.

Abstract services with possible variability are represented as variation points in the feature model (it is as a base for functional structure variability model), e. g., for abstract edu

d/o information identification service $S_{2.1}$ according to base service requirements there are two variants (see the model represented in Section 3.3), namely, services for direct and mediated edu d/o information identification. The representation of the variability of abstract services is performed with the developed Feature Model Design (FMD) method, which ensures system functional structure variability model alignment with the requirements stated in the base service model. However, the implementation variants of abstract services, namely, concrete services, are represented in an additional layer of the extended feature model. For example, the variability of implementation variants of EduMON services for direct and mediated edu d/o information identification is represented with concrete services and their automation levels (see Figure 4.1).

In the behavior variability model, the variability is represented using abstract service flows and concrete service flows that implement them. One and the same abstract service flow for achievement of one intention can be implemented by multiple concrete service flows. For example, EduMON intention oriented service $IS_{(1.1.1;\ 3.2.2)}$ (i. e., achieves the intention "retrieve documents from Web resources and get the report of edu d/o information source documents mediated mapping") can be achieved by 8 concrete service flows (see Figure 4.2). The representation of system behavior variability is guided by the proposed Intention Oriented Service Composition (IOSC) method ensuring the system behavior variability model alignment with the system functional structure variability model.

In the context of variability representation, it is possible to evaluate how the GEduMON model complies with the edu d/o information monitoring requirements (defined in Section 1.3). Rq1 is satisfied because in the functional structure variability view of GEduMON model the abstract services for the retrieval of various edu d/o information source documents from different locations are represented, namely, retrieval from the Web, databases and Web services, as well as the services for unstructured text processing and edu d/o information source document mapping are represented. Rq2 is satisfied because the stakeholders in edu d/o information monitoring are represented in the GEduMON base service model. Rq3 is satisfied because the GEduMON functional structure variability and behavior variability models support the representation of implementation variants of abstract services with different levels of automation.

As the GEduMON model allows representing the system and its variability at two abstraction levels and satisfies 3 main edu d/o information monitoring requirements, we can conclude that the model is complete and it is suitable for representing the variability posed by edu d/o information monitoring. As the GEduMON general architecture is aligned with detailed architecture (i. e., a base service model is aligned with a functional structure variability model)

and the GEduMON functional structure variability model is aligned with a behavior variability model, we can conclude that the GEduMON model is consistent. Based on these conclusions, thesis statement **S1** stated in the Doctoral Thesis is proved, because the developed GEduMON model ensures the related representation of system stakeholders and the services relevant to them, as well as the system structural and behavioral variability.

5.2. Usability of GEduMON Model

GEduMON model is used to develop functional structure and behavior variability models of concrete systems, namely, EduMON portal and KIVIS tool. These models are applicable to implement the software prototypes of these systems (see illustrative views of the systems in Figure 5.1). EduMON portal and KIVIS tool are described in Chapter 4. This section describes how the prototypes of implemented systems comply with the edu d/o information monitoring requirements.

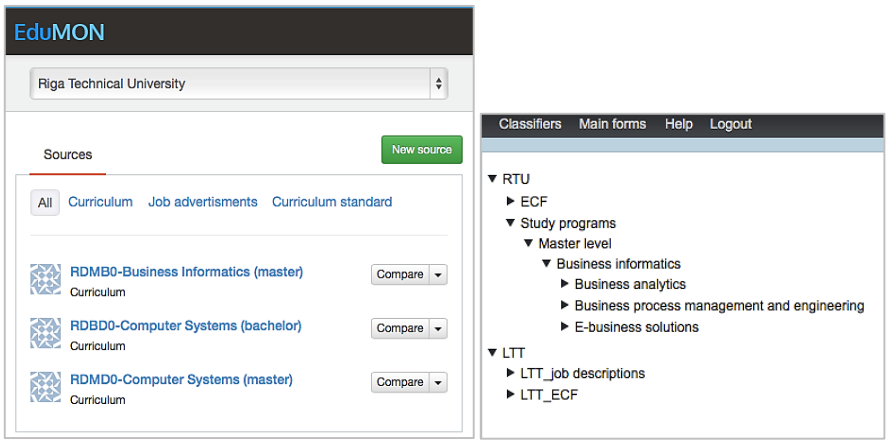


Figure 5.1. User interfaces of EduMON portal (on the left) and KIVIS tool (on the right) representing the information sources.

The EduMON portal was designed and implemented by updating GEduMON functional structure and behavior variability models with concrete services. The EduMON portal allows implementing services for knowledge structure retrieval, edu d/o information source document retrieval, direct and mediated edu d/o information identification and document mapping, as well as presentation of identification and mapping results. Table 5.1 represents how the EduMON portal complies with the edu d/o information monitoring requirements.

Table 5.1

Requirements Satisfied by the Implemented EduMON Portal

Requirement	EduMON
Rq1	Services provided by the EduMON portal allow processing diverse types and large number of edu d/o information source documents retrieved from different locations (e. g., job advertisements, course descriptions on the Web and databases) and identifying the correspondence between edu d/o information source documents. The analysis services are able to process the unstructured format text documents, the processing of which is more complex than processing of structured and semi-structured documents due to the specific methods employed.
Rq2	Multiple stakeholders (e. g., teachers, representatives of companies, system maintainers and others) are allowed to access the EduMON portal, execute the transitions between services and consume the results of services.
Rq3	Several services with different automation levels are implemented. Implementation variants of services are represented in EduMON functional structure and behavior variability models.

KIVIS tool also complies with the developed GEduMON model, because it implements the variants of services represented in the GEduMON model namely, services for knowledge structure retrieval, mediated edu d/o information identification and mapping, as well as services for identification and mapping results reporting. Similar to the EduMON portal, also the KIVIS tool satisfies edu d/o information monitoring requirements; however, compared to the EduMON portal the KIVIS tool provides fewer services and requires greater involvement of the human actor in the execution of analysis services, as well as the services of KIVIS tool are able to process only structured text documents.

Taking into account that the EduMON portal is designed and developed on the basis of GEduMON model and that the KIVIS tool complies with this model, thus satisfying edu d/o information monitoring requirements of processing edu d/o information with various characteristics, involvement of various stakeholders in the system, and satisfying the requirements for various implementation variants of activities with different levels of automation, we can conclude that the GEduMON model is applicable to the design and implementation of edu d/o information monitoring systems. This conclusion strengthens the proof given in previous section for thesis statement **S1**, as the developed model is suitable for the design and development of edu d/o information monitoring systems.

5.3. Utility of GEduMON Model

The practical utility of the GEduMON model is evaluated by its implementation — the EduMON portal that supports scenarios for the achievement of edu d/o information monitoring stakeholder goals, namely, scenario for systemic edu d/o information status monitoring (according to G1) and scenario for systemic edu d/o information correspondence monitoring (according to G2).

For the monitoring of edu d/o information status, the following scenario is designed: curriculum director is willing to determine the knowledge demand for the software developers. This scenario is implemented by concrete service flows of intention oriented service $IS_{(1.1.1.;3.1.2)}$ included in the behavior variability model of the EduMON portal (it proves that this type of scenario is already supported by design of the system). This service is used for retrieving documents from the Web resources and getting the report of mediated edu d/o information identification. In this scenario, we consider the following service flow: •($S^{M}_{1.2.1}$, $S^{M}_{1.1.1.1}$, $S^{A}_{2.1.2.2}$, $S^{A}_{3.2.2.2}$), where edu d/o information source documents are manually retrieved from the Web, mediated edu d/o information identification is performed by the Apache UIMA (by using 3 knowledge structures — ACM-CCS, DISCO and ONET) and the identification result report is presented by exporting it to a CSV format file. Exporting to a CSV format file provides a more extensive analysis of identified edu d/o information in various spreadsheet software (e. g., MS Excel or LibreOffice Calc), where the pivot table reporting functionality is available.

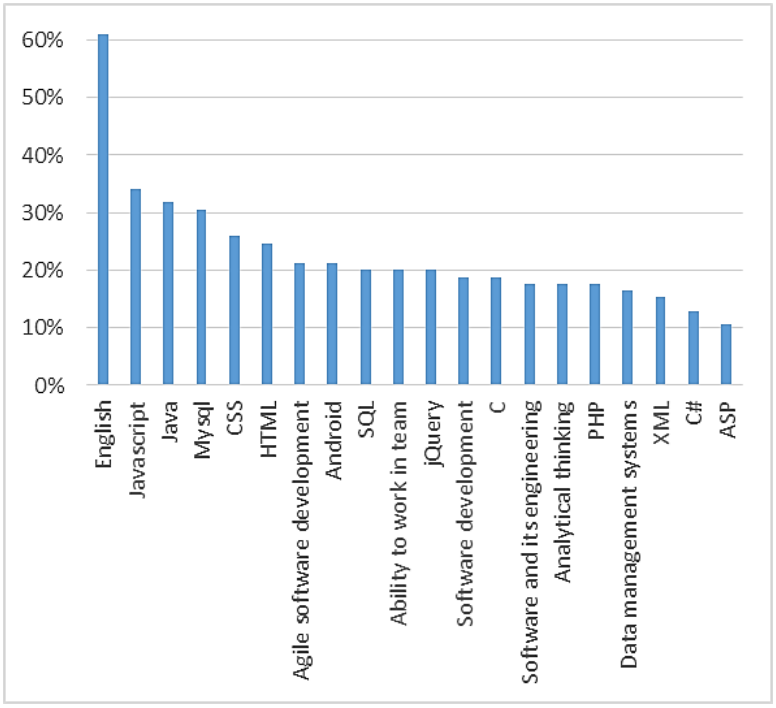


Figure 5.2. Knowledge structure elements identified in documents (count of documents in % from all job advertisements on software developer position).

Knowledge demand for software developers is represented in job advertisements. Thus, from the job advertisement portal cv.lv 85 job advertisements on software developer position were obtained manually (EduMON service $S^{M}_{1.1.1.1}$ was performed; those advertisements with

the text “developer”, “programmer”, “software engineer” or “software architect” in the title were identified as software developer positions).

Automatically identified edu d/o information is represented in each document view in the EduMON portal (presentation service $S^{A}_{3.1.2.1}$ for mediated edu d/o information identification results reporting by a UI), though for extended interpretation the results are exported to a CSV format file and the analysis is performed using MS Excel spreadsheet pivot table reporting functionality.

Services provided by the EduMON portal support the reporting of identified edu d/o information, thus allowing one to interpret the identification results by using pivot reporting functionality in spreadsheet software. Thus, we can conclude that the EduMON portal supports the scenario that fosters the achievement of stakeholder goal G1. Hence, thesis statement **S2** is proved partly. In this scenario, the edu d/o information identification results in software developer job advertisements have been obtained and interpreted systemically. As a result of interpretation (see Figure 5.2), it has been concluded that 61 % of selected job advertisements demand the knowledge of the English language, 34 % — knowledge of the JavaScript language, 32 % — knowledge of the programming language Java, 31 % — knowledge of the data management system MySQL.

For monitoring of the edu d/o information source document mapping (corresponds to stakeholder goal G2), the following scenario is designed: the director of bachelor level curriculum “Computer Systems” at Riga Technical University (RTU) is willing to determine the correspondence of the curriculum to the job advertisements by Accenture Ltd. In total, 10 job advertisements and 85 study courses have been identified. This scenario is implemented by concrete service flows of intention oriented service $IS_{(1.1.1.;3.2.2)}$ included in the behavior variability model of the EduMON portal (it proves that this type of scenario is also supported by design of the system). This service is used for retrieving documents from the Web resources and getting the report of mediated edu d/o information source document mapping. In this scenario, we consider the service flow, where edu d/o information source documents are manually retrieved from the Web, mediated edu d/o information identification is performed by the Apache UIMA, mediated edu d/o information source document mapping is performed by using knowledge structure element vectors, and mapping results report is presented by exporting it to a CSV format file.

The report of mediated edu d/o information source document mapping results represented in EduMON portal UI is shown in Figure 5.3.

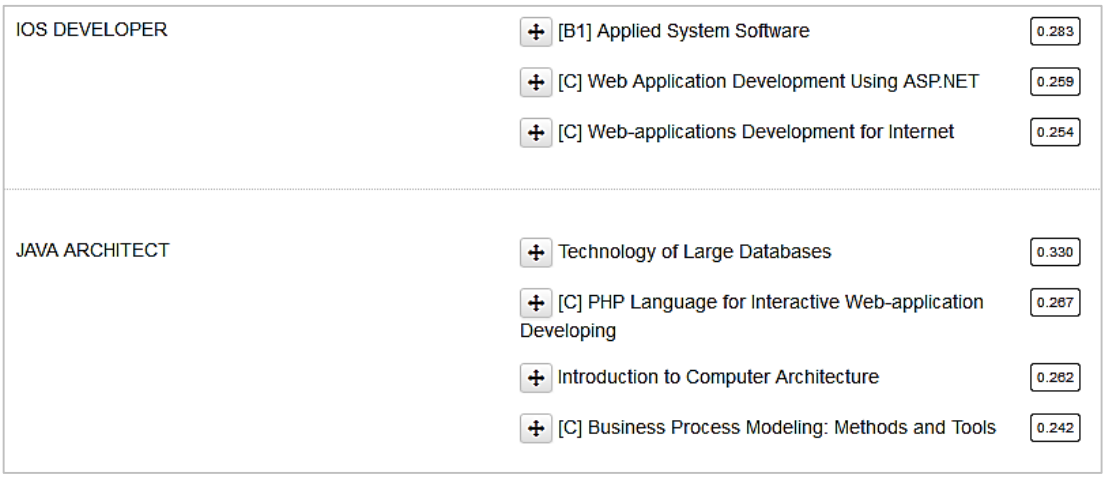
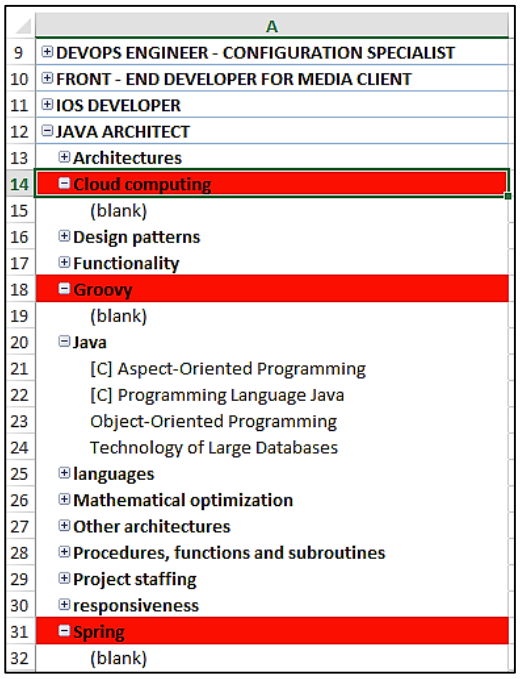


Figure 5.3. Fragment of the result of EduMON presentation service — Accenture job advertisement correspondence to RTU curriculum "Computer Systems" courses.

The report represented in the EduMON portal UI does not provide an extended analysis of mapping results. To perform a detailed mapping analysis, the service for exporting results to a CSV format file is used. Then by using spreadsheet software and pivot table reporting functionality mapping results are analyzed to evaluate what elements of knowledge structures identified in some edu d/o information source documents are/are not identified in other edu d/o information source documents. That way the representative of the company or the curriculum director can evaluate, whether the demand from company is/is not offered by the selected curriculum courses. Figure 5.4 illustrates the fragment of the obtained results. It shows that the following knowledge demanded in job advertisement "Java Architect" is not covered in the curriculum courses: cloud computing, programming language Groovy and Java framework Spring. The representative of Accenture (i. e., employer) can use these results to identify further education possibilities or to improve the courses by cooperating with the instructors of the corresponding courses.

Services provided by the EduMON portal support the reporting of edu d/o information source document mapping results, thus allowing one to interpret these results by using pivot reporting functionality in spreadsheet software. Thus, we can conclude that the EduMON portal supports the scenario that fosters the achievement of stakeholder goal G2. The overall conclusion is that the implemented EduMON portal prototype supports the scenarios that foster the achievement of stakeholder goals G1 and G2, namely, corresponding types of scenarios are already defined when designing functional structure and behavior variability models of the system and the scenarios are supported by the implemented portal as well. Hence, thesis statement **S2** is proved.



	A
9	⊞ DEVOPS ENGINEER - CONFIGURATION SPECIALIST
10	⊞ FRONT - END DEVELOPER FOR MEDIA CLIENT
11	⊞ IOS DEVELOPER
12	⊟ JAVA ARCHITECT
13	⊞ Architectures
14	⊟ Cloud computing
15	(blank)
16	⊞ Design patterns
17	⊞ Functionality
18	⊟ Groovy
19	(blank)
20	⊟ Java
21	[C] Aspect-Oriented Programming
22	[C] Programming Language Java
23	Object-Oriented Programming
24	Technology of Large Databases
25	⊞ languages
26	⊞ Mathematical optimization
27	⊞ Other architectures
28	⊞ Procedures, functions and subroutines
29	⊞ Project staffing
30	⊞ responsiveness
31	⊟ Spring
32	(blank)

Figure 5.4. Fragment from extended analysis results — compliance of Accenture job advertisements with RTU curriculum "Computer Systems" courses. Knowledge structure elements highlighted in red indicate that they are not taught in courses.

MAIN RESULTS AND CONCLUSIONS

The research in the Doctoral Thesis is conducted in the context of the education-related information processing devoted to systemic education demand and offer monitoring. For this purpose, in the Thesis general edu d/o information monitoring system model (GEduMON) has been developed satisfying the edu d/o information monitoring requirements, thus fostering the achievement of stakeholder goals. For the systemic edu d/o information monitoring problem tackling, the GEduMON model (architecture) has been developed, including the following sub-models: base service model, base service flow model, system functional structure variability model and system behavior variability model. To ensure the alignment of models, the methods for feature model design (FMD) and intention oriented service composition (IOSC) have been developed. For the evaluation of GEduMON model, two implementations of the model have been used, namely, prototypes of EduMON portal and KIVIS tool. GEduMON model is appropriate for tackling the edu d/o information monitoring problem, as it:

- Supports a general framework for the structure and behavior of edu d/o information monitoring system.
- Supports the ability to represent the variability of edu d/o information monitoring both in the system structure and behavior.
- Provides methods to align the views of general and detailed system architecture.
- Is applicable to develop concrete edu d/o information monitoring systems.
- Supports the scenarios that foster the achievement of stakeholder goals.

Theoretical Results of the Doctoral Thesis

Development of the Thesis has given the following theoretical results, which can be grouped as follows:

- GEduMON model, which is presented in form of two-level system architecture and satisfies the requirements of processing edu d/o information with various characteristics, involvement of various stakeholders in the system, and satisfying the requirements for various implementation variants of activities with different levels of automation, thus fostering the achievement of stakeholder goals for edu d/o information status and correspondence monitoring:
  - An extension of feature model to represent the abstract services and concrete services, which are characterized by automation levels.
  - An architecture viewpoint and view for representation of system functional structure variability, which uses the extended feature model.

- Feature Model Design (FMD) method for the alignment of GEduMON base service model and functional structure variability model (i. e., extended feature model).
- An architecture viewpoint and view for representation of system behavior variability, which uses the service flows, including both abstract and concrete services.
- Intention Oriented Service Composition (IOSC) method for the alignment of GEduMON functional structure variability model with the system behavior variability model.

- Adapted and implemented methods in edu d/o information monitoring domain for direct and mediated edu d/o information identification and source document mapping, based on findings on the existing edu d/o information source management solutions.
- Systematized overview of related literature:
  - Structural characteristics of several types of monitoring systems.
  - A framework for the description of monitoring system structure.
  - Classification of service systems.

Practical Results of the Doctoral Thesis

Development of the Thesis has generated the following practical results**:**

- Implemented prototype of the EduMON portal, which provides:
  - Input forms that allow storing in the database the results of manual edu d/o information source document retrieval services.
  - The service for mediated edu d/o information identification by using the text analysis platform Apache UIMA.
  - Services for direct edu d/o information identification and direct edu d/o information source document mapping by using the text indexing and search software library Lucene.
  - The service for mediated document mapping by using knowledge structure element vectors and Cosine similarity metric.
  - Services for mediated edu d/o information identification and document mapping results reporting by EduMON portal user interface and by exporting to a CSV format file.
  - The service for direct edu d/o information source document mapping results reporting by the EduMON portal user interface.
  - System user management and retrieved edu d/o information source document management.
- Implemented prototype of KIVIS tool developed with the support of Lattelecom Technology Ltd. and Riga Technical University in the context of research project No. ZP-

2009/15 “Development of the Method and the Prototype for the Normalization and Linkage of Computer-based Competence Descriptions. The tool provides:

  - Input forms to store in the database the results of manual services for edu d/o information source document retrieval, knowledge structure retrieval, and mediated edu d/o information identification.
  - The service for mediated document mapping by using knowledge structure element vectors.
  - Services for mediated edu d/o information identification and document mapping results reporting by the KIVIS tool user interface.
  - System user management and retrieved edu d/o information source document management.

- Detected correspondences between documents of various edu d/o information sources, namely, between the courses of bachelor level curriculum “Computer Systems” at Riga Technical University and job advertisements by companies in the information technology domain.

Future Research

The theoretical and practical results of the Thesis provide opportunities for further research and practical developments:

- To develop tool to support the Feature Model Design and Intention Oriented Service Composition methods.
- To extend EduMON mediated edu d/o information identification service implementation by an automated analysis of semantic meaning of the text to provide more precise identification results.
- To implement the Web crawling service for edu d/o information source document retrieval and integrate it in the EduMON portal.
- To extend the mediated mapping service with quality attributes, e. g., weights for particular competences important for particular stakeholder that would provide stakeholder oriented presentation of mapping results.

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