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Technological Solutions for Knowledge Management in Smart Cities

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1 ABSTRACT

Nowadays huge volume of information, data and knowledge, that directly or indirectly relates to modern cities, their state and problems is gathered and stored. Effectiveness of its use significantly influences on effectiveness of city development. Due to constantly increasing amount of information and knowledge, for its best use special tools for knowledge management, including tools for knowledge systematization and building formalized descriptions as well as new algorithms for knowledge processing and application are required. In the paper a set of technological solutions focused on knowledge retrieval from multidimensional measurements provided by different sources of information is suggested. Use of developed technologies allow to organize operative processing of new measurements, taking into account all available knowledge. Dealing with measurements at the level of knowledge about measurements provides solutions of end user problems in terms of subject domain objects or situations but not separate measurements. Several subject domains and their tasks, that can be solved using the proposed set of technological solutions, are defined.

2 INTRODUCTION

Time, when tasks of departments of city economy could be solved locally and independently have passed. Nowadays almost all tasks are supposed to be solved jointly; moreover in many cases it is reasonable to consider the set of the solved tasks as a unique complex task that is oriented on providing stability in the economic and social spheres of a city. Many external factors influence on the process of forming solutions such as state of the interconnected departments of the city management, state of the neighbouring territories, state of the environment and etc.

In the sphere of the city's economy hundreds of various domain specific business processes are created every day. Business processes specify how operational activities have to be executed in order to provide a defined set of services [1]. The number and the complexity of the executed processes are constantly increasing. Results of their execution significantly depend on amount and quality of available information. Consequently, the state of the development of modern city economy as a whole can be characterized as highly information dependent. Under information a semantic interpretation of data is considered [2]. Data is a product of observations or facts used to calculate, analyze, or plan something. After data is processed into a usable form, information is received [3]. The distinguishing feature of information is that it has sense. Entire amount of information available about the considered subject domain as well as about related subject domains forms information space. An information space provides an environment for allocation of information flows. Information flows transfer information from a provider to a consumer in the information space. All tasks of information processing and analyses as well as tasks of information space and information flow support and management require knowledge for building solutions. Knowledge is typically defined with reference to information. Most frequently knowledge is defined as a fluid mix of framed experience, values, contextual information, expert insight and grounded intuition, that provides an environment and framework for evaluating and incorporating new experiences and information [4]. The terms data, information and knowledge are linked together in Ackoff's hierarchy described in [5].

The key problem of data and information processing and analyses is to select knowledge, which is necessary or useful for solving the defined task or the subtask from the huge amount of knowledge, that is available nowadays and to apply knowledge correctly. This task refers to the tasks of knowledge management (KM) and as well as all other tasks of this type requires considerable amount of time, financial resources and assumes involvement of experts of the subject domains. To reduce amount of resources, that are spent on supporting the infrastructure required for solving end tasks of the city's economy, it is important to develop software applications that are capable to solve highly complicated tasks of data, information and knowledge processing, analyses and management for the subject domain of the smart cities.

For solving the enumerated tasks applications must meet following requirements:

- applications must gather actual data about the state of the controlled objects;
- applications must be able to assimilate gathered data and to use it for solving end tasks;

- applications in the case of available computational resources have to estimate the state of the information space, to create and manage processes, that are oriented on the improvement of the information space;
- applications must be able to acquire knowledge of different types, to interpret and to integrate knowledge, in order to obtain new knowledge on the base of existing knowledge.

Software applications that have features, necessary for solving considered tasks, are known as knowledge based or knowledge centric applications. A knowledge based software application in the narrow sense means an application for extending and/or querying a knowledge base. In extended sense the term is perceived as a synonym of the term expert system, but normally expert systems refer to more domain-specific systems used for a specialized purpose such as medical diagnosis [6]. In the broad sense knowledge based applications are applications, that use artificial intelligence or expert system techniques in problem solving processes. They incorporate a store (database) of expert knowledge with couplings and linkages designed to facilitate its retrieval in response to specific queries, or to transfer expertise from one domain of knowledge to another [7]. Knowledge centric applications are applications, that use knowledge at all stages of their life cycle including construction, development, usage and support.

For solving tasks of KM the following set of technological solutions are highly required: harmonization, integration and fusion technologies [8], intelligent data processing technologies, technologies of preliminary and exploration data analyses. Implementation of the enumerated technologies is commonly based on usage of various means and tools that include tools of artificial intelligence, in particular, expert systems and inference engines, modelling tools, tools for business processes management and libraries of intelligent methods and algorithms.

In the paper the technological solutions for KM in the applications developed for smart cities and the ways for their implementation are considered. The proposed technological solutions are focused on solving a limited group of tasks based on measurement processing. Input data for the considered group of tasks contain by the most part measurements of the parameters of both natural and technical objects and parameters of the environment. Measurements can be represented in the form of time series or sets of separate measured values.

The paper is organized in the following way. In the next section common approaches for KM are considered. In the fourth section the proposed basic technology for KM is described. In the subsequent sections the proposed technology is detailed. In the last section questions of application of the technology for solving several tasks of the city’s economy are discussed.

3 COMMON APPROACHES FOR KNOWLEDGE MANAGMENT

KM is defined as a process of getting correct knowledge to the proper consumer, that can be either a person or a system at the right time [9]. KM also allows solving tasks of new knowledge creation, acquiring and retrieving, the tasks focused on knowledge sharing and storage and the tasks of knowledge refinement.

Considerable experience in KM is gained in the sphere of corporate information systems (CIS). The developed solutions for KM in CIS implies a strong tie to corporate strategy, understanding of where and in what forms corporative knowledge exists, creating processes, that span organizational functions, and ensuring that initiatives are accepted and supported by organizational members. KM in CIS is aimed to improve and refine the organization's competences and knowledge assets to meet organizational goals and targets. The main aspects of organizations that are considered in implementation of KM include [9]:

- organizational strategy. KM strategy is dependent on corporate strategy and is aimed to meet tactical and strategic requirements;
- organizational culture. The organizational culture defines the context within which knowledge is created and shared in an organization;
- organizational processes. The organizational processes define processes, environments, and software, that can be used for implementation of KM in an organization.
- management and leadership. The structure of management and leadership of the organization defines a set of possible KM-related roles and defines the need in each of them;

- technology. The technology aspect defines systems, tools, and technologies, that can be used for implementation of KM and fit organization's requirements;
- politics. The politic aspect describes politics of the organization from the point of view of long-term perspective initiatives and investments, that requires development of the existing solutions for KM.

The best practices of KM are described in many publications, for example, [10-13].

Scientific and technological solutions for KM, developed for an organizations cannot be directly applied for solving tasks of smart cities. The main reasons for that are following:

- business processes, that are required for solving tasks at the city level, are much more complicated and unlike the processes, implemented in organizations, are undetermined and hardly predictable;
- almost all of the considered aspects, that define the backbone of KM at the level of organizations, cannot be defined at the level of cities.

To overcome the difficulties, that are caused by the complexity of the business processes of cities, it is proposed to develop a system of patterns, that describe business processes in the general form and business rules for the processes adaptation to the sphere and the context of their application.

The possibility of development of patterns is defined by distinctive features of the subject domain of city's economy, that are considered below.

Feature 1. The subject domain of the city's economy can be considered as a set of interconnected applied subject domains, that are integrated in a complicated single subject domain, that has its own goals and tasks. For example, a model of the subject domain of smart city economy contains models of the subdomains, that define the structure of the city's economy, in particular, the model of the subdomain of the social organizations, of the natural resources and etc. For each of the subdomains the formal models have been developed or can be built. The models of the subdomains are oriented on solving applied tasks.

Feature 2. Tasks solved in the subject domain of the city's economy form two groups. To the first group refer the specialized tasks, that can be solved using the predefined set of business processes. The second group contains tasks, that are context dependent. The tasks of the first group can be solved using approaches for KM implemented in CIS. For solving the tasks, that belong to the second group, solution-oriented subject domain models are used. The example of the solution-oriented subject domain is the subject domain of data processing and analyses. Integration of problem-oriented and solution-oriented domains allows solve complicated undetermined tasks of the applied subject domains using basic solutions.

Feature 3. Software applications, developed for various departments of cities economy, have been always based on the most advanced information technologies. Due to that technologies of data and information gathering and storage have been used for many years already and now amount of available data and information is enough for building extended knowledge bases. Knowledge provided by knowledge bases is sufficient for defining rules, that can be used for adaptation of the process patterns to the sphere and the context of their application. The high level of qualification of the specialist, working in the departments of city economy, allows them to estimate and to verify the defined business rules.

Using the proposed solutions, based on the features of the subject domain of city's economy, a basic technology for KM for smart cities has been worked out. The proposed technology is described in the next section.

4 BASIC TECHNOLOGY FOR KM

The basic technology for KM requires three main components: a base set of subject domains models, a set of patterns for data processing and analyses and a set of appropriate mathematical libraries. The models provide actual information, required for solving end user tasks. The base set of models contains the model of the subject domain of city economy that provides information and knowledge about the objects of the domain, their characteristics and relations between objects, the model of the domain of data processing and analyses that is used to describe initial data and results of its processing and optionally models of the related subject domains (Fig. 1). Problem-oriented models of the subject domain and models of the applied subject domains (subdomains of the domain of city economy) are implementations of the defined base set of the models. The set of patterns for data processing and analyses is given in Fig.2. The overwhelming majority of patterns were developed for processing measurements represented in the form of time series or in the form of sets of separate values. The set of developed patterns contains two groups of patterns. To the first group refer the typical patterns, that are oriented on executing basic operations of data processing, aimed to extract knowledge from analyzed data. The second group contains patterns for solving data processing tasks, specialized for the considered subject domain. The patterns of the first group describe processes of data harmonization, integration and fusion as well as the processes of data prospecting analyses and data exploration analyses. The main goal of data prospecting analyses is to retrieve additional information about analyzed data before processes are started and during their execution. Exploration data analyses processes allow solving tasks of mining knowledge both from operational and historical data. The set of the mathematical libraries may significantly differ, depending on the subject domain and available implementations of algorithms.

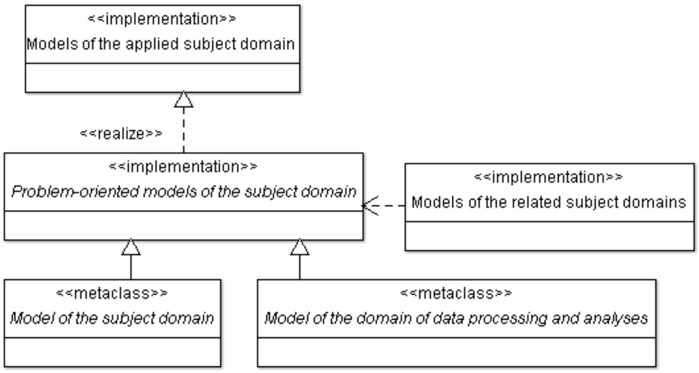

Fig. 1. The set of information models required for KM

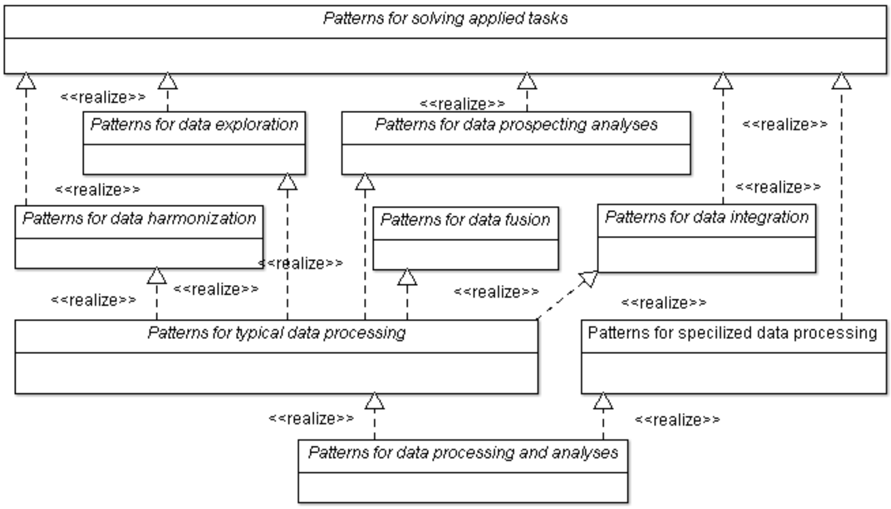

Fig. 2. Set of patterns for data processing and analyses

The proposed technology assumes execution of the following main steps.

1. Using information and knowledge about the applied subject domain and the set of patterns for data processing the subset of the patterns, that are required for solving the tasks of the considered subject domain is formed.

2. Patterns of the defined subset are detailed according to available knowledge about the subject domain and rules for patterns detailing [14]. The detailed set of patterns defines the range of processes, that are assumed to be used for data processing in the considered subject domain. The patterns, defined for the subject domain, may be represented in the form of processes, that can be executed or in the form of patterns, that need further detailing directly before or during their execution.

3. Structure of knowledge required for data processing at each of the steps of the process, build on the base of the detailed patterns, is inherited from the models of the domain of data processing and analyses. Knowledge according to the inherited structure is extracted from the model of the applied subject domain.

4. Amount of used knowledge can be extended using results of analyses of the historical data or it can be enlarged with expert knowledge. Knowledge can be refined using knowledge, provided by the model of the subject domain and means and tools of data, information and knowledge processing and analyses.

Below each of the key technologies, used for data processing, is considered and knowledge required at each of their stages is defined. Theoretical backgrounds of the technologies and examples of their implementation are considered in [9,15].

5 USAGE OF KNOWLEDGE FOR SOLVING HARMONIZATION PROBLEMS

For solving problems of data harmonization two groups of patterns are developed. The first group of patterns is oriented on processing initial data, that is represented in the form of structured data streams. The second group of patterns is used for processing measured values. The list of the patterns of the first group contains the patterns for interaction with external data sources, for revealing the structures of the streams, for estimating the main parameters of the streams and for defining the format of the streams. The second group contains patterns for gathering metadata about the acquired data, for restoring missing values in the measurements, for building formal descriptions of the measurements and for the transformation of the measurements formats. For each group of patterns base patterns are developed. The base pattern of the first group is a pattern for harmonization of the data stream, the base pattern for the second group is the pattern for harmonization of measured values. Both patterns are high level patterns, that are based on the general pattern of data harmonization.

Patterns are linked with the relations of the association type. Existence of the association relation between two patterns means, that the processes build on the base of associated pattern are supposed to be executed before the processes build using the associable pattern. The set of the defined associations reflect the sequence of the patterns execution. All of the represented associations are binary association. The patterns and the relations between the patterns are shown in Fig.3 in the form of the class diagram.

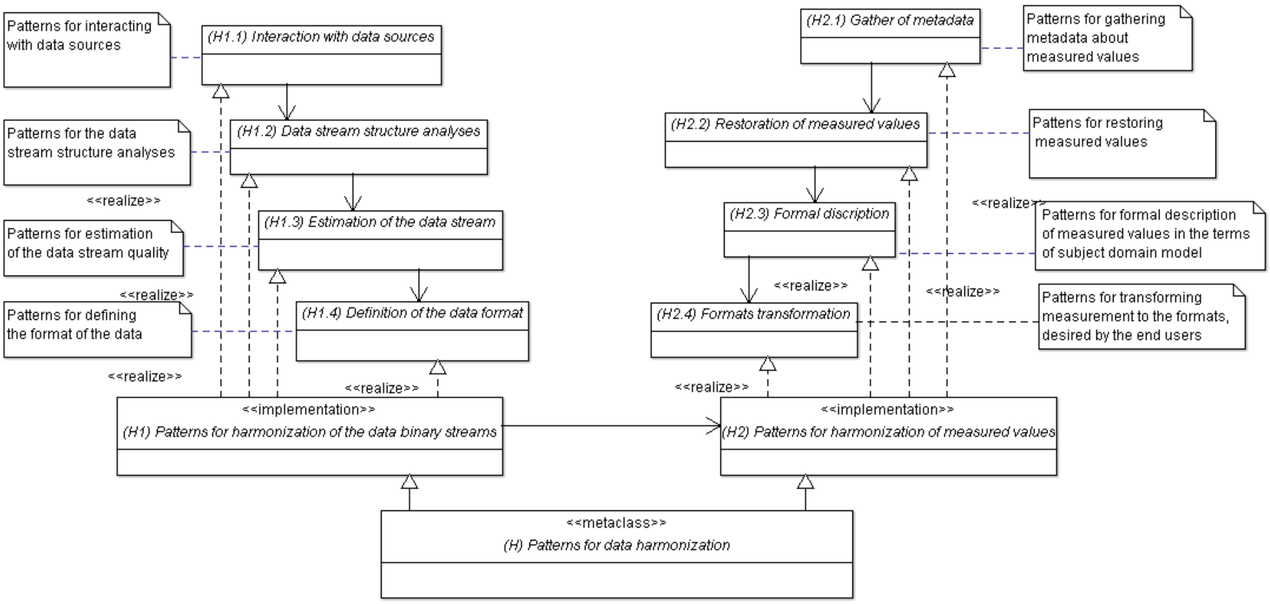

Fig. 3. Patterns for implementation of the data harmonization technology

In the table 1 for each low level pattern its description, the required and the produced knowledge are given.

No.	Pattern	Description	Required knowledge	Produced knowledge
H1.1	Interaction with data sources	Patterns for receiving data from providers and patterns for providing data to possible consumers	List of formats supported by providers / consumers and descriptions of the formats	-
H1.2	Data stream structure analyses	Patterns for defining or for improving the description of the structure of the input data represented in the form of structured streams	-	Knowledge about the structure of data streams
H1.3	Estimation of data stream	Patterns for estimating quality of the data streams; if quality of a stream is different at different intervals then intervals are defined and the quality at the intervals are estimated	-	Knowledge about quality of data streams

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H1.4	Definition of the data format	Patterns for defining formats of the input data	Knowledge about formats used by different providers	-
H1.5	Gather of metadata	Patterns for gathering information about input data. Meta information can be received from the model of the subject domain and from data providers	The vocabulary for interpreting metadata	Additional knowledge about data. The structure of the knowledge is preliminary not determined
H1.6	Restoration of measured values	Patterns for restoring measured values from the data streams according to the description of the streams structures and their quality	Knowledge about the structure of the streams and the quality of the data streams	-
H1.7	Formal description	Pattern for building formal descriptions of the restored measurements	Model of the subject domain; knowledge about data sources and measured values; the descriptions of the terms in which knowledge is expressed	Model of the subject domain that contains information and knowledge about the received measurements.
H1.8	Format transfor-mation	Patterns for transforming measurements to different formats required by the consumers	Knowledge about the supported formats, formalized descriptions of the formats and rules for the formats transformation	-

Table 1. Description of harmonization patterns.

6 USAGE OF KNOWLEDGE FOR SOLVING INTEGRATION PROBLEMS

Problems of data integration are proposed to be solved using two groups of patterns. The first group contains patterns oriented on solving problems of measurements integration, the second contains patterns, that are supposed to be applied for solving end users specialized problems. Composition and relations between the patterns in the considered groups are shown in Fig.4.

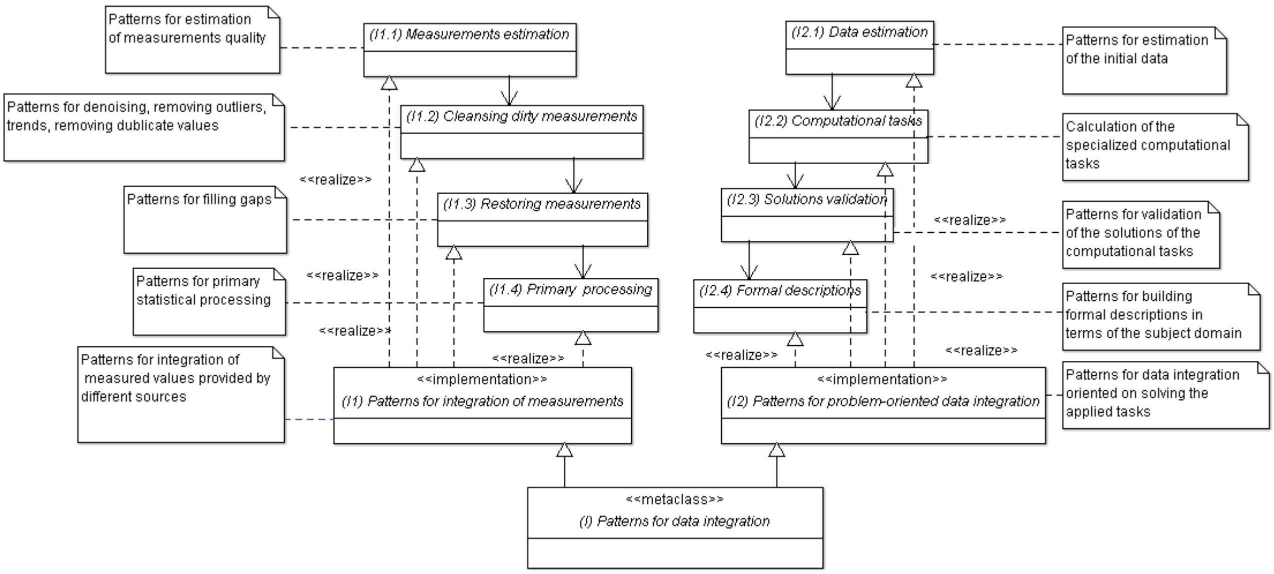

Fig. 4. Patterns for implementation of the data integration technology

Description of the integration patterns, knowledge required for the application of the patterns and knowledge produced at different steps of data integration technology is given in the table 2.

No.	Pattern	Description	Required knowledge	Produced knowledge
I1.1	Measure-ments estimation	Patterns for estimation of the quality of measurements, represented in the form of separate measurements or time series	Knowledge about quality of the data streams, knowledge about the data sources, additional knowledge about measurements	Knowledge about quality of the measurements
I1.2	Cleansing dirty measure-ments	Patterns for removing noise, outliers, trends, identifying and removing duplicated values	Knowledge about the quality of the measurements	Knowledge about probable true values of measured parameters
I1.3	Restoring measure-ments	Patterns for filling gaps in measurements	Knowledge about measured parameters behavior, behavior of the observed objects, conditions in which measurements were performed	Knowledge about probable true values of measured parameters at all required time points
I1.4	Primary processing	Patterns for primary data processing using statistical procedures	Knowledge about the statistical characteristics that are significant for the processed data	Complex statistical primary description of measurements that reflect the key features of the data
I2.1	Data estimation	Estimation of input data required for solving end user tasks	Knowledge about composition of estimations required for solving	Knowledge about the level of adequacy and compliance with

			tasks and the border values for the estimations	the requirements to the data
I2.2	Computa-tional tasks	Patterns for solving end user computational tasks	Knowledge about the requirements to input data and means, necessary for executing the tasks	Knowledge produced as the result of executed calculations
I2.3	Solutions validation	Patterns for validation and estimation of the formed solutions	Subject domain model, knowledge about solved tasks, knowledge about the requirements imposed to results	Knowledge about the formed solutions and expediency of their further application
I2.4	Formal descriptions	Patterns for building formal descriptions of the results of the end user tasks calculations	Subject domain model, knowledge about the results of the executed calculations	Model of the subject domain that contains additional knowledge acquired as the result of solving tasks

Table 2. Description of integration patterns

7 USAGE OF KNOWLEDGE FOR SOLVING FUSION PROBLEMS

The set of patterns, developed for solving data fusion problems contains patterns oriented on solving typical problems and patterns oriented on solving specialized complicated end user problems (Fig.5). To the patterns, oriented on solving typical problems, refer the following groups of patterns: patterns for revealing the structure of measurements, patterns for revealing dependencies in measurements, patterns for measurements exploration, patterns for building statistical models, patterns for building fields. The structure of the listed groups of patterns and relations between the patterns inside the groups and between the groups are shown in Fig. 6. The descriptions of the patterns and knowledge, required and provided by the patterns, are given in table 3 and table 4.

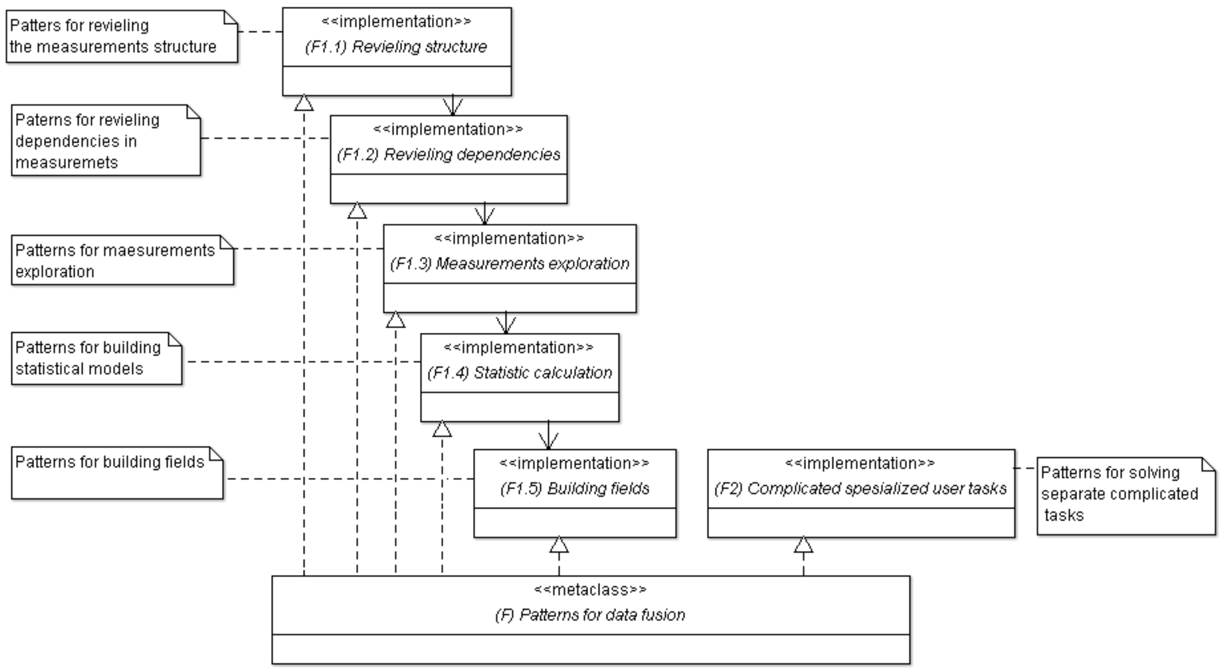

Fig. 5. Groups of patterns for implementation of the data fusion technology

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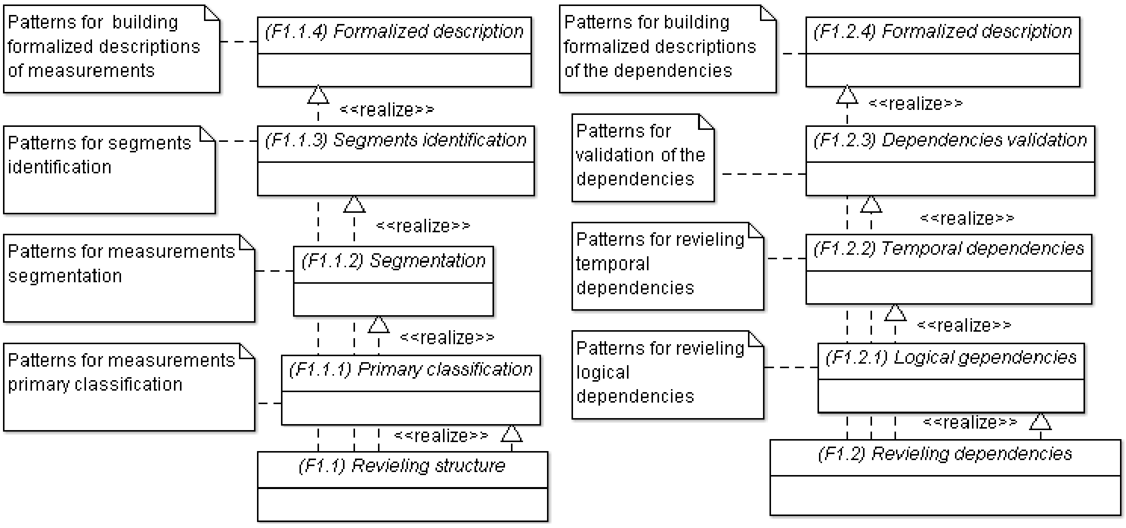

Fig. 6 (a). Patterns for implementation of the data fusion technology

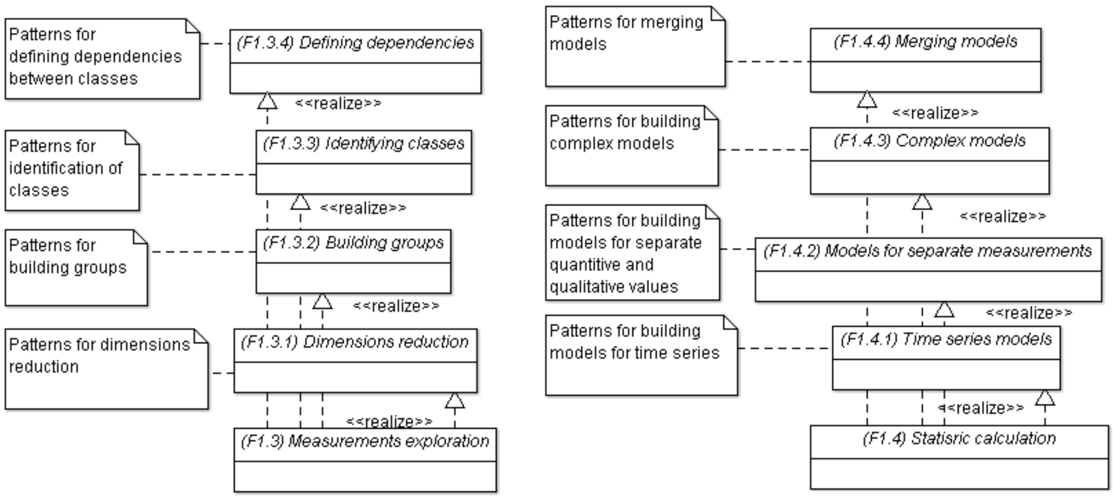

Fig. 6 (b). Patterns for implementation of the data fusion technology

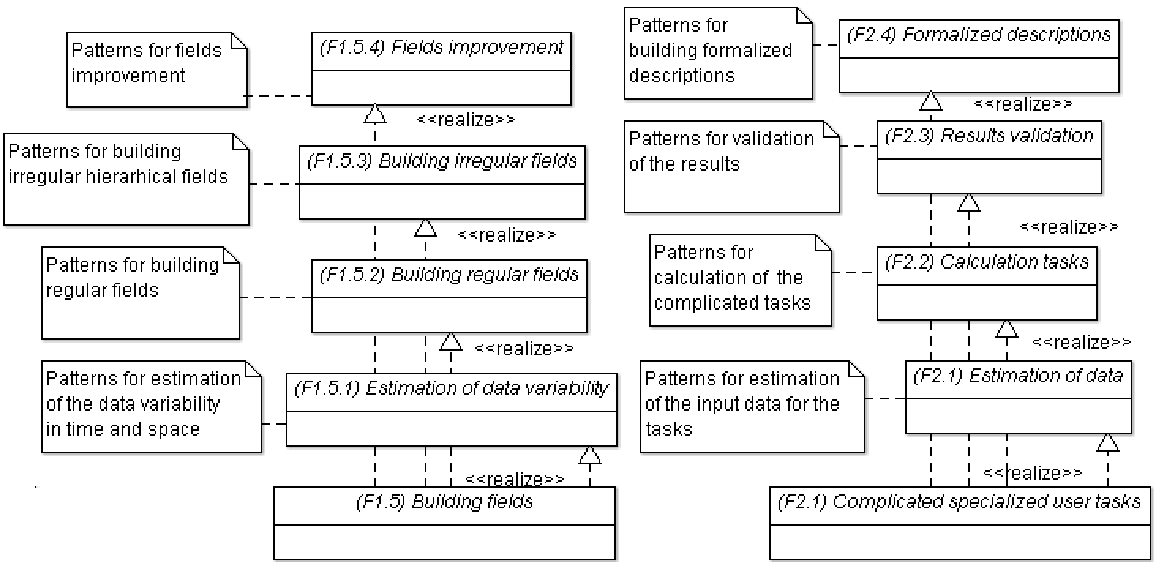

Fig. 6 (c). Patterns for implementation of the data fusion technology

No.	Pattern	Description	Required knowledge	Produced knowledge
F1.1.1	Primary classifi-cation	Patterns for defining types of the measurements. The types can be defined according to calculated statistical characteristics, specialized rules for types identification, results of execution of the	Primary statistical description of the data, knowledge-based rules for types identification, sets of tests and the sequence of their execution for identification of the	Knowledge about the types of measurements

		specialized tests	measurements of the defined type	
F1.1.2	Segmen-tation	Patterns for representation of time series of measurements in the form of the sequence of intervals, on which the time series have stationary behavior and the patterns for describing each interval with the separate vector of characteristics	Knowledge about behavior of the parameters, the states of the observed objects, conditions in which measurements were made; knowledge about characteristics that can be used for describing time series	Knowledge about the structure of the time series
F1.1.3	Segments identifica-tion	Patterns for identifying the types of the distinguished segments	Knowledge about the possible types of the segments and their descriptions	Knowledge about the types of the segments
F1.1.4	Formalized description	Patterns for building formalized descriptions of the time series structures on the base of the identified segments	Model of the subject domain, knowledge about the structures of the time series	Model of the subject domain, that contains additional information about the time series structures
F1.2.1	Logical depen-dencies	Patterns for detection logical dependencies in behavior of the time series of parameters measurements, that are represented in the form of a sequence of the identified segments	Knowledge about the structures of the time series	Knowledge about the logical dependencies in the parameters behavior
F1.2.2	Temporal dependen-cies	Patterns for detection of temporal dependencies in the behavior of the time series of parameters measurements, that are represented in the form of a sequence of the identified segments	Knowledge about the structures of the time series	Knowledge about the temporal dependencies in the parameter behavior
F1.2.3	Dependen-cies validation	Patterns for identification and validation of logical and temporal dependencies of the parameters behavior	Knowledge about logical and temporal dependencies in the behavior of parameters	Knowledge about physical sense of identified dependencies, knowledge about probable true dependencies
F1.2.4	Formalized description	Patterns for building formal descriptions of the dependencies in the parameters behavior	Knowledge about probable true logical and temporal dependencies in the behavior of the parameters	Model of the subject domain that contains additional information about the dependencies in the behavior of the parameters
F1.3.1	Dimension reduction	Patterns for reducing dimensions of the feature spaces used for describing time series	Knowledge about the structures of the time series	Knowledge about the structures of the time series represented in compact forms
F1.3.2	Building groups	Patterns for building compact groups of the measured parameters described in the reduced feature spaces	Knowledge about the structure of the time series represented in compact forms	Knowledge about similar parameters according to the defined set of parameters features
F1.3.3	Identifying classes	Patterns for identifying classes for the formed groups of the parameters. The classes can be identified using expert knowledge, classifiers or procedures for finding similar earlier identified groups	Knowledge about the classes of the parameters and the features of the classes, knowledge about the formed groups of the parameters	Knowledge about the classes of the formed groups of the parameters
F1.3.4	Defining dependen-cies	Patterns for defining dependencies for the groups of the parameters. On the base of the groups hierarchical trees are build and logical dependencies between separate groups are defined	Knowledge about the formed groups of the parameters both identified and not identified	Knowledge about the dependencies of the formed groups of the parameters
F1.4.1	Time series models	Patterns for building the hierarchy of the formal descriptions of time series. The levels are defined according to the amount of available knowledge [16, 17]	Knowledge about the described time series	Systematized knowledge about the time series
F1.4.2	Models for separate measure-ments	Patterns for building the hierarchy of the formal descriptions of the sets of separate measured values. The levels are defined according to amount of available knowledge [17]	Knowledge about the described sets of measurements	Systematized knowledge about sets of measured values of the parameters
F1.4.3	Complex models	Patterns for building complex formalized descriptions of the data sets, that contain data of different types using the formalized descriptions of time series and sets of separate measured values	Knowledge about the described sets of data that contain different types of data	Systematized knowledge about the described sets of data, that contain different types of data
F1.4.4	Merging models	Patterns for merging models, that describe time series, patterns for merging models, that describe the sets of separate measurements, patterns for merging complex models	Systematized knowledge about the time series, about the sets of measured values and about the sets of data that contain data of different types	Extended systematized knowledge about the time series, the sets of measured values, the sets of data that contain data of different types
F1.5.1	Estimation of data variability	Patterns for estimation of time and space variability of data, patterns for defining regions with low variability, patterns for idetifying dynamic of changes in regions	-	Knowledge about variability of data
F1.5.2	Building	Patterns for building regular grids	Knowledge about behavior of the	Knowledge about probable

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	regular fields		analyzed parameters in the defined regions	values of the parameters in the nodes of the regular grids
F1.5.3	Building irregular fields	Patterns for building hierarchical irregular grids	Knowledge about behavior of the analyzed parameters in the defined regions; knowledge about measurements quality	Knowledge about probable values of parameters in the nodes of the hierarchical irregular grids
F1.5.4	Fields improve-ment	Patterns for improving regular and hierarchical irregular grids	Knowledge about behavior of the analyzed parameters in the defined regions	Extended knowledge about probable values of the parameters in the nodes of the regular and hierarchical irregular grids

Table 3. Description of fusion patterns for measurement processing

No.	Pattern	Description	Required knowledge	Produced knowledge
F2.1	Estimation of data	Patterns for estimation of adequacy of the available data, information and knowledge for solving defined set of the end user tasks	Knowledge about features of input data, important for solving the end user tasks, knowledge about the solved tasks	Knowledge about correspondence of available data, information and knowledge to the solved tasks
F2.2	Calcula-tion tasks	Patterns for calculation of the complicated end user tasks based on application of knowledge	The model of the subject domain, knowledge about correspondence of available data, information and knowledge to the solved tasks, knowledge about the solved tasks	Knowledge acquired as the result of the tasks calculation
F2.3	Results validation	Patterns for validation of the results of the end user tasks calculation	Knowledge of the subject domain, in particular knowledge about the features of the objects and their behavior, knowledge about the similar earlier solved tasks	Knowledge about possibility of usage of the formed solutions of the end user tasks
F2.4	Formalized descriptions	Patterns for building formal descriptions of the formed solutions for the end user tasks	Subject domain model, knowledge about solutions of the end user tasks	Model of the subject domain, that contains additional knowledge acquired as the result of solving the end user tasks

Table 4. Description of fusion patterns for solving complicated user tasks

8 USAGE OF TECHNOLOGICAL SOLUTIONS

Proposed technological solutions can be used for building applications almost for all spheres of smart cities economy for solving various tasks. As an example of the spheres, where KM in data processing is of the primary need, three spheres can be considered: the sphere of cities industry, the cities transport and the cities natural environment. The distinguishing feature of the spheres is that in all of them telemetric systems are widely used and consequently the tasks of telemetric information processing are solved. In the enumerated spheres extraction of knowledge from data is strongly required for solving three key tasks: the task of monitoring, the tasks of the short term and the long term prediction of the sphere state and the task of the planning of the sphere future development.

The task of monitoring is based on gathering data about the state of the analyzed objects. Two types of data is usually available: separate measurements and series of measurements. Measurements are received from various measurement instruments, that are installed on objects. Complexity of a monitoring task is conditioned with the necessity of processing huge amounts of data in real time or with minimum delay. Additional difficulties, that arise during data processing, are defined by complexity and bad quality of data. Besides the features of data as well as methods and algorithms applied for data processing significantly depend on conditions, in which data was acquired and has to be processed. Application of the predefined set of methods and algorithms can lead to essential errors in calculated estimations of the objects states. Due to that experts are almost always involved in the processes of monitoring. They analyze received data and make decisions about the controlled objects state. The developed technological solutions allow to use knowledge during data processing and extract knowledge from the analyzed data. Calculation of estimations of the controlled objects states based on using knowledge are expectedly of higher precision and reliability. Some experimental results of solving monitoring tasks using knowledge are described in [18]. In separate cases knowledge based solutions allow to automate processes of monitoring, in other cases – to improve quality of information provided to experts and consequently to simplify their work.

Short term and long term predictions of the states of the considered spheres are commonly based on a set of formal mathematical models, that describe separate objects, their behavior, the rules of their interaction, their life cycle as well as many other parameters of the objects and the environment in which they are functioning. This approach has been used for a long time almost in all spheres. During this period experts of applied subject domains in close collaboration with mathematicians have developed plenty of models, that have been successfully used. The high speed of development and constant changes, that are observed in all spheres nowadays cause three problems. The first problem is that some models because of occurred changes don't completely reflect the corresponding objects. The second problem is concerned with necessity of creation of new models. The third problem is conditioned by exponentially increasing amount of data that must be processed in real time. Increasing amount of data requires additional computing resources for processing and analyses. The developed mathematical models are in most part highly complicated from the computational point of view. Complexity of the models aggravates the problem of lack of the computing resources. Application of the solutions for KM at all stages of data processing allows to extract knowledge from historical data and to build knowledge-oriented formal descriptions. These descriptions can be considered as statistical models. Main advantages of the statistical models are the following. The models can be simply built and updated using historical data, available information and knowledge of the subject domains. They are easily interpretable by both experts and computers and are actual, as they can be updated each time when new data is received. The statistical models can be used separately or together with mathematical models. An example of statistical models build for ocean data can be found in [19].

The most complicated task from the list of the considered tasks is the task of planning of the spheres future development. There are many approaches that can be used for planning. The most part of them are domain-oriented and task-oriented. Usually these approaches are quite simple and assume application of the predefined technologies or sets of methods and algorithms. They can be used for planning activities of separate small and middle organizations. The task of planning at the level of the city because of its extremly high complexity refers to creative tasks rather than to technological tasks. The only way to form proper solutions of the creative tasks is to use imitation modeling tools along with means and tools of artificial intelligence. To solve the planning task it is proposed to decompose it into the five subtasks: to build formal descriptions of the subject domain or its separate elements, to define models that can be used for predicting the subject domain state, to define imitation models, to execute several modeling cycles and to estimate the results of the modeling. Each of the considered subtasks assumes application of knowledge. Solutions for the first two subtasks are considered above. To build imitation models and to model different plans scenario approach [20] is suggested to be used. Scenarios are algorithms represented as a sequences of stages and decisions. Execution of the scenarios requires a set of artificial intelligence tools, including expert system and inference engine [21]. The results of the modeling and their estimations form the base for making well founded decisions about the plans of the cities development created by the experts.

9 CONCLUSION

In the paper technological solutions for KM for the subject domain of the smart cities economy are proposed. Main attention is paid to the problem of using knowledge for data processing and to the problem of knowledge extraction from data. The described set of the technological solutions includes base technology for KM that assumes building high level patterns and their detailing. In the framework of the base technology three main technologies for data processing and analyses are considered: the technology of data harmonization, integration and data fusion as well as the technologies of data prospecting analyses and data exploration. The developed solutions can be used for solving various applied tasks, based on data processing in different spheres of the city's economy. Main advantage of the proposed solutions is that they are flexible and easy in use and support. The technologies are represented in the form of the class diagrams that are ready for implementation. Further development of the suggested solutions for KM assumes enlargement the set of the technologies with the technologies oriented on processing symbolic information, in particular, textual information.

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