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A Business Intelligence Approach to Mine Safety Management

Ljiljana Kolonja[1], Ranka Stanković[1], Ivan Obradović[1], Olivera Kitanović[1], Dejan Stevanović[1], Marija Radojičić[1]

[1] University of Belgrade, Faculty of Mining and Geology, Serbia, ljiljana.kolonja@rgf.bg.ac.rs
[1] ranka.stankovic@rgf.bg.ac.rs; ivan.obradovic@rgf.bg.ac.rs; olivera.kitanovic@rgf.bg.ac.rs; dejan.stevanovic@rgf.bg.ac.rs; marija.radojicic@rgf.bg.ac.rs
Corresponding author ljiljana.kolonja@rgf.bg.ac.rs, phone: +381 11 3219 288

Abstract: *In this paper we give an outline of the approach taken by the University of Belgrade Faculty of Mining and Geology research team in the development of a business intelligence system for accident analysis in mines. Mining engineering, as all other engineering disciplines, generates large amounts of heterogeneous data and needs interoperability among various related information technology applications and knowledge assets, supported by knowledge management analytical services implemented in a business intelligence system. This paper describes such a system for mine safety and its application for accident analysis in mines, developed to improve efficiency, offer fast answers and key business metrics reports, discover week points etc. The interoperability between diverse software components is secured by a system of ontologies developed for mining engineering named RudOnto.*

Keywords: *Business intelligence, Mine safety, Accident analysis, Online analytical processing (OLAP), Mine accident (injury)*

1. Introduction

Mine safety is one of the key issues in mining industry, and it is safe to say that research in industrial safety in general originates from mine safety [1]. Mining is one of those high-risk industries where errors carry such potentially disastrous consequences (a mine explosion, for instance) that new workers cannot learn through experience what happens when something goes wrong under certain conditions. Rather, they have to rely on protocols, post-hoc analyses of past incidents, and transfer of knowledge gained in other circumstances that can be applied in potentially critical situations. Mining organizations need to preserve and transfer knowledge in order to be able to respond to emergencies, and knowledge management (KM) provides a useful perspective from which to tackle this issue [2]. In mining industry KM can play a crucial role in transmission of knowledge between experienced and new workers in order to ensure safe and efficient integration of new workers as well as retention of aging workers [3].

Business intelligence (BI) is closely related to KM and the two of them are often regarded as one and the same within the entrepreneurial community. However, BI is more focused on decision making using data warehousing and online analytical processing (OLAP) techniques, where data warehousing pertains to collecting knowledge asset data into a repository, where it is organized and validated for decision-making purposes.

The use of proper and unique terminology with a BI system is of crucial importance and hence terminological resources, and among them ontologies in particular, play an important role. As Simonet et al [4] point out, although there is no consensus on a common definition of an ontology, it is necessary to understand their main features to be able to use them in a pertinent and efficient manner for data mining purposes.

In this paper we outline our approach to development of a business intelligence system for mine safety illustrated by its application to accident analysis in mines. The aim of the BI system is not only to improve efficiency of mine safety procedures, enable faster answers and key safety metrics reports, but also to discover week points within these procedures. The system consists of several software components representing a combination of different information technologies, where interoperability between diverse software components is secured by a system of ontologies developed for mining engineering named RudOnto.

In the next section we give an overview of ICT support in knowledge management in Serbian mining companies, followed by an outline of related terminological resources developed to secure interoperability between ICT components within our BI system, but also within larger business networks. The section that follows is dedicated to the main results of our study, namely our approach to development of a BI system for mine safety management. The paper closes with a section offering some concluding remarks.

2. ICT support to KM and terminological resources in Serbia

Knowledge management in Serbian mining companies using ICT support for managing knowledge assets is still scarce in Serbian mining practice. However, various other applications of ICT in the field of mining have emerged in the past decade. In general, ICT is introduced in various mining engineering systems most often in the form of information systems, with the basic goal to secure reliable information for managers and decision makers. In addition to that, different ICT support systems and tools have been developed and implemented, such as diagnostic and prognostic decision support systems, computerized maintenance management systems (CMMS) and enterprise resource planning systems (ERP).

Similar to other engineering disciplines the application of ICT in mining engineering results in different software components, which makes their mutual interoperability a critical issue. One of the means to secure this interoperability within a specific domain is the use of ontologies, containing a comprehensive common domain vocabulary. This means that all terms used within a domain need to be standardized, with a clear and unambiguous definition, accompanied by lexical and semantic relations with other terms. Examples are relations established between general and more specific terms, such as "coal mine", and "open pit", which is a specific type of coal mine, as well as synonyms relations, such as those between "opencast", "surface mine", and "quarry". One approach to development of mining ontologies has been reported in [5]. Some interesting results on ontology-based modeling and inference for occupational risk prevention are presented in [6].

One of the first terminological resources in the mining domain was developed at the University of Belgrade Faculty of Mining and Geology (FMG) within the Technological coal mine information system [7]. Further growth and variety of terminological resources for specific subdomains developed at FMG initiated the development of a comprehensive reference resource for mining terminology in Serbian. The niche for this resource was found in SUKU, a mining engineering information system, also developed at FMG [8].

Recognizing the importance of ontologies as key resources for knowledge management, as well as most complex terminological resources, a methodological approach to upgrading the terminological resources developed at FMG to a system of ontologies for Serbian mining industry has been undertaken [8]. This ontology system, RudOnto, is envisaged as a general resource, with the main goal of enabling knowledge structuring and efficient knowledge management in the mining domain. Among other things, RudOnto can be used for ontology-based knowledge management within occupational risks prevention. Ultimately, it should enable automatic discovery of prevention documents as well as actions that provide personalized training for a specified context, e.g. a given activity, workplace, operator type, work machine, etc. In order to make knowledge within RudOnto available to a wider circle of users, a client-server application was developed enabling web access to this resource at http://rudonto.rgf.bg.ac.rs (Figure 1). The user can search RudOnto using keywords or browse through available concepts either in Serbian or English using a tree-like structure [9].

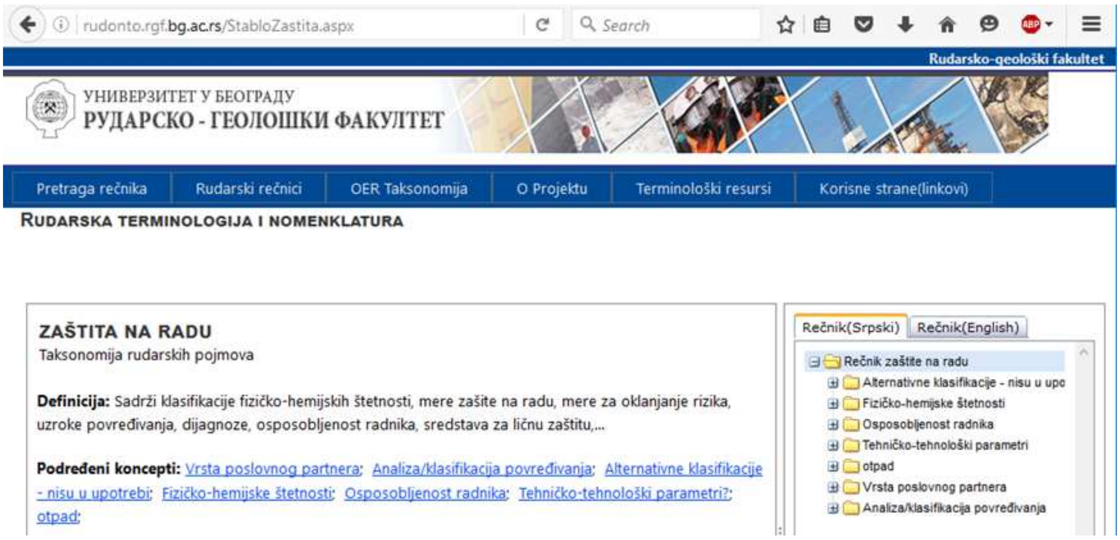


Figure 1. Ontology system - RudOnto

The approach to mine safety knowledge codification in RudOnto is mainly based on the Taxonomy for Indexing Web-Based Mining Safety and Health Research [10] developed at the U.S. National Institute for Occupational Safety and Health's (NIOSH), which is the leading world organization in this area. At the beginning of June 2014, the Office of Mine Safety and Health Research (OMSHR) within NIOSH announced the implementation of a taxonomy-based navigation tool called "Site Browser" (http://wwwn.cdc.gov/niosh-mining) that allows researchers and other users to browse content tagged with subject terms from their taxonomy.

Besides improving their performance using ICT, companies within Serbian mining industry are also striving towards advancing collaboration with their business partners' networks both within the country and abroad. Thus ICT support is aimed not only at improving intra-business processes, but also at inter-enterprise business processes, in order to secure better performance and interoperability in business networks [11]. The concepts of enterprise ontology and reusable knowledge assets are essential for knowledge management and business intelligence within mining industry enterprises and enterprise networks.

In addition to providing intra-business interoperability RudOnto thus secures inter-enterprise interoperability by offering a unique knowledge codification scheme, which enables software agents and human actors of different mining companies and related organizations to share knowledge assets and organizational data as a common resource.

3. Online analytical processing in mine safety

3.1. Methodology for data management

Safety management relies on job standards, rules, regulations, performance evaluations, and policies, which are used within the chain of command to secure that employees fulfill their assigned responsibilities satisfactorily [12]. The fundamental objective of safety management is to eradicate human anguish and suffering and to achieve economy of operation in an effective manner [13].

The BI system for support of decision making in safety management described in this paper uses a combination of various information technologies, such as OLTP (On Line Transactional Processing), OLAP, WEB, SQL Server Reporting Services, etc. Hence, it is a system for direct analytical data processing implemented through Microsoft® SQL Server™ 2008 Analysis Services, which supports multidimensional views on business data, using the technology of multidimensional or relational databases. This technology is often used by managers and analysts who require higher levels of aggregated views on business data.

Mining companies in the world find it increasingly difficult to meet the highest standards for security, work environment, health, and safety, this being one of the prerequisites for securing the best human resources and ensuring stable operation at minimal risk. In order to achieve this, it does not suffice simply to react to a problem when it occurs, but an analysis of weak points is needed, leading to a reduction of risk. A prerequisite for such an analysis is the creation of a comprehensive database with a history of injuries and conditions that led to an injury, so that in the future preventive measures can be taken. Companies often do not recognize all the risks within the production process, which can be mitigated by the use of software to record all occurring incidents.

In line with the examples of existing good international practices, the development of our system is focused on tracking records in a modern way, while respecting national legislation.

Figure 2 shows the panel for recording injuries, where basic data about the injured worker are recorded, as well as data on worker's qualifications, occupation and professional and soft skill training, on the directly responsible supervisor, and on possible eyewitnesses of the accident. Further, the organizational unit and the workplace of the worker are recorded, while the job that the worker was performing is selected from a catalog and additionally described if necessary.

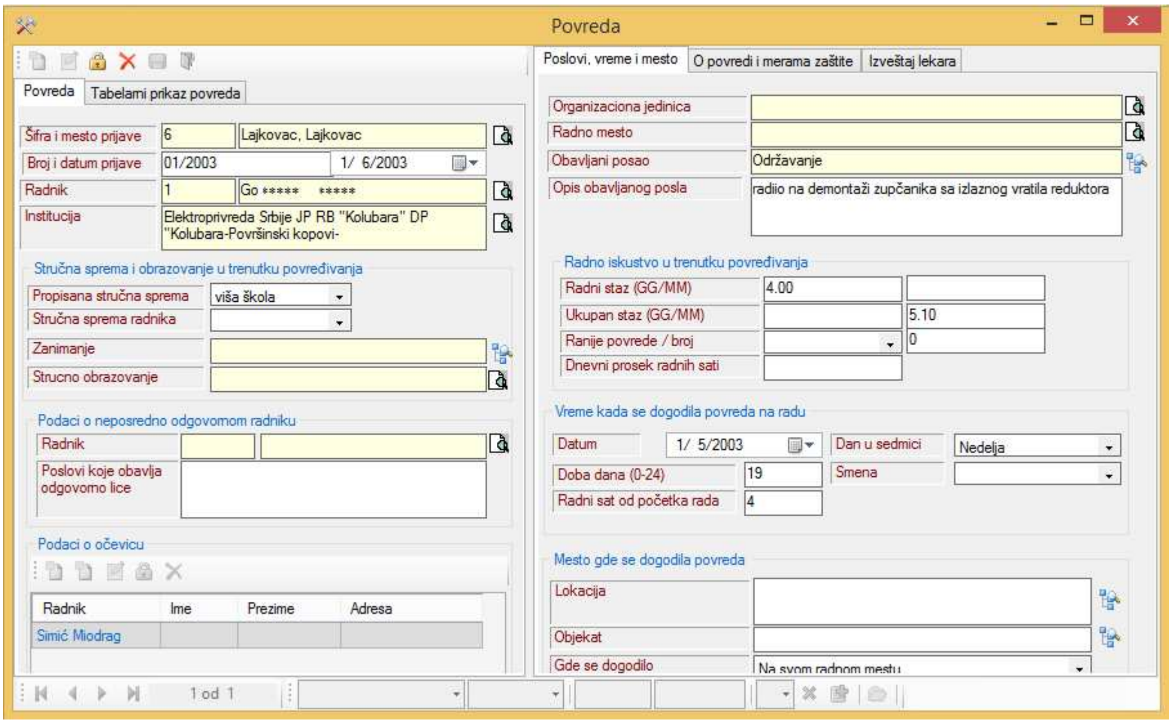


Figure 2. The main panel with data about the injury

The system also records the worker's experience at the time of injury, namely: employment and total years of service, previous injuries and the average number of work hours. The time when the injury at work occurred is defined by the date, the working hour, and the shift, whereas the time of the day and day of the week are also entered for the purpose of later analyses. The place where the accident occurred is determined by location and site, and a record is also made of whether the accident occurred during working time, or during arrival to or departure from work.

Finally, our BI system records the sources and causes of injuries, the occurrence and the number of injured workers, with a detailed description of the injury and the safety measures.

An electronic questionnaire records whether the workplace at which the worker was injured is classified as one with special conditions, whether all regulations were respected, whether the worker was subject to a medical examination, whether the personal safety measures were applied, which safety measures were followed, and the like. The medical report on the injury is also entered into the electronic form, and its most important parts are the classification of external causes of injury, injury severity assessment and specification of part or parts of the body that were injured.

3.2 Methodology for data analysis

Online analytical processing is a capability of management, decision support and executive information systems that enables managers and analysts to interactively examine and manipulate large amounts of detailed and consolidated data from many perspectives. OLAP involves analyzing complex relationships among thousands or even millions of data items stored in multidimensional databases to discover patterns, trends, and exception conditions. An OLAP session takes place online in real time, with rapid responses to manager's or analyst's queries, so that their analytical or decision-making process is undisturbed. Online analytical processing involves several basic analytical operations, including consolidation, "drill-down" and "slicing and dicing" [7].

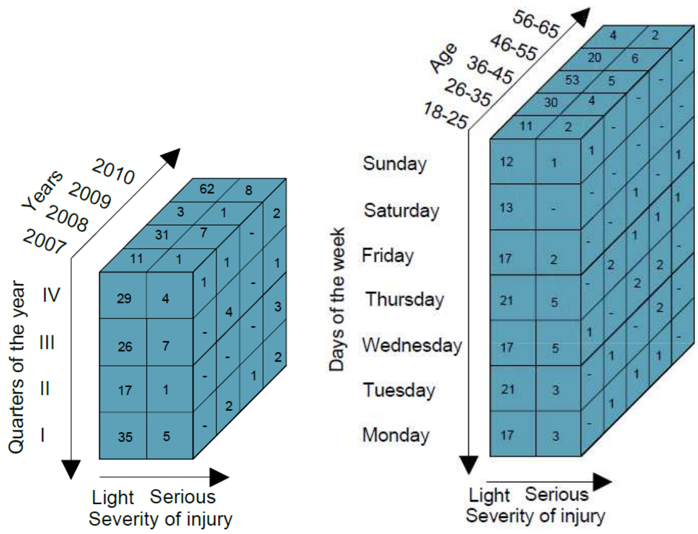
In mine safety it is necessary to follow several attributes related to injuries, perform their multi-dimensional analysis, as well as display data in different forms. Data are presented in the form of OLAP cubes that contain measures and dimensions. Compared with the standard representations of business data, dimensions are business parameters represented as row and column headings of reports. A dimension can be seen as intuitive way of organizing and selecting data for retrieval, exploration and analysis. The number of injuries, which represents a measure, is the central value of the cube that is analyzed. In our system, dimensions that are structural attributes of the cube, grouping data of similar category, are: type of injury, body part, severity of injury, worker's age and qualifications, time dimension, organizational structure of mine, shift and working day in which the injury occurred, the source and cause of the injury, etc.

Figure 3 depicts two OLAP cubes. Each cell of the cubes holds a number of injuries. In the first cube (a) injuries are categorized according to the type of injury and the quarter of the year in which it happened. For the second cube (b), the measures taken into consideration are the type of injury, the day in the week on which it happened and the age of the injured worker. Based on the first cube we can conclude that the number of injuries in the year 2010 was considerably higher than in the previous three years, and that the greatest number of injuries happened in the first quarter. From the second cube we can see that the majority of injured workers were of the age between 36 and 45 years, as well as that the number of light injuries was much greater than the number of severe ones.

3.3. BI development environment

The BI model for mine safety integrates standard OLAP techniques based on RudOnto, where dimensions of OLAP cubes are concepts of RudOnto ontology, and its hierarchy of concepts is mapped to build flexible OLAP models with multi-level hierarchies.

The software also contains tools for calculations, key performance indicators (KPIs), actions, partitions, aggregations, etc. The browser option serves for data survey and within this slot different dimensions to be used for calculating the number of injuries can be defined in a quick and simple manner.



(a) *(b)*

Figure 3. *OLAP cubes*

The BI model can offer important information for safety management but also allows different ways of presenting data. Figure 4 depicts two ways of presenting data on the number of injuries categorized by body part and body side. Due to the hierarchical structure of the RudOnto dictionary the analysis can be performed on several levels of detail.

Thus we can ask for injuries of the arm, head, leg, or hull (Figure 4 right), or browse for a knee, feet or forearm injury within the leg category (Figure 4 left). A time dimension can also be added, and all this information can be viewed by months, trimesters, years, or within a specific time period. This information enables preventive action with the aim of raising the level of safety equipment for body parts that are most frequently injured.

Count of PovredaID	Column Labels			
Row Labels	-	left	right	Total
leg	**22**	**19**	**13**	**54**
ankle	5	3	2	10
thigh	11	1	2	14
shank		4	3	7
foot		4	2	6
toe			2	2
knee	6	7	2	15
head	**13**	**3**	**5**	**21**
eye		3	5	8
head (oth.)	11			11
face	2			2
arm	**11**	**18**	**26**	**55**
fingers	11	4	5	20
upper arm		1	8	9
shoulder		3	1	4
hand		9	9	18
forearm		1	3	4
torso	**18**			**18**
inter.organs	7			7
other parts	11			11
Total	**64**	**40**	**44**	**148**

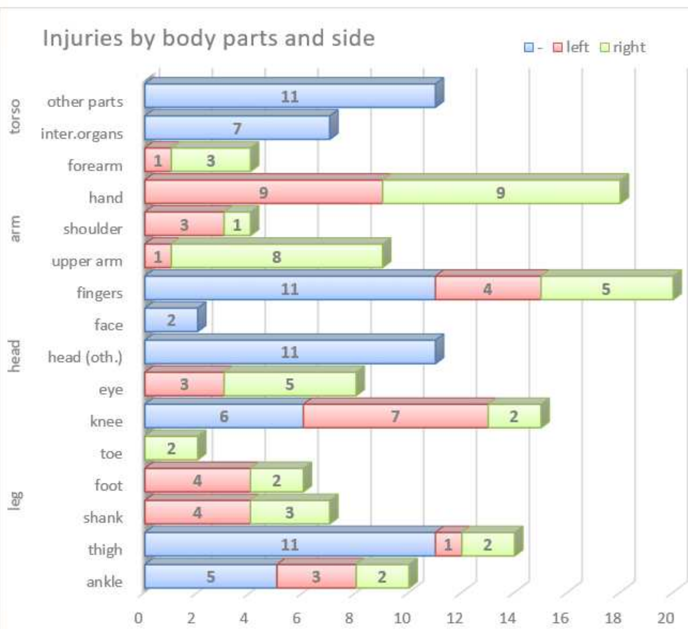


Figure 4. Representation of injuries by body part and body side

Figure 5 shows the percentage of the total number of injuries in the database for a selected period by days of the week. One can observe from this figure that the majority of minor injuries happens on Thursdays, which can be related to a reduction in working capacity of workers due to fatigue. This parameter is an indication for the mine management to organize the work of employees in shifts in a better way. It can also be observed that the fatal injuries occur only on weekends i.e. on Saturdays.

Count of Povre Colu / w Labels	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Total
fatal injury	0.0%	0.0%	0.0%	0.0%	0.0%	0.7%	0.0%	0.7%
light injury	12.4%	15.3%	12.4%	15.3%	12.4%	8.8%	8.8%	85.4%
severe injury	2.2%	2.2%	3.6%	3.6%	1.5%	0.0%	0.7%	13.9%
Total	**14.6%**	**17.5%**	**16.1%**	**19.0%**	**13.9%**	**9.5%**	**9.5%**	**100.0%**

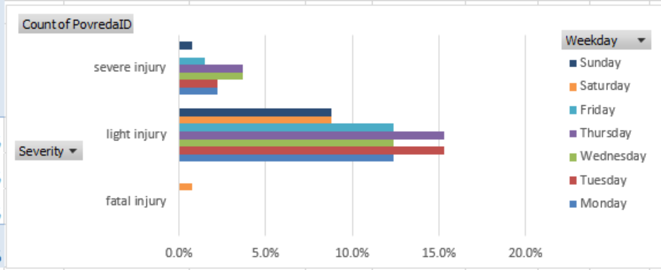


Figure 5. The total number of injuries on specific days in percent

Figure 6 offers an overview of injuries by body parts and working hours. The most common injuries are limb (leg and arm) injuries that occur in the middle of the working day (shift). The reason for this can be found in the carelessness of workers not wearing proper protective equipment as well as their failure to comply with work health and safety measures.

Injur.b.p.No / Work.hour	Body part: arm	head	leg	torso
1	3	1	5	2
2	9	3	5	1
3	7	4	6	1
4	11	3	9	4
5	4	1	8	1
6	5	2	3	1
7	3	3	4	3
8	7	2	6	1
Grand Total	**49**	**19**	**46**	**14**

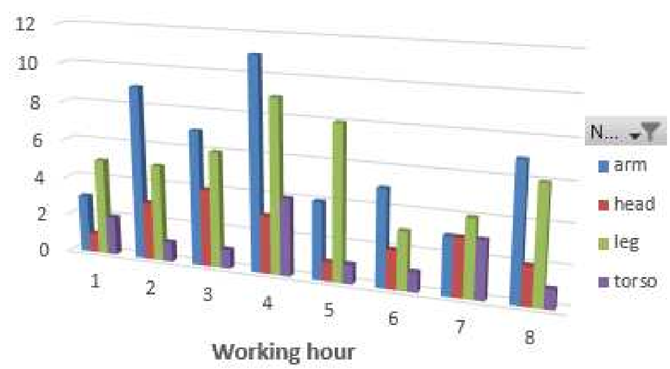


Figure 6. The working hour combined with injured body part

Data on injured body parts (total) presented in Figure 7 illustrate different visual representations, namely displaying percentage or absolute numbers.

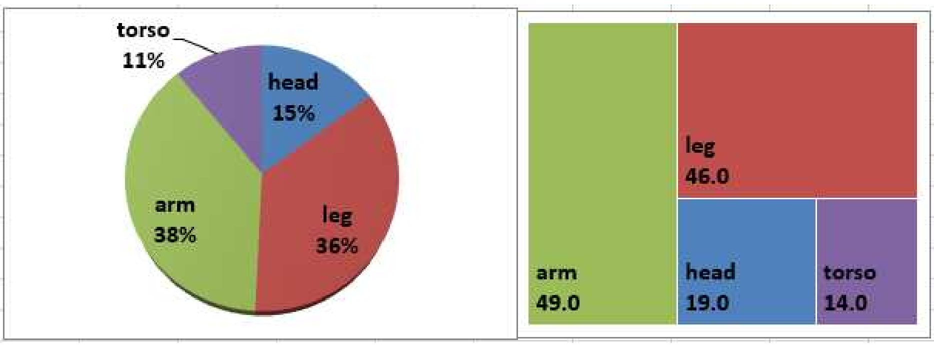


Figure 7. Data on injured body parts with two hierarchy levels and body side

When data on injuries are analyzed within a longer period, the time dimension can be displayed by year, by quarter of the year, then by month, by date and finally selected injury levels. Figure 8 presents the number of injuries by quarter of the year, then by month, with severity of the injury, in tabular and graphical format, thus combining the time dimension (with its hierarchy) and injury severity.

Count of Pov	Column l		
Row Label	light injury	severe	Grand Total
⊟1	35	5	40
1	18	4	22
2	7		7
3	10	1	11
⊟2	17	1	18
4	5		5
5	5	1	6
6	7		7
⊟3	26	7	33
7	10	3	13
8	6	1	7
9	10	3	13
Grand Total	78	13	91

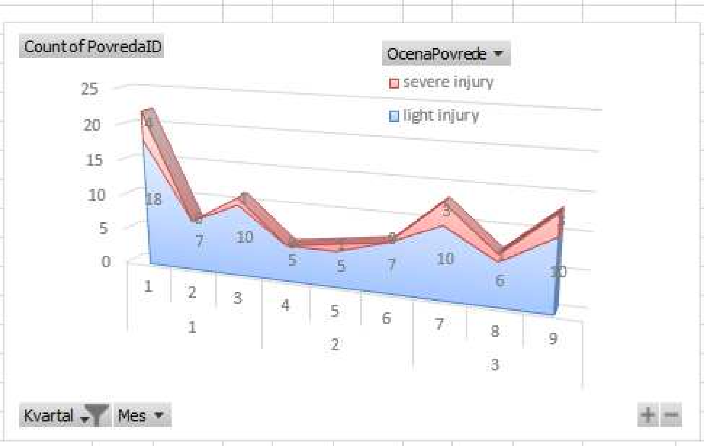


Figure 8. Various OLAP presentations

4. Conclusion

Both managers and employees in mine safety need to analyze the dynamically changing sets of information to improve and support their working tasks. Traditionally, available data is limited to queries or reports which have been predefined for them by IT experts. Business intelligence offers some novel approaches to presentation and analysis of business information. The field is expected to further benefit from application of semantic technology, especially ontologies.

The BI system developed for mine safety management and presented in this paper offers to the users an insight into large quantities of complex data. This insight can further be transformed into useful new knowledge which the management in a mine plant needs for decision making. Managements of mine plants that implement BI tools can make timely decisions of a higher quality thus improving the overall work safety of their employees.

In this paper we presented the use of an ontology-based tool in improvement of the analysis and reporting system with easy data access and query for users in the mine safety area. We have demonstrated various possibilities that the use of such a business intelligence tool opens, supported by a practical example of application of the tool for accident analysis in mines that brings considerable benefits to mine safety.

It is important to note that the methodology and approach implemented can be used as a valuable basis for risk assessment. Proper assessment of critical elements in mining process can be a powerful tool for preventing injuries and improving mine safety. Having that in mind, incorporation of a mechanism for risk assessment in the presented methodology would be the next step and logical direction for further work and improvement.

Acknowledgements

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