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Ontology evaluation: An example of delay analysis

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Abstract

Ontologies have a place in knowledge sharing with their ability to capture real world information in a machine readable environment. Their application varies from any approach structured on ontological commitment to meta-level ontologies serving for variety of purposes. This variety continues also in methodologies for constructing the ontologies. There are wide range of ontologies differing in size and complexity that are created with different design criteria. The main point with the ontologies is their structure and ability to serve for the intended purpose. This is only granted with the continuous evaluation of ontologies in the construction process, and also before release or reuse of the ontology. Ontology evaluation methods cluster around two concepts such as verification methods that ensure the structure of the ontology, and validation methods that examine their applicability in real world. In light of these, different approaches as quantitative and qualitative methods are depicted in literature from subjective evaluations by experts to tools, all of which investigate different characteristics of ontologies.
Objectives of this study are to underline the importance of ontology evaluation and to present an employed validation method used during ontology development for delay analysis. In this context, first; literature review on ontology evaluation is presented. Second, a delay analysis ontology is introduced with its basics to lay the foundations of the study. Cases taken from the Turkish construction industry are exemplified to explain the utilized ontology validation process. Comparison of the concepts in the constructed ontology with the expert reports written for each case is used to evaluate the ontology. Furthermore, alternative validation techniques are discussed as well as possible attempts to keep it responsive and up-to-date.

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Keywords: construction sector; delay analysis; ontology; ontology evaluation; ontology validation.

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1. Introduction

Ontologies occupy a prominent place in knowledge sharing. The ontology concept is flexible and its adaptability leads variety and so prevents a common ontology development or evaluation method to be accepted. Their usage area is wide and they are developed to respond many need in the area. The soundness of an ontology between all the created ones is manifested only by its evaluation. Accordingly, evaluation is highly recommended during whole life cycle of an ontology. In this context, many evaluation methods are available that are responsive for different evaluation aims.

An ontology of delay analysis in construction sector underlies this study. This inevitable problem of construction sector is tried to be handled in this way to increase knowledge in the issue and to form a base for any attempt that would be held in machines environment. Possible use of the ontology by construction companies in project, risk and/or claim management; and as a database for the companies is expected by this ontology. To meet this object, validation by real expert reports on delay analysis is selected to ensure the soundness of the literature based ontology.

In this paper, literature review on ontology evaluation methods is handled and the followed validation method is presented to show the variety and importance of ontology evaluation methods.

2. Research background

In this section, firstly ontology is defined and following that literature review on its evaluation is presented to reveal its extent.

2.1. Ontology

Ontologies have been widely used in knowledge engineering since 1990s to meet the need of unified forms for information sharing to provide common understanding and reuse [1,2]. With its widely known definition, an ontology is "an explicit specification of a conceptualization" [3,4]. Corcho et al. [1] present a unified definition as "ontologies aim to capture consensual knowledge in a generic and formal way, and that they may be reused and shared across applications (software) and by groups of people". Additionally, Gangemi et al. [5] structurally define an ontology as "a graph whose nodes and arcs represent conceptualizations". Basically it is the graph of meta-data ranging from thesauri, taxonomies and axiomatized theories. The taxonomic (sub-class of / is-a) relationships of an ontology constitute the depth and breadth of an ontology, whereas non-taxonomic relations constitute the density of the ontology. It is the dexterity of its developer to keep the conceptualization in a semantically formalized form, namely in the graph [5]. Ontologies are basically taxonomic tree of conceptualizations from general objects at the top level to the specific ones at the bottom level [6]. When taxonomies are improved with more information through relations and rules for modeling a domain, they become ontology [7]. Accordingly, one is free to construct any lightweight (generally including concepts, concept taxonomies, relationships between concepts and properties of concepts) or heavyweight (additionally including axioms and constraints) ontology that would be structured to be responsive to any need [1]. There are various ontology construction methods ranging from construction from scratch to merging existing ontologies and generating ontologies with automatic construction principles (ontology learning) [8]. In response to this, there are wide range of evaluation metrics available presented to evaluate the intended structure and functionality of the ontology [9,10]. Moreover, researchers that propose development strategies also mention some design and evaluation criteria for ontologies like the ones presented by Fox and Gruninger [11]; Gomez-Perez [12]; and Gruber [4].

2.2. Ontology evaluation

With wide-spread usage of ontologies in knowledge representation, development and re-use of ontologies bring up question of evaluation of ontologies. There are various evaluation methods that search for different measures with qualitative or quantitative metrics for different ontologies, however no global approach has been adopted [5]. As it is previously stated; ontologies vary in their domain, size, purpose, language, and may be hand-carved, may be constructed by scholars or domain experts or may be obtained by an automatic or semi-automatic process. This situation leads evaluation of ontologies to be complicated and prevents release of a standard evaluation procedure [13]. Additionally evaluation is required during whole life-cycle of an ontology; namely during pre-modelling, during modelling, before release and after release [14-16]. Many studies held by different researchers in the ontology evaluation area address the problem and point up importance of the issue. There are methods that are either manual or automatic, either dealing with taxonomy or evaluating the content, and either dependent to some specific tool/language or independent [17]. This double variety of ontology development and evaluation increases the complexity in the area and keeps the evaluation problem unsolved [15,18]. Accordingly; to obtain a reliable ontology, complementary use of different evaluation methods is appreciated [17].

2.2.1. Classification of ontology evaluation methods

There are various classification attempts on evaluation methods and tools, the details of which are given below. The common point between them is; in general terms they are either *verification methods* that ensure the ontology is constructed correctly, or *validation methods* that ensure the ontology represents the real world [19].

Hartmann et al. [16] classify ontology evaluation for the methods as (1) *OntoMetric* – Analytic Hierarchy Process based method that presents set of measures to select the best ontology for a particular need; (2) *Natural Language Application Metrics* – mainly associating mentions in the text with the concepts in that ontology (precision and recall metrics, cost-based evaluation metric, ontology fit – the tennis measure, and lexical comparison level measure); (3) *OntoClean* – evaluation of formal structure of the taxonomy by the ontological notions of rigidity, unity, identity, and dependence; (4) *EvaLexon* – mainly creating ontologies from text, comparison of the vocabulary with text calculation of coverage, accuracy, precision, recall. Additionally, they present the applications and tools as (1) *ODEval* – tool that detects possible problems in concept taxonomies, (2) *OntoManager* – tool that evaluates the truthfulness of an ontology with respect to the domain.

Gangemi et al. [5] identify three categories as *structural measures* – evaluation of formal structure of the ontology, the graph; *functional measures* – evaluation of the relation between the ontology and the intended meaning, how it serves for the purpose, its cognitive semantics, mainly precision/recall-based measures; and *usability-profiling measures* – evaluation of the ontology profile, communication context of the ontology, its pragmatics. *Structural measures* are depth, breadth, tangledness, fan-outness, specific difference, density, modularity, logical adequacy, meta-logical adequacy, degree distribution. *Functional measures* are precision, recall and accuracy which are measured against experts' judgment or a data set assumed as a qualified expression of experts'. They give further detail for functional measures as judgment by (1) agreement assessment, (2) user-satisfaction assessment, (3) task assessment – what is supported by the ontology? (service-specification-based, gold-standard-solution-based, explicit-task-based), (4) topic assessment – boundaries of the knowledge domain addressed by the ontology (5) modularity assessment – building blocks for the design of the ontology. Finally, *usability-profiling measures* are handled as recognition, efficiency, and interfacing.

Fernandez-Breis et al. [18] state that ontology evaluation issue has been handled from different perspectives so it is possible to group them as evaluation with the aim of *ranking*, *correctness* or *quality*. Generally ranking and correctness are evaluated for the *structural property*; whereas usability, reliability, and functionality is considered in the search of ontology *quality*. They underline that ontology development procedures bear traces of Software Engineering and they undertake the evaluation issue from that perspective (ISO 9216 standard for software quality) as well. Software evaluation consists of *internal*, *external* and *in-use* quality measures. *Internal measures* constitute the measures that are related with the software itself and generally held during early design process; whereas *external measures* are the ones evaluated during testing or operating process in later design or before release process, and they are generally related with the behavior of the software. In light of these, they propose an ontology evaluation framework that is structured from seven quality dimensions as *structural*, *functionality*, *reliability*, *usability*, *efficiency*, *maintainability*, and *quality in use*.

Netzer et al. [13] group the ontology evaluation purpose as *assessing the quality* by its developers, or *ranking the ontologies* to choose for some particular use. Additionally they group the evaluation methods as *intrinsic* and *extrinsic* methods. *Intrinsic methods* focus evaluation of the structural properties; whereas *extrinsic methods* require some external information such as a corpus that represents the domain knowledge (data-driven evaluation), expert opinion, or a particular task.

Zouaq and Nkambou [20] mention *structural evaluations* and other approaches as *gold standards* – comparing the ontology with a "gold standard", *application-based* – using the ontology with an application and evaluating the results, *data-driven* – comparing the ontology with a source of data from the domain to be covered, and *assessment by domain experts*.

Patrick and Florian [21] classify ontology evaluation process according to its *approach* – golden standard, application-based, data-driven, assessment by humans; *complexity* – methods evaluating lexical/vocabulary/data layer, hierarchy/taxonomy, context/application level, syntax/structure/architecture/design; and *evaluation method* – evolution based, logical/rule based, and metric/feature based. They also mention evaluation tools and methods as (1) OntoManager, (2) OntoMetric, (3) OntoClean, (4) EvaLexon, (5) WEBCORE, and (6) S-OntoEval.

Bachir Bouiadjra and Benslimane [14] divide available methods into four groups starting with *what should be evaluated* as "whole ontology evaluation" or "partial ontology evaluation". They further present the groups of *why it should be evaluated* – "validity (of ontological structure)" or "quality (for use)"; *when it should be evaluated* – "before the ontology building process", "during the ontology building process", "during the ontology evolution process", "before reusing the ontology"; and *based on what it should be evaluated* – "corpus-based evaluation (to estimate accuracy and coverage of the ontology)", "gold-standard-based evaluation (to compare ontology with a gold-standard)", "task-based evaluation (to search how use of ontology effects the application)", "expert-based evaluation (evaluation by human experts)", "criteria-based evaluation (to measure fit of ontology to some criteria)".

Bolotnikova et al. [15] classify the methods of ontology evaluation according to *the goal of evaluation*, *the stage of evaluation*, *the degree of automation*, *the object of the analysis*, and *the tools applied for analysis*. Analysis tools are classified as "data-driven tools", "expert evaluations", "investigation of profiles of use", "comparison with 'golden standard'", and "investigation of topologies of the ontology graph". The automation degree of these tools are handled through their "automatic", "semi-automatic", and "manual" indication; while the application stage of the analysis is grouped as "development and prototyping", "testing before release", and "use". Object of the evaluation can be "structure", "dictionary", and "efficiency of practical application"; and there can be different evaluation goals as depicted in the evaluation schema provided in the study. As an addition to this classification, they underline the importance of quality of the design of the ontologies and mention two aspects to be evaluated as "(1) correctness and depth of reflection of the subject domain, and (2) ergonomic aspect of the ontology representation from the point of view of quality and human speed of perception". Further they present detailed quantifiable metrics to evaluate the cognitive ergonomics of the ontologies and state the importance of cognitive ergonomicity when ontology is aimed for learning or passing on knowledge.

2.2.2. Data-driven evaluation and NLP

Brewster et al. [22] state that ontologies are simply set of concepts and relations that are either explicitly defined or following from set of axioms, and accordingly they are abstractions from a set of natural language texts that are describing the domain. Accordingly; they propose reversing the procedure for evaluation as finding concepts in the texts that are related with the ones in the ontology, and name this process as "corpus" or "data-driven" evaluation. Additionally, Gangemi et al. [5] mention that functional measurement is based on "matching" between two structures, basically the search of correspondence between the ontology and something else. They additionally refer Natural Language Processing (NLP) based methods, methods based on matching between a corpus of documents and the ontology, as generally used methods for functional assessment. They refer to Daelemans and Reinberger [23] that NLP based methods provide to show the ontologies are "consensual conceptualizations" rather than just its developers' ideas. Through a corpus-based analysis, empirical estimation of the *accuracy* and *coverage* of the ontology can be made [5]. In parallel with these, Hartmann et al. [16] point out two metrics as "one that shows how well a 'sample ontology' built as the result of a certain methodology (human modelling or automated mining) ‘represents’ a commonly accepted reference corpus, and one that details how the ontology actually ordered ‘corresponds’ with the input text(s) of the customer’s application domain”.

3. Evaluation of delay analysis ontology

In this section, the delay analysis ontology is introduced and the established evaluation procedure is presented.

3.1. Delay analysis ontology

As it is previously stated a delay analysis ontology may act as a vocabulary of the delay analysis domain and provide the easy understanding of the debate. Additionally, with its ability of easy adaptation to the machines world, ontology may be used in a software program or form the basis of a company database or decision support system. Methontology procedure [24] is followed step by step for the establishment of ontological structure and the tool Protege is used for its implementation. For the design of the ontology, principle of Noy and McGuinness [2] as; *nouns* in sentences that describe domain constitute *objects/concepts* in an ontology whereas, *verbs* in sentences correspond to *relations* of the concepts in the ontology constitutes the foundation of the conceptual background of the ontology. The main concepts in the issue are extracted from literature review on delay analysis as “*causes of delay*”, “*types of delay*”, “*responsibility of delay*”, “*claim for impact of delay*”, “*analysis of delay*” and “*prevention of delay*”; accordingly the delay analysis ontology is defined in few sentences that are able to be read through ways formed by passages from the surrounding classes to the core class “delay”. The following Unified Modelling Language (UML) diagram constitutes the graph of the generated ontology (Fig. 1). The relations at concept level are depicted in black and blue, while the relations at instance level are depicted in red. For the full taxonomy of concepts behind the graph of the ontology, the details of the ontology can be investigated in the study of Bilgin [25].

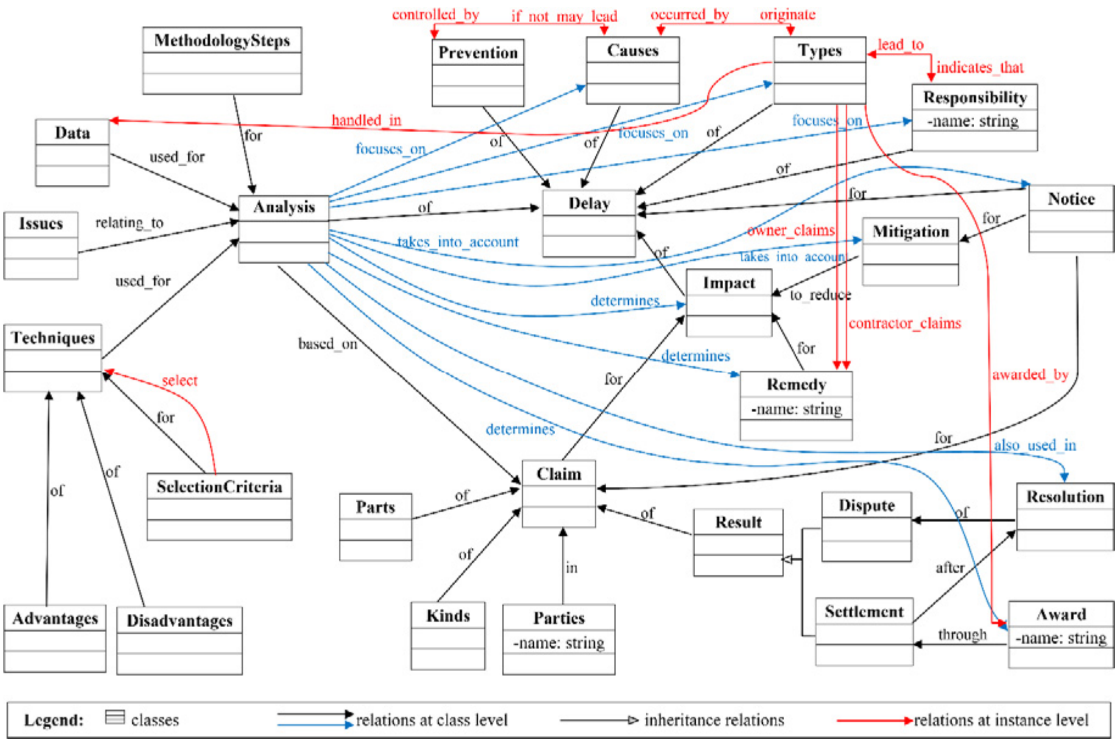

Fig. 1. Complete model of delay analysis ontology [25].

3.2. Evaluation procedure

As it is presented, there are many methods available for almost any kind of evaluation, and new ones can be added according to the specific features of the created ontology. Within the variety of evaluation methods, it is important to use complementary methods that will respond to both evaluation aspects as *verification* and *validation*. Multiple use of methods leads a consistent and usable ontology [17]. For example, El-Diraby and Wang [26] use competency questions, expert evaluations and tests on sample documents to evaluate their ontology in terms of ease of navigation, abstraction consensus, representation, and consistency. Evaluation can be done for the search of various measures; however when its specific use is thought, criteria relevant for that use should be taken into consideration [5]. Gangemi et al. [5] refer to Noy [27] as it is stated that knowing the ontology is accurate to some formal criteria, namely its structural quality, only implies that the ontology is usable but it does not give any idea about its suitability for the case in hand. In light of these, regarding the evaluation of delay analysis ontology; first of all since it is constructed with a methodology (Methontology) that indicates evaluation step as a continuous step during the construction of the ontology, verification of the ontology is considered from the beginning to the end of the ontology construction process. Competency questions are used in the specification step of the methodology which is a method proposed by Gruninger and Fox [28] as the queries helping the construction and also evaluation of the ontology. The following *competency questions* are used to structure the ontology: “Why this ontology is being built?”, “Who are its users?”, “What is delay?”, “What is delay analysis?”, “What does happen in case of a delay?”, “What are the causes of delay?”, “Who are responsible from delay?”, “What should be done in case of a delay?”, “What should be done for the prevention of delay?”. Additionally various design criteria presented by different researchers [4,11,12] have a control over the construction of the ontology, and are taken into consideration as far as possible. Objectivity is tried to be provided to prevent ambiguity, and inconsistent definitions are not included in the ontology. Also, the created ontology is easy to update due to its common representation system and has only the common definitions of the subject, so does not limit its users when its usage is in question. Moreover; for the implementation of the ontology, a reliable tool (Protege) is used that would form an anticipated ontology skeleton. Accordingly, the verification of the ontology is searched as an initial step of evaluation and what is crucial at this point is the investigation of matching of the constructed ontology to real world. Besides, Lovrencic and Cubrilo [17] state that small ontologies can be created with only few mistakes however incompleteness problem always exists. Accordingly for a lightweight and this type of ontology, search for completeness is also important [29]. Between available options for validation (expert interviews, case studies, comparative analysis of industry documents and competency questions), the validation of the ontology through case studies is selected [26,28,30,31]. Real *expert reports* for claim analysis are selected since they are the primary documents for delay analysis. The technique handled in this study is parallel with NLP based methods, and it searches for the *completeness* and *suitability for the use* of the ontology. According to the classification presented by Bolotnikova et al. [15]; the method followed can be deemed as a “manual” and “data-driven” method, applied for “testing before release”, with the goal of “completeness and precision of the dictionary of the subject domain”, and with the analysis object as the “dictionary”.

4. Depiction of evaluation details

Three case studies from claim analysis are selected between five available due to their detail handled in. Phrases in the reports are separated into concepts (underlined) and they are matched with the related concepts in the ontology as in the example provided in following table (Table 1). Phrases of the report are totally kept in quotation marks, whereas only concepts in the ontology are presented in quotation marks. To specify the place of the concept in the ontology, upper concepts defined are also included. For the inclusion of information of relations in the ontology; the word “under” is used to refer taxonomic relations between concepts, whereas the demonstration “-association_name-” is used for the non-taxonomic relations. So, “phrases in ontology” are indicated in path forms such as: “concept” under “concept” -association- “concept”. The following table (Table 1) exemplifies the process held during evaluation.

Table 1. Example for comparison of concepts.

Phrase in the Report	Phrase in the Ontology
"Obtaining building permits: Contractor informs the Engineer about the delay due to obtaining building permits is not in their (contractor's) responsibility and claims the required extension of time. Engineer approves the contractor's claim and with the consent of owner 17 days of extension is awarded to contractor and the new contract completion date is determined."	"Notice" -for- "Claim"-for- "Impact" -of- "Delay" "Building permits approval process" under "Rules and Regulations Related Causes" under "External Causes" under "Causes" -of- "Delay" "Owner (or his agents) responsible" under "Responsibility" -of- "Delay" "Neither contractual party responsible" under "Responsibility" -of- "Delay" "Claim" -for- "Impact" -of- "Delay" "Extension of time claim" under "Time Related Claims" under "Kinds" -of- "Claim" -for- "Impact" -of- "Delay" "Settlement" -is-a- "Result" -of- "Claim" -for- "Impact" -of- "Delay" "Extension of time" under "Award" -through- "Settlement" -is-a- "Result" -of- "Claim" -for- "Impact" -of- "Delay" "Award" -through- "Settlement" -is-a- "Result" -of- "Claim" -for- "Impact" -of- "Delay" "Current completion date" under "Details of Claim" under "Parts" -of- "Claim" -for- "Impact" -of- "Delay" "Practical completion/Substantial completion and initial certificate" under "Contract Clauses" under "Main Contract Documents" under "Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay" "Update and reanalyze the network: specify the project is ahead or behind the schedule at delay date." under "Apply Analysis Technique" under "Event Analysis" under "Methodology Steps" for "Analysis" -of- "Delay" "Adjusted/Updated schedule: schedule depicting impacts by changes on as-planned schedule" under "Major Schedules" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"

5. Discussion and conclusion

The concepts within the reports and the ontology are matched, only several additions are made as a result of this evaluation. The relations are not investigated separately since they complement the existence of the stated concepts. When the matching between concepts in the ontology and reports is considered; it is seen that the ontology has enough concepts to represent real world knowledge for these cases, and it has the potential to ease claim management process like the ones in the case studies. Additionally, changes can easily be made as in the process of addition of concepts to meet some requirement for its specific use. This evaluation process constitutes a final evaluation of the constructed ontology before its release. More expert reports can be handled and expert opinions on ontology can be taken for further evaluation. However, evaluation of the ontology is limited to a level with the mentioned methods. Actual evaluation of the ontology can be done by active usage of the ontology in a company database and by the possible updates that would be required during its usage.

Ontologies and their evaluation methods is introduced in this study and exemplified with a delay analysis ontology and its evaluation process. It is believed that, ontology and its evaluation are always welcomed as long as they are supported with formal processes, and ontologies can be actually validated as long as they are actively used.

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