Digital Maturity of Higher Education Institution: A Meta Model of the Analytical Network Process (ANP) and Decision EXpert (DEX)*

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Abstract. *Digital maturity of higher education institutions (HEI) becomes more and more important as the influence of ICT grows. In this paper, the methods Analytic Network Process (ANP) and Decision EXpert (DEX) are presented and demonstrated in the example of domains for digital maturity of HEIs. The ANP is a quantitative method, DEX is a qualitative method and digital maturity level (DML) is a two-component combination of results for the two methods' application. Additionally, the ERA model of those methods combined to calculate two-component DML of HEIs is designed, and its process will be specified and evaluated in future research.*

Keywords. ANP, DEX, metamodeling, digital maturity, framework, higher education institutions

1 Introduction

This research is a part of wider study that aims to create an instrument to measure overall DML of a certain HEI. Here, the DML is modelled as a two-component measure. One component calculates the DML by application of ANP, and the other determines the DML by application of DEX.

A high-quality higher education institution (HEI) and research excellence are not possible without information and communication technology (ICT). ICT could be a foundation for brand new achievements in analysis and cooperative atmosphere. The employment and integration of ICT in learning, teaching, research and technology transfer contribute to digital maturity of HEIs. The conception of digital maturity is critical for HEIs that, thanks to the fast development of ICTs, have a growing need to develop new teaching and business processes to realize changes in society, the market and organizations (Kampylis, Punie, & Devine, 2015; SCALE CCR, 2012).

The qualitative analysis of the literature analysed several maturity models with the application in education and 16 digital maturity frameworks in education. The results of this analysis are established such that there is no developed comprehensive Digital Maturity Framework for Higher Education Institutions (DMFHEI) and Instrument for the Assessment of Digital Maturity of Higher Education Institutions (IADMHEI) (Đurek, Begičević Ređep, & Divjak, 2017).

In the development of DMFHEI and IADMHEI, a complex methodology was applied, together with a set of methods, techniques and instruments, including qualitative analysis and comparison of comparable frameworks for describing digitally mature organizations with strategic documents at the national and international level and analysis of existing project documentation. DEMATEL (Decision Making Trial and Evaluation Laboratory) (Shih-Hsi Yin, 2012), the ANP Method (Analytic Network Process) (Divjak & Ređep, 2015), the Q-sorting method (Watts & Stenner, 2005), focus groups (Hines, 2000), composite index (Hines, 2000), questionnaires and interviews were also used during the development phase. The qualitative analysis method, Q-sorting method, focus group, and Delphi method—as well as the content validation ratio method (Lawshe, 1975)—were used by experts in the field of HEI and digital technologies to identify and match the domains and elements of the DMFHEI.

The DMFHEI identifies seven areas, within which there are 43 elements. Due to space limitations, we are not able to show the elements and descriptors of all 43 elements. The questionnaire and interview methodology was used in the description phase of the DMFHEI section, the IADMHEI section, and the revision of the first version of DMFHEI and IADMHEI based on qualitative analysis and focus groups. Developed DMFHEI is the basis for strategic planning and decision-making in the application of digital technologies at HEIs based on relevant domain elements' maturity (Đurek i ostali, 2017).

Since digital maturity is a multicomponent concept, it is possible to analyse it through multi-criteria decision-making methods. Multi-criteria decision analysis (MCDA) is a discipline concerned with

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solving decision problems that include presumably conflicting criteria. MDCA employs a variety of methods to create preference models by using information provided by the decision maker (Figueira, Greco, & Ehrgott, 2005). During the research, information can be given in different forms and representations. Converting representations from one form to another is usually very welcome, as it can bridge the gap between different methodological approaches and enrich the capabilities of individual methods. The DEMATEL method, ANP method, composite index and DEX method were used in the development of IADMHEI and the methodology of calculating the digital maturity of the HEI. DEMATEL was used to structure and determine the relationship between the elements. ANP was used to determine the weighting coefficients of domains and elements in IADMHEI, and the composite index and DEX method (Bohanec, Žnidaršič, Rajkovič, Bratko, & Zupan, 2013) was used for the integration of estimation and determination of overall maturity level and for the needs of ranking a HEI.

In this paper, we will present a meta model of a quantitative method for multi-criteria decision-making. The Analytical Network Process (ANP)—and the qualitative multi-criteria decision-making method, Decision EXpert (DEX)—were both applied in the assessment of the digital maturity of higher education institutions (HEIs).

This paper is divided into the following sections: quantitative method Analytic Network Process in Section 2; Qualitative method Decision Expert in Section 3; Two-component measure of digital maturity level of HEI in Section 4; and meta model of ANP-DEX integration in a two-component measure of digital maturity level of HEI in Section 5. The paper concludes with a discussion about data and future research.

2 Analytic Network Process (ANP)

The method specific for decision-making and human judgment is the multiple criteria decision-making method the Analytic Network Process (ANP). ANP can be described as a method which decomposes decision problems into a network consisting of smaller parts (Saaty, 1999).

In the ANP methodology, the structure of the decision problem is bestowed as a network that presents a system of parts vital for the matter in question. The network can be expanded by introducing the relationships between groups of elements and feedback. The standard of connections depends on the outlined degree of mutual impact of the elements on individual parts. ANP is the extension of Analytic Hierarchy Process (AHP) (Saaty, 1999) that enables networks to be created from the hierarchy as an end result of the gradual enlarge in the quantity of hierarchical connections. The pair comparisons are made in reference to all mixtures of mutual connections between the factors and their groups (Saaty, 1999). The AHP is the most-used multi-criteria decision-making method in HEIs (Kadoić, Begičević Ređep, & Divjak, 2016). It is based on pairwise comparisons of decision-making elements. In pairwise comparisons, the Saaty scale is used. The scale consists of nine degrees (1–9). Value 1 means that two elements in the pair are equally important. Value 3 means weak domination of one element over other. Value 5 means strong domination of one element over other. Value 7 means very strong domination of one element over other. Value 9 means absolute domination of one element over other (Begičević, 2008; Saaty, 2008).

When pairwise comparisons are completed, the inconsistency ratio is calculated. There are four basic steps in the AHP (Begičević, 2008; Saaty, 2008). The first step is the creation of hierarchy structure, followed by the completion of pairwise comparisons of elements from the same level in the structure with respect to superior elements in the hierarchy. The third step is calculating the priorities, and the final step requires performing sensitivity analysis.

Network design is one of the most important steps of the method because it forces the decision maker to conduct a fundamental analysis of the problem. The design of the network in a decision problem is a key factor in finding an appropriate solution. There are no clear directions in the literature on how to design the network (Saaty & Vargas, 2006). To conclude ANP method, several steps have to be followed (Saaty & Cillo, 2008):

1. In the first step, identification of the components, network elements and their relationships should be done. This step can be divided into three basic tasks: identification of the network elements that are decision criteria and alternatives; grouping the elements based on some common feature; and finally, analyzing the relationships between network elements. The third task can be supported by using the DEMATEL method.

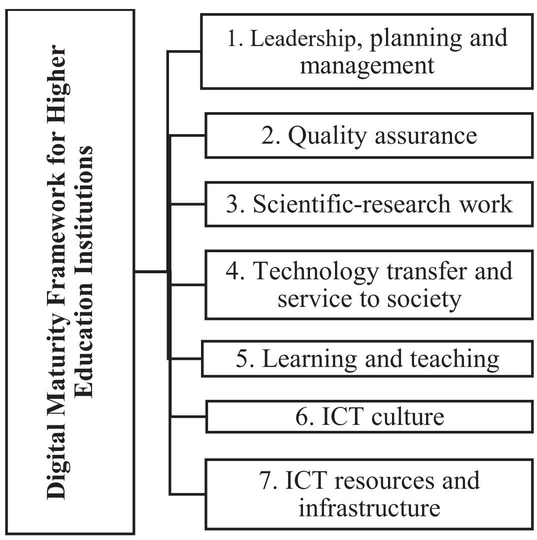

Figure 1. Network elements of DMFHEI

2. The second step consists of calculating the priorities between elements of the same cluster and determining which element is more influential and to what extent.

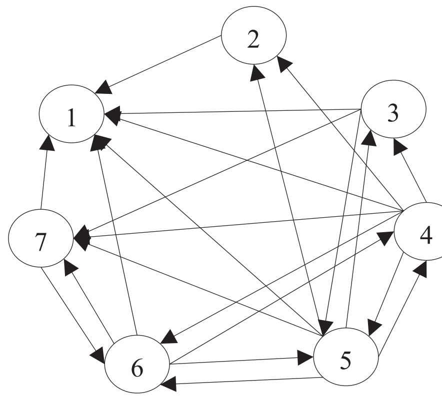

Figure 2. Relationships between network elements of DMFHEI (numbers 1-7 present the domains of DMFHEI in Figure 1.)

3. This step performs pairwise comparison matrices between clusters and calculates the priorities between clusters.
4. Next, it is necessary to do weighting of the unweighted supermatrix blocks using the priorities of each cluster, so that the resulting supermatrix, or *weighted supermatrix*, is column-stochastic.
5. The final step obtains the limit supermatrix where the elements of each column represent the final weightings of the different elements considered.

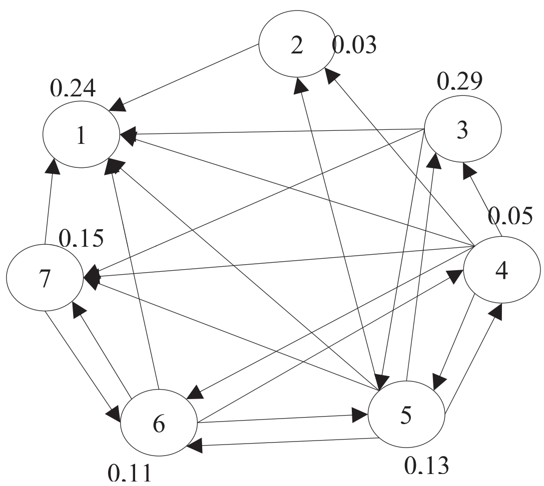

Figure 3. Weightings of the network elements of DMFHEI

The result of steps 2-5 are presented in Figure 3. The domain weights presented in the figure are only demonstrative.

Limitations of the ANP method include the high number of pairwise comparisons, lengthy implementation process, and high potential for misunderstanding some of the pairwise comparisons that have to be done. The complexity of the pairwise comparisons on the cluster level will also be decreased when integrating the ANP with the Decision-Making Trial and Evaluation Laboratory (DEMATEL) (Kadoić, Begičević Ređep, & Divjak, 2017; Đurek, Kadoić, & Begičević Ređep, 2018). This approach has been applied in the example of calculating the priorities of the DMFHEI (Figure 2). DEMATEL was used to identify the strongest relationships in the network that decreased the number of pairwise comparisons that had to be made. Inputs regarding the weights of influences between the domains, as well as the related pairwise comparisons, were obtained from managers of HEIs who participated in workshops organized under the scope of the Higher Decision project. The results are only demonstrative. For the complete research, level of elements (not only domains) also have to be included. Additionally, a higher number of respondents will be included in complete research.

3 Decision EXpert (DEX)

Decision EXpert (Bohanec i ostali, 2013) is a multi-criteria decision modelling method. The DEX method is a qualitative, multi-criteria decision analysis approach that provides support to decision makers in evaluating and choosing decision alternatives by using discrete attributes and rule-based utility functions (Mihelčić & Bohanec, 2017).

The DEX method consists of a set of decision alternatives that are fundamental for the evaluation and analysis. Alternatives are described with a set of variables called attributes, which represent some observed or evaluated property of alternatives (Bohanec i ostali, 2013).

DEX is a hierarchical method, meaning the attributes are organized in a hierarchy that represents a decomposition of the decision problem into sub-problems. The bottom-up direction denotes dependence, so that higher-level attributes depend on the lower-level, more elementary ones. The most elementary attributes—called basic attributes—appear as terminal nodes of the hierarchy and represent the basic observable characteristics of alternatives. Higher-level attributes, which depend on one or more lower-level ones, are called aggregated attributes that represent evaluations of alternatives. The topmost nodes (usually, there is only one such node) are called roots, and they represent the final evaluation(s) of alternatives (Mihelčić & Bohanec, 2017).

Furthermore, DEX is a qualitative method. While most of MCDM methods are quantitative and thus use numeric variables, qualitative methods use symbolic ones. In DEX, each attribute has a value scale that is represented with some ordinary word, such as ‘low’, ‘medium’, ‘high’ and ‘very high’. Scales are usually small, containing two to five values, and scales are also usually preferentially ordered. Attributes that have preferentially ordered scales are called criteria (Figueira i ostali, 2005). Finally, DEX is a rule-based method. The bottom-up aggregation of alternatives' values is defined in terms of decision rules, which are specified by the decision maker.

In this paper we will present the DEX method in three steps using the two domains (Technology transfer and service to society and Scientific-research work) of DMFHEI due to space limitation (Bohanec et al., 2013):

1. Creating a hierarchical tree – the decision-making problem is modelled through a decision tree that can be interpreted in three ways: decomposition, dependence and aggregation. A qualitative scale is defined for each tree element. The scale consists of several elements. On the leaf level of tree, there are many criteria, which are being aggregated to one goal at the root of the tree. Hierarchical tree for case of domains of digital maturity is given in Figure 1. There are 7 elements on the leaf level that are aggregated into one element at the root. Like being said in ANP section, this is only a demonstrative example, because real leaves (elements of the maturity model) are not currently included in the research.
2. Decision rules – decision-making rules represent the basic mechanism of conclusion and decision-making in the DEX method (Mihelčić & Bohanec, 2017). At the elementary level, there are uniquely measurable criteria for each alternative to the scale of each criterion on the list. Presented case values that are used include: low and high (Table 1). Functions are defined at the level of aggregated criteria (low, medium, high) and at root level decisions that describe which value will take the criterion (on its scale) for each combination of criteria values from the level below (low, medium, high).

Table 1. Domain values

Domain	Value 1	Value 2
1.Leadership, planning and management	low	high
2.Quality assurance	low	high
3.Scientific-research work	low	high
4.Technology transfer and service to society	low	high
5.Learning and teaching	low	high
6.ICT culture	low	high
7.ICT resources and infrastructure	low	high

Figure 4 represents the decision rules of DMFHEI. Columns represent the DMFHEI domain, which are presented in Figure 1. In the presented case, it is necessary to make 128 decision rules.

	1	2	3	4	5	6	7	DMFHEI
1	low	low	low	low	low	low	low	low
2	low	low	low	low	low	low	high	low
3	low	low	low	low	low	high	low	low
4	low	low	low	low	low	high	high	low
5	low	low	low	low	high	low	low	low
6	low	low	low	low	high	low	high	low
7	low	low	low	low	high	high	low	low
8	low	low	low	low	high	high	high	medium
9	low	low	low	high	low	low	low	low
10	low	low	low	high	low	low	high	low
11	low	low	low	high	low	high	low	low
12	low	low	low	high	low	high	high	medium
13	low	low	low	high	high	low	low	low
14	low	low	low	high	high	low	high	medium
15	low	low	low	high	high	high	low	medium
16	low	low	low	high	high	high	high	>=medium

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	1	2	3	4	5	6	7	DMFHEI
57	low	high	high	high	low	low	low	medium
58	low	high	high	high	low	low	high	>=medium
59	low	high	high	high	low	high	low	>=medium
60	low	high	high	high	low	high	high	>=medium
61	low	high	high	high	high	low	low	>=medium
62	low	high	high	high	high	low	high	>=medium
63	low	high	high	high	high	high	low	>=medium
64	low	high	high	high	high	high	high	>=medium
65	high	low	low	low	low	low	low	low
66	high	low	low	low	low	low	high	low
67	high	low	low	low	low	high	low	low
68	high	low	low	low	low	high	high	medium
69	high	low	low	low	high	low	low	low
70	high	low	low	low	high	low	high	medium
71	high	low	low	low	high	high	low	medium
72	high	low	low	low	high	high	high	>=medium

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	1	2	3	4	5	6	7	DMFHEI
113	high	high	high	low	low	low	low	medium
114	high	high	high	low	low	low	high	>=medium
115	high	high	high	low	low	high	low	>=medium
116	high	high	high	low	low	high	high	>=medium
117	high	high	high	low	high	low	low	high
118	high	high	high	low	high	low	high	high
119	high	high	high	low	high	high	low	high
120	high	high	high	low	high	high	high	high
121	high	high	high	high	low	low	low	>=medium
122	high	high	high	high	low	low	high	>=medium
123	high	high	high	high	low	high	low	>=medium
124	high	high	high	high	low	high	high	>=medium
125	high	high	high	high	high	low	low	high
126	high	high	high	high	high	low	high	high
127	high	high	high	high	high	high	low	high
128	high	high	high	high	high	high	high	high

Figure 4. Decision rules for DMFHEI (domain level)

3. Once a hierarchical model has been created, and after the rules of decision are defined, the final step is evaluation of alternatives. Once the alternatives are evaluated, mutual comparison determines which is the best. The input values of the alternatives by individual criteria are determined by discretization of the continuous value space. This process can be done in following ways:

a. The first approach that can be used is the threshold. Values above the threshold assign the best qualitative value to criterion scale (high). The interval below the threshold is divided into several equal intervals (depending on the scale criteria) that frame the scale's criterion values. The threshold is often defined in a way that 1% or 10% of the best alternatives meet the highest criterion value. This is done for each criterion separately.
b. The second approach of discretization is based on the calculation of the percentile, and the values belonging to the 25 – 75 percentiles are classified as "middle" on the criterion scale.

The third step of the DEX method is presented in Table 2 in two examples of HEI.

Table 2. Evaluation of alternatives

Options	HEI1	HEI2
DMFHEI	medium	medium
Leadership, planning and management	high	high
Quality assurance	high	high
Scientific-research work	low	high
Technology transfer and service to society	high	high
Learning and teaching	low	high
ICT culture	low	low
ICT resources and infrastructure	high	high

Table 2 contains examples of two HEIs and their values on domain level. They are related to two of 128 decision rules from Figure 4, and in both cases the total DML is *medium*.

4 Two-component Measure of Digital Maturity Level of HEI

In the process of designing the framework and instrument for determining the digital maturity level (DML) of HEIs, it was decided that the digital maturity level would incorporate two components:

- The first component is quantitative, and it is a result of application of the ANP method.
- The second component is qualitative, and it is a result of application of the DEX method.

There are several reasons for DML to be a two-component measure:

- Some aspects of the digital maturity framework are qualitative, and some aspects are quantitative.
- Applying two methods acts as a sort of control, or at least a comparison mechanism, in determining the DML of HEI. For example, the ANP can result in a high quantitative value of DML. Then, if DEX offered a low qualitative value, further analysis would be mandatory.
- The two methods, ANP and DEX, have different aggregation mechanisms, and it is possible that when certain HEIs have a *very low* value on some element and others are *high*, then (1) quantitative DML values obtained by ANP will be *just a bit lower than the high* value, but (2) qualitative DML values obtained by DEX can be *low* because starting *very low* value on some element can overcome through hierarchy.
- ANP and DEX complement each other.

5 Meta model of ANP-DEX Integration in Case of Two-component Measure of Digital Maturity Level of HEI

The modelling paradigm is one of the most important concepts for realizing the enterprise-wide integration. The model is a simplification of the reality—a blueprint of a system. As the result of an abstraction process, the model reflects the general, essential and permanent features from the modelling target's view, and it serves as a formal specification to describe the functionality, structure, and/or behaviour of the system.

A good model includes elements that have broad effects and omits minor elements irrelevant to the given level of abstraction. As the reality is very complex, it may be described from different aspects—what we call "model views"—being semantically closed abstractions of a system. The highest level of the abstraction is the metamodeling level (Raffai, 2008).

Most generally, metamodeling is the analysis, construction and development of the frames, rules, constraints, models and theories applicable and useful for the modelling in a predefined class of problems. This concept is composed with the notions of the terms meta and modelling. Thus, metamodeling is the construction of a collection of concepts within a certain domain, a precise definition of the constructs and rules needed for creating semantic models. As a model is an abstraction of real world phenomena, a metamodeling is yet another abstraction, highlighting properties of the model itself in the form of an abstract language for defining different kinds of metadata.

Authors (Vangheluwe & de Lara, 2002) describes modelling as a complex systems of difficult task, with components and aspects whose structure as well as behaviour cannot be described in a single comprehensive formalism. The term metamodel, actually means "model modeling language". The "meta" prefix indicates again that it is a concept at a higher abstraction level than the modeling language itself. Metamodel can provide ways to describe abstract syntax, specific syntax or semantics of a language.

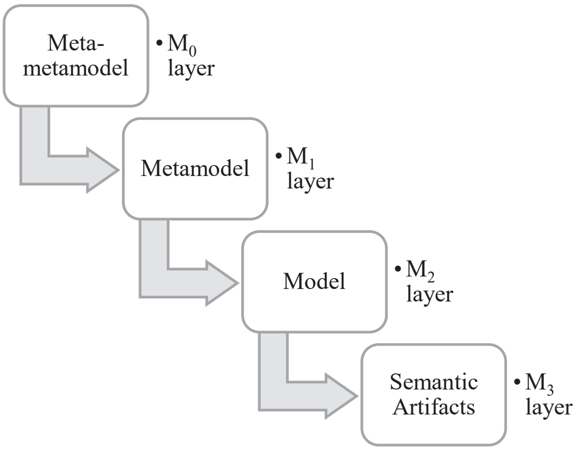

***Figure 5**: The four-layer metamodeling architecture*

The Object Management Group (OMG) is an independent organization that focuses on issuing standards specifically related to modeling of programs, business processes, information systems, etc. Their most famous and best-used specification is the Unified Modeling Language (UML) specification. In its concept of "Model-driven Architecture" (MDA) - one of the foundations and the very language of the UML - the OMG group proposes a four-grade meta-architecture (Figure 5) that can accommodate languages according to their own characteristics, provide these other languages with which they may be linked in some way (Karsai, Nordstrom, Ledeczi, & Sztipanovits, 2000), (J. Sprinkle, 2004), (Jonathan Sprinkle, Rumpe, Vangheluwe, & Karsai, 2010).

Level M_0 is the data itself. These can be objects in the program language, ranks in tables in the database, etc. Level M_1 contains a "model" of data at level M_0. In the case of object, programming languages at M_1 level are templates of objects, ie classes. If the database management system at level M_1 is a table definition, the data is stored (eg. SQL DDL commands). At this level, you can also find the entity-connection pattern of a system. At M_2 level, there are metamodels, ie languages that provide the model syntax. Finally, the M_3 level is the meta-metamodel level. What is important to note is that elements of higher metalevels provide building blocks for the definition of lower-level elements. When choosing a way to model a system, the most common choice is to select a language at M_2 level; this choice dictates how the system's systems look like which elements to contain, what limitations will be available and what purpose the model ultimately has. By selecting a language at level M_2, it can be started with M_1 modeling and final implementation at level M_0. OMG defined M_3 level language and called it Meta-Object Facility (MOF). The language is recursively descriptive; it can itself be described with the help of the elements it defines, thus solving the problem of the existence of higher metalevels. The MOF language represents the generic starting point for building blocks that can be used to define M_2-level languages.

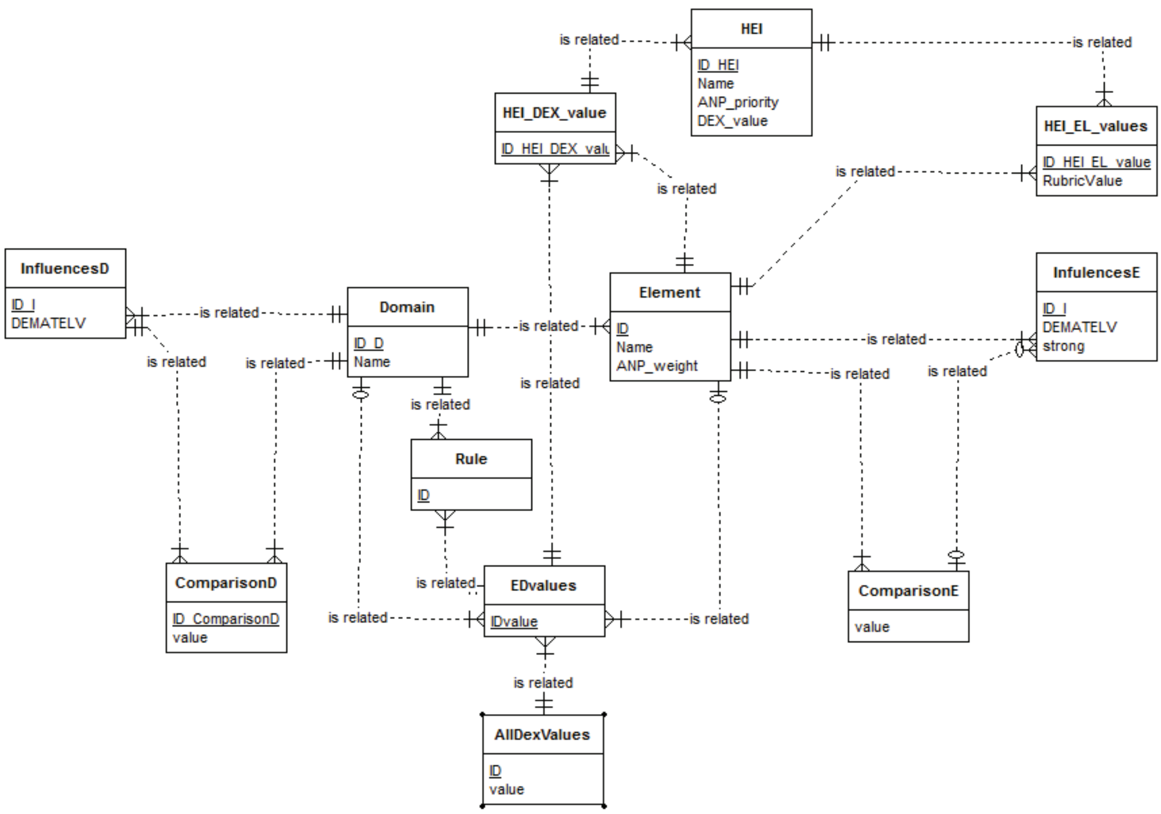

Figure 6. ERA model of ANP-DEX integration in case of two-component measure of DML of HEI

As a part of this paper, we prepared an ERA model of an ANP-DEX integration in a case of two-component measure of the digital maturity level of HEIs. The ERA model contains data about entities (tables), relationships between entities and attributes of entities.

The model is presented in Figure 6. The model consists of several entities:

1. Domain – contains data about domains from DMFHEI and their descriptions
2. Element – contains data about elements of all domains. After the ANP is applied, finale element weights will be written into table
3. Rule – contains all rules defined in the DEX method on the domain and root levels
4. EDvalues – contains possible values that can be achieved in certain element, domain and on the root level
5. AllDexValues – contains list of all possible values (elements, domains and root)
6. InfluencesE – contains data about the influences between criteria identified by using the DEMATEL scale
7. ComparisonE – contains data about the pairwise comparisons between elements with respect to other elements
8. ComparisonD – contains data about the influences between domains identified by using the DEMATEL scale
9. InfluencesD – contains data about the pairwise comparisons between domains with respect to other domains
10. HEI – contains data about HEIs and their priorities obtained by applying the ANP method, as well as results obtained by applying the DEX method (two-component result of DML)
11. HEI_Dex_value – contains data about values achieved by HEIs in terms of each element of the DEX hierarchy
12. HEI_El_value – contains data about all values that are achieved by HEI in terms of each ANP element. In this situation, the rubric will be used as a data collecting method. The rubric consists of five values per element described through statements previously evaluated by experts.

Entities 1-5 and 11 are related to the DEX. Entities 6-9 are related to the ANP. Entity 10 is related to the ANP-DEX integration. The entities are connected according to the relationships shown in Figure 6. In the phase of creating the software that will support ANP-DEX integration, it is possible that some changes in ERA have to be implemented. Besides possible changes, functions that support data collecting and ANP and DEX application have to be implemented as well.

6 Conclusion

This paper proposes a design for the two-component digital maturity level of certain HEIs. This is a different approach than currently known methods used in developing different frameworks and instruments related to concepts of *readiness* and *maturity*. This approach has some advantages, as described in the paper. Two-component design is modelled using the ERA model.

In future research, it is planned that experts from the field of digital maturity of HEIs and members of HEI management will give their inputs related to weights of influences between elements and domains, pairwise comparisons of elements and domains, elements and domains DEX values and design of decision-making rules in the DEX method. After that, element weights will be calculated.

In the evaluation phase, the IADMHEI will be applied at several HEIs in Croatia, and results will be compared to digital maturity of HEIs obtained by qualitative analysis. Ultimately, it will be possible to determine the two-component DML of Croatian HEIs.

Besides in the HEI digital maturity level area, this two-component approach can be applied in other contexts that are related to the investigating the readiness or maturity. Additionally, this approach can be generally applied in multi-criteria decision making.

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