Construction and application of hierarchical socioeconomic decision models

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The article presents a utility of multi-attributed hierarchical modelling approach to represent, analyze and study socioeconomic processes. The models are based on criteria tree for which the expert specifies the utility functions. The specific advantages of the approach are structuring the problem domain, a relative ease to build the models and the existence of underlying tools for comparative and what-if type of data analysis. We use these tools to construct two socioeconomic models, one for assessment of country's knowledge infrastructure and the other one for assessment of quality of political and economic system. We demonstrate the utility of these two models through experimental application in the analysis of real-world data from Word Competitiveness Yearbook.

1 Introduction

A determined orientation of the developed countries to foster the growth of information infrastructure that will allow their transition to information society [7] shows that we are undergoing a period that will exert a decisive influence on their future development. This is also or even more true for the Central European countries like Slovenia, Czech Republic, and Poland where the change of the political, economic, and legal system is the basis for their gradual transition to a modern society and their prospective integration within European Union.

In order to monitor and evaluate such transition, compare countries' successfulness, and investigate for the alternative development scenarios, one may benefit from models that assess the value of country's system given a selection of its *observable criteria*. A well-known example of such approach has been carried out by International Institute for Management Development (IMD), a non-profit foundation from Lausanne, Switzerland. IMD systematically collects different criteria from over 40 world-wide countries (roughly one half of them being OECD members and another half being newly industrialized and emerging market economies), resulting in a yearly report called The World Competitiveness Yearbook (see, for example, [6]; in this article we will refer to as Yearbook).

Each Yearbook normally includes more than 200 criteria, of which about two thirds present measurable quantities (*e.g.* GDP, unemployment, *etc.*), while the other third is obtained from the Executive Opinion Survey. Different aspects of world competitiveness are described by eight *factors* (like Domestic Economy, Government, Finance, *etc.*) which are derived from observable criteria. To organize the criteria further, each factor includes several criteria subgroups — in this tree-like three-level structure (Figure 1), each criterion belongs to a single subgroup, and consequently to a single factor.

Factor and factor subgroups thus represent an aggregation of the observable criteria. The observable criteria are first scaled, and then weighted and summed to obtain the value of their corresponding factor subgroup (see [6] for details). Finally, factors are computed as the sum of their corresponding factor subgroups. The country's data is then analyzed by presenting country's rank when considering each of the criteria, subgroups or factors. The advantage of IMD's approach lies in the high number of quality criteria being gathered, and providing a simple two-level structure in which these criteria are aggregated and studied. The disadvantage, however, is that the criteria aggregation by means of weighted sum may be over-simplistic as it does not take into consideration any potentially more complex criteria interaction. Furthermore, IMD's evaluation procedure that assigns all measurable criteria an equal weight of 1 and all the survey criteria an equal weight of about 0.9 may be too restrictive as it would be expected that different criteria are differently important (relevant). And finally, the Yearbook is in a sense static and calls for a computer-supported environment that would allow an interactive use of underlying evaluation model, supporting the decision making in terms of what-if and comparative analysis.

Crucial to the utility of such computer-supported models is their ability not only to reach a valid and (hopefully) accurate conclusions, but also to explain why such conclusion were reached [11, 10]. The modeling methodology should provide grounds for explorative analysis of alternatives being evaluated, making the model and decision support envi-

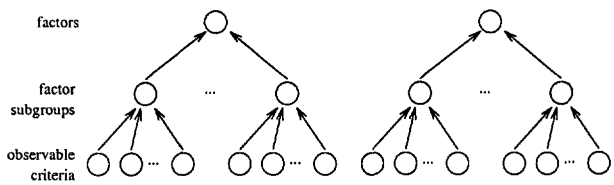


Figure 1: General systematization schema for criteria used by IMD.

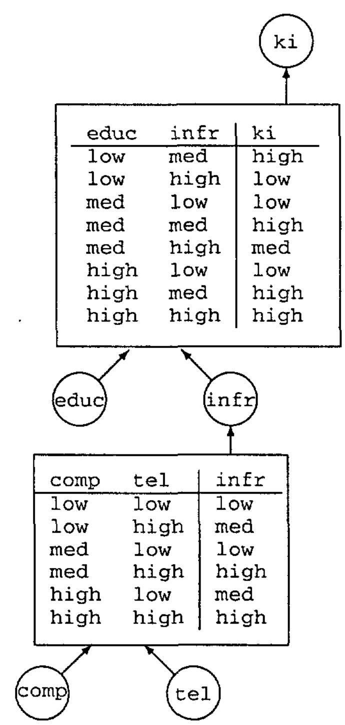
ronment a valuable tool for decision expert. In these terms, classical numerical decision models that are based on criteria weighting [5] may be inadequate and pose problems where modeling a more complex interdependence of criteria is required [3]. This article builds on alternative approach for multi-attribute decision making that hierarchically organizes the criteria in the criteria tree and introduces new aggregate criteria. The aggregate criteria simplify utility function elicitation and play major role for explorative analysis. The approach was first proposed by Efstathiou and Rajkovič [8] and subsequently used in many applications, including the evaluation of R&D projects [3], evaluation of applications for nursery schools [14], priority ranking of applications for housing loans [1], portfolio analysis [9] and strategic planning [16]. In this article, we refer to its implementation in an expert system shell for decision support DEX [2].

Compared to IMD's three-level (criteria-subgroups-factors) criteria tree, we define models that have arbitrary number of layers, and refer to all internal nodes of the trees as *intermediate criteria* and the root of the tree as *target criteria*. Intermediate and target criteria are also referred to as *aggregated criteria*, as their value is computed from other underlying criteria rather than provided as an input to the model. The leaves of the trees represent criteria selected from those defined in the Yearbook — we refer to them as *basic criteria*. Using this terminology, the IMD's criteria subgroups are intermediate, and factors are target criteria. We propose two different models, one for *Knowledge infrastructure* and one for *System* target criteria.

The article is organized as follows. Section 2 introduces DEX paradigm for hierarchical multi-attribute decision models. DEX-based socioeconomic models for Knowledge infrastructure and the Quality of Political and Economic System are presented in Section 3. Section 4 illustrates the benefits of the DEX methodology through using the two socioeconomic models for tasks such as what-if and comparative analysis for the countries and data from the Yearbook, as well as for Slovenia — a country at the time of the writing of this paper not (yet) enlisted in the Yearbook but interesting since being a country in transition. Section 5 summarizes the results and concludes the article.

2 Hierarchical multi-attribute decision models

Hierarchical multi-attribute decision models as used by DEX consist of *criteria tree* and *utility functions*. Figure 2 shows a simple decision model — constructed only for illustrative purposes — to assess the quality of country's knowledge infrastructure from the quality of education, telecommunication network and computer deployment. Knowledge infrastructure (`ki`) is the *overall utility* or a *target criterion*, located at the root of the tree, that is modeled and derived from a set of *basic criteria* which are found at leaves of the criteria tree and which include the level of general education (`educ`), the quality of telecommunication network (`tel`) and the level of computer deployment (`comp`). The basic criteria are those that can be measured and/or obtained for specific country. The criteria tree also includes an internal node, which is an *intermediate criterion* that assesses the quality of technical infrastructure (`infr`). Both `ki` and `infr` are also referred to as *aggregated criteria*, as their value is determined from the values of other criteria in the criteria tree (*e.g.*, `infr` from `comp` and `tel`, and `ki` from `educ` and `infr`). The aggregated criteria are those that can not be directly observed or measured, but are besides the target criterion useful to be modeled. For the real-world problems, a criteria tree would include several aggregated criteria, depending on a complexity of the domain being modeled.



educ	infr	ki
low	med	high
low	high	low
med	low	low
med	med	high
med	high	med
high	low	low
high	med	high
high	high	high

comp	tel	infr
low	low	low
low	high	med
med	low	low
med	high	high
high	low	med
high	high	high

Figure 2: A simple decision model with three basic criteria (`educ`, `comp`, `tel`) and one intermediate criterion (`infr`).

DEX uses qualitative criteria, *i.e.*, every criterion in the criteria tree is assigned a finite value domain. In our case, the value domain for `ki`, `educ`, and `comp` is {`low`, `med`, `high`} and the value domain for `tel` is {`low`, `high`}.

Utility functions are used to compute the value of aggregated criteria. DEX utility functions use so-called *if-then decision rules*, where each rule includes a specific combination of values for criteria entering the criteria function (the *if* part) and associated utility (the *then* part of the rule). These rules can then be represented with *utility table*. For example, in Figure 2, the utility function for `infr` specifies that when `comp` is `low` and `tel` is `low`, the value of the technical infrastructure is `low` (the first line in the utility table). Differently, when `comp` is `med` and `tel` is `high`, the value of `infr` is `high` (the fourth line in the utility table).

Within DEX, the rules in utility tables are defined manually, most often in a setup where a domain expert collaborates with a knowledge engineer. Once a sufficient number of the rules for some aggregated criteria have been entered, DEX assists in the elicitation of the new rules by proposing a viable set of values of the corresponding aggregated criteria. The complete process of defining the criteria structure and utility tables typically takes from one to five days, where a definition of criteria tree is often a more demanding task.

DEX models are evaluated from bottom up, starting at the aggregated criteria that depend solely on basic criteria to finally derive the overall utility. For our model from Figure 2, aggregated criterion `infr` is evaluated first based on criteria `comp` and `tel`, and then the overall utility `ki` is obtained from the values of `educ` and `infr`. For example, given the values of basic criteria for the two countries A and B from Table 1, the same Table shows the derived value of the intermediate criterion and the overall utility.

3 Socioeconomic models for knowledge infrastructure and the quality of political and economic system

Using DEX modeling paradigm, we have developed two different socioeconomic models, the first one modeling the level of the knowledge infrastructure (Knowledge infrastructure model) and a second one the quality of political and economic system with respect to their support of the economy and business (System model). Each model uses a separate set of basic criteria taken from the World Competitiveness Yearbook (Table 2).

The Knowledge infrastructure target criteria (KI) represents the level of development of knowledge infrastructure to support business and economic development. The KI model employs the criteria hierarchy as given in Figure 3. The model incorporates the utilization (IT_USAGE) and level of development of information technology (TEC_INFRA) and the quality of education (EDUCATION). The general education with regard to IT depends on computer literacy (C_LIT) and the overall quality of general education (GEN_EDUCATION). The development of technological infrastructure is estimated from diffusion of computers (C_INFRA) and the state of development of telecommunications (TELECOMM), which in turn depends on the current level and development potential of telecommunication infrastructure (TEL_INFR_INV) and accessibility and diffusion of telephones (TELEPHONES).

The quality of political and economic system in regard to their support of the economy and business is modeled as a target criteria SYSTEM. Its dependency on intermediate and basic criteria is outlined in a criteria tree shown in Figure 4. The value of the SYSTEM depends on the quality of government and economic system (QUAL_GOV_ECON), which aggregates the value of economic system and policies (ECONOMIC) and quality of government with respect to the support economy (GOV_QUALITY) and on the quality of politics and public trust (QUAL_POL). The later aggregates the values of quality of system and policies (POLITICAL) and the value of public trust to the current political system (TRUST). In its quality of government subtree, the model includes also the aggregated criteria that estimate the impact of lobbying (LOBBYING) and the government effectiveness and openness (EFFECT).

The knowledge infrastructure model uses 12, while the model for system uses 15 basic criteria. Each basic criterion has a domain of four values labeled "1" to "4", where "1" denotes the "worst" value of the criterion, *i.e.*, the one that has a negative influence to the value of the target criterion, and "4" denotes the "best" value of the criteria, again with respect to the influence to the target criteria. In this sense, the criteria values are nominal and ordered. The same domain definition was used for all aggregated criteria.

Together, the two models define 17 aggregated criteria. Presenting all utility functions defined is beyond the scope of this article, and for illustrative reasons we provide only an example. Consider thus one of the utility functions for knowledge infrastructure model that aggregates the value of educational system (EDUC_SYS) and in-company training (TRAINING) to the value of aggregated criteria for general education (GEN_EDUCATION, see Table 3). The utility function defines all 16 possible combinations of values for EDUC_SYS and TRAINING. For example, consider the rule number 7, which states that the value of general education level is 3 if the quality of educational system is 3 and in-company training is 2. We found that this pointwise definition of utility functions provides means to straightforward elicitation of knowledge from experts, since the experts find relatively easy to answer concrete questions (such as, "what is GEN_EDUCAT if the level for EDUCAT_SYS is 3 and TRAINING is 2"). Pointwise definition allows for defining non-linear functions. For example, in the function for GEN_EDUCAT the outcome never exceeds 2 if one of the input criteria (EDUC_SYS and TRAINING) has the value of 1. Non-linearity in the aggregate function for GEN_EDUCAT is

	Basic criteria			*Aggregated criterion*	*Overall utility*
Option name	educat	comp	tel	infra	ki
Country A	med	low	low	low	low
Country B	high	high	low	med	high

Table 1: Evaluation results for countries A and B

Knowledge infrastructure	
MANAG_IT	Management of information technology: utilization of and familiarity with information technology by management
IT	Information technology: exploiting by companies
C_LIT	Computer literacy among employees
EDUC_SYS	The educational system: educational system meets the needs of competitive economy
TRAINING	In-company training: investing of companies in training of their employees
C_USE	Computers in use: share of worldwide computers in use
C_PC	Computers per capita: number of computers per person
INF_REQ	Infrastructure requirements, Telecommunications: Extend to which infrastructure meets business requirements
TEL_INFR	Telecommunications infrastructure
INVEST	State investments in telecommunications
TEL_LINES	Telephones: number of main lines in use per 1000 inhabitants
TEL_COST	International telephone costs

System	
INTERF	State interference: State interference does not hinder the development of business
SUBSID	Subsidies: Government subsidies are directed towards future winners
CONTROL	Control of enterprises: State control of enterprises does not distort fair competition in the country
IMP_PRACT	Improper practices (such as bribing and corruption)
EXTENT	Lobbying: Extent to which lobbying accelerates government decision making
INT_GROUPS	Lobbying by special interest groups
RESPONS	Government responsiveness: Ability to quickly adapt policies to new realities
DECENTRAL	Administrative decentralization: Decision-making independence of local/regional authorities from central government
PUB_SEC	Public sector contracts: openness to foreign bidders
POLICIES	Government economic policies: Extend to which government adapts its policies to new realities effectively
ADAPTATION	Political system: Extend to which political system is well adapted to today's economic challenges
TRANSPAR	Transparency of government towards citizens
POL_RISK	Political risk rating
GOV_POL	Government policies: Supporting by public consensus
SUPPORT	Public consensus and support for economic policies

Table 2: List of basic criteria used by Knowledge infrastructure and System model, respectively.

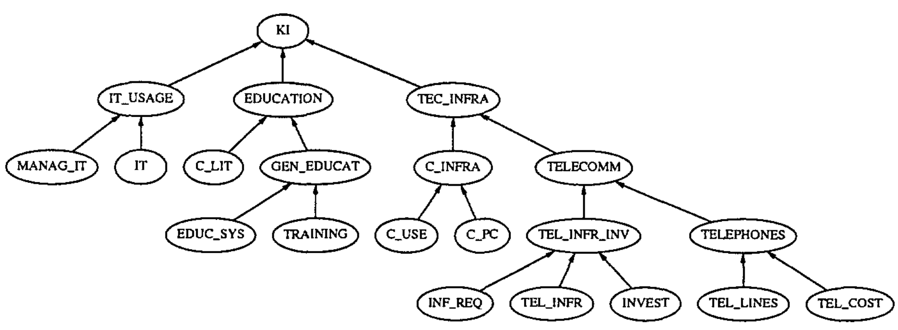


Figure 3: Criteria hierarchy for Knowledge infrastructure model.

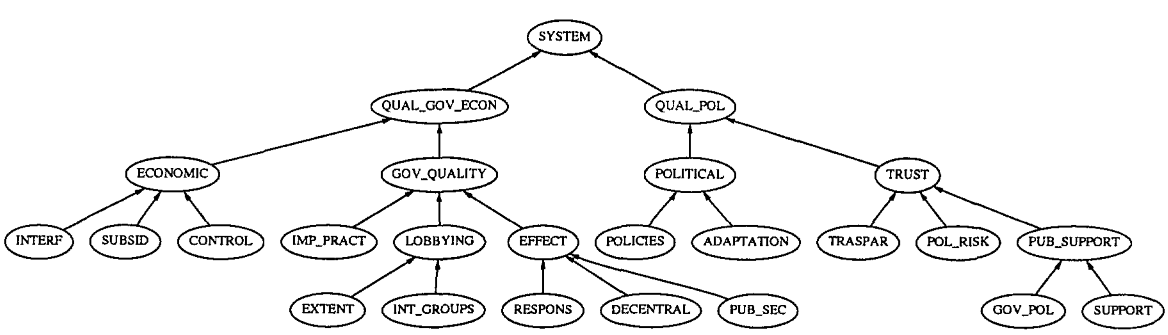


Figure 4: Criteria hierarchy for System model.

rule #	EDUC_SYS	TRAINING	GEN_EDUCAT
1.	1	1	1
2.	2	1	1
3.	3	1	2
4.	4	1	2
5.	1	2	1
6.	2	2	2
7.	3	2	3
8.	4	2	3
9.	1	3	2
10.	2	3	3
11.	3	3	3
12.	4	3	4
13.	1	4	2
14.	2	4	3
15.	3	4	3
16.	4	4	4

Table 3: An example of a utility function defined within the knowledge infrastructure model.

also evident from a graphical presentation of decision rules (Figure 5).

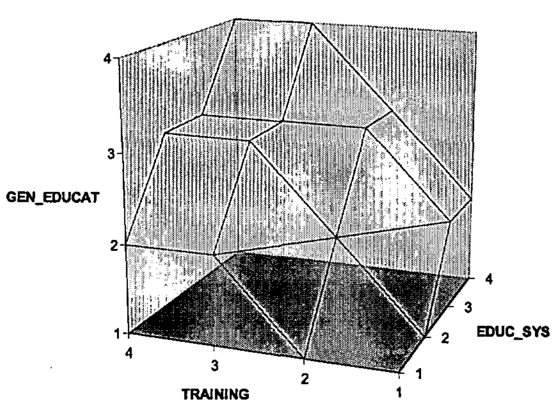


Figure 5: A graphical presentation of utility function from Table 3.

The pointwise definition of utility functions follows a case-based human way of thinking and as such implicitly states the relevance of each of the criteria. In practice, besides requiring linear relationships between input and aggregated criteria, eliciting explicit weights from the expert is usually a difficult task, as it forces the expert to think in more abstract way [2]. Note that not all of these were manually defined by expert, since DEX incorporates a mechanism that, based on the currently entered rules, provides suggestions for the rules not defined. In practice, we needed to define only about one half of the rules in utility functions for the two socioeconomic models — for the other half the expert most often accepted the suggestions provided by DEX.

4 Socioeconomic models in use

To demonstrate the applicability of the models defined in the previous section, we have first prepared the data set to be used. The models were built such that their set of basic criteria was taken from the list of criteria included in the World Competitiveness Yearbook (WCY, [6]). Obviously, the data of the countries included in WCY constitutes our basic data set.

For each of the criteria from WCY, the values were first ordered such that low values would potentially lower the model's outcome (final criterion) and that high values would increase it. Since DEX models require criteria to be qualitative (*i.e.*, "1", "2", "3", and "4"), the criteria values needed to be discretized. Discretization used quantiles, such that each resulting qualitative value would represent roughly the same number of countries for that criterion. Note that in this setup the qualitative values of criteria can also be interpreted as: "1" as "low", "2" as "below average", "3" as "above average", and "4" as "high".

The models developed can be used in a number of different ways. First, the models and their utility functions may provide additional insight to the domains. Next, the models can be used to evaluate the countries' data and derive corresponding values for aggregated and final criteria. The differences between two or more countries can then be studied by means of graphical comparison of criteria values. Finally, a specific country may be studied to see the effect of changing the values of basic criteria and studying its good and bad points.

4.1 Analysis of the model

The decision model as such can be analyzed locally by inspecting each of the defined utility function or globally by observing the overall impact of basic criteria on the target criterion. For the first task, DEX provides several tools. First, the utility functions can be visualized by selecting two input criteria and observing the output of aggregated function (see Figure 5 for an example). Another interesting DEX's tool is construction of aggregated rules from the set of elementary rules. For instance, an example of utility function that represents the function from Table 3 but is expressed by aggregated rules is given in Table 4. Note that instead of 16 there are just 9 rules required to define the aggregated criteria GEN_EDUCAT. Also, the utility function is much easier to comprehend. For example, from the last rule it is easy to see that GEN_EDUCAT can reach the highest value (4) only when EDUC_SYS is 4. Furthermore, the first two rules indicate that GEN_EDUCAT is 1 whenever one of the input criteria is 1 and the other less than or equal to 2.

We have further used both socioeconomic models to estimate the relevance of basic criteria to the value of the target criteria. For these, from each model a dataset was constructed that consisted of only basic criteria values and corresponding value of a target criterion. We have arbitrarily sampled each model with about 2000 such "data points", and then used the *information measure* (IM) score as defined in [13] to estimate the relevance. IM was originally used in recursive partition algorithms for decision tree induction to identify most appropriate (*i.e.*, important) criteria for decision tree nodes [15]. The criterion importance

agg. rule #	EDUC_SYS	TRAINING	GEN_EDUCAT
1.	1	≤2	1
2.	≤2	1	1
3.	≥3	1	2
4.	2	2	2
5.	1	≥3	2
6.	3	≥2	3
7.	≥3	2	3
8.	2:3	≥3	3
9.	4	≥3	4

Table 4: An example of aggregated rules for utility function from Table 3.

rank	criterion	IM
1	MANAG_IT	0.2200
2	C_LIT	0.1297
3	EDUC_SYS	0.0694
4	TRAINING	0.0618
5	IT	0.0576
6	TEL_LINES	0.0201
7	C_PC	0.0174
8	INF_REQ	0.0164
9	TEL_COST	0.0102
10	TEL_INFR	0.0097
11	C_USE	0.0043
12	INVEST	0.0033

rank	criterion	IM
1	CONTROL	0.1526
2	INTERF	0.1463
3	SUBSID	0.1404
4	IMP_PRACT	0.0438
5	POLICIES	0.0351
6	EXTENT	0.0263
7	PUB_SEC	0.0202
8	RESPONS	0.0186
9	ADAPTATION	0.0125
10	DECENTRAL	0.0092
11	INT_GROUPS	0.0059
12	GOV_POL	0.0054
13	SUPPORT	0.0052
14	POL_RISK	0.0019
15	TRASPAR	0.0012

Table 5: Ranking of basic criteria from Knowledge infrastructure (above) and System (below) model.

is assessed in independence of the other basic criteria: only the relationship with the target criterion is observed.

For the two socioeconomic models, the basic criteria are ranked according to their importance in Table 6. For knowledge infrastructure model, the three most important basic criteria are management of information technology, computer literacy and the value of education system. The three most important criteria from the System model are the control of enterprises, the level of state interference, and government subsidies. These results in general meet experts' intuitive expectations.

4.2 Comparative data analysis

The Knowledge infrastructure and System models were used to derive the value of the corresponding target criteria (KI and SYSTEM, respectively). Although DEX can be used for this task, another system called Vredana [17] was employed instead. Besides graphical presentation, the unique feature of Vredana is that it can evaluate each country not only to a single qualitative value of the target criterion, but can also estimate country's relative position within this range. For example, consider that the two countries having the values of EDUC_SYS and TRAINING 1 and 1 or 2 and 1, respectively, would both be classified to 1 for GEN_EDUCAT (see Table 3). In such case, Vredana would — within the qualitative value of 1 — rate the first country a bit lower than the second one by assigning a lower quantitative adjustment to the first country. In general, the gain of such rating is that Vredana allows further differentiation of the countries that were evaluated to the same qualitative rank. Since it is beyond the scope of this paper to further describe Vredana's evaluation algorithm, please see [4] for details.

Before presenting the results of comparative analysis, we needed to consider that the World Competitiveness Yearbook data we have used contains missing values. Both DEX and Vredana can properly handle these by deriving a range of values (probability distribution) for aggregated and final criteria. Although this is often a very desired feature, the requirement for the analysis in this section was that we required to unambiguously rank the countries and thus we needed crisp evaluation outcomes. For this purpose, the missing values were estimated as follows. If a country C was having a missing value for some criterion, we first found three other countries having most similar GDP/capita to the country C. Next, we replaced a missing criterion value of C with the average for this criterion over the three countries found.

Using the above introduced schema for handling missing values, the results of evaluation for both models are given in Figure 6. Note that in terms of the knowledge infrastructure, Finland, Sweden, Singapore, Hong Kong, and Germany rank the highest. It would be expected that USA would rank very high here, but additional analysis shows that it is ranked in class "3" because of the low value of general education. The specific comparison of Finland and USA that also highlights this deficiency is shown in Figure 7.

In terms of the quality of political and economic system in regard to their support of economy and business Figure 6 shows that Hong Kong, Singapore, and Malaysia — the Tiger countries — are the ones that rate the highest.

We have further explored the relation between country ratings of the two models by means of correlation coefficients. Three other ratings were used as well based on the following measures: GDP/capita, average value of criteria computers per capita (C_PC) and information technology (IT) from Knowledge infrastructure model (sel.KI), and average value of criteria government economic policies (POLICIES) and adaptation of political system (ADAPTATION) from System model (sel.SYSTEM). The correlation coefficients are given in Table 6. Note that completely correlated ranks would have a coefficient of 1, and

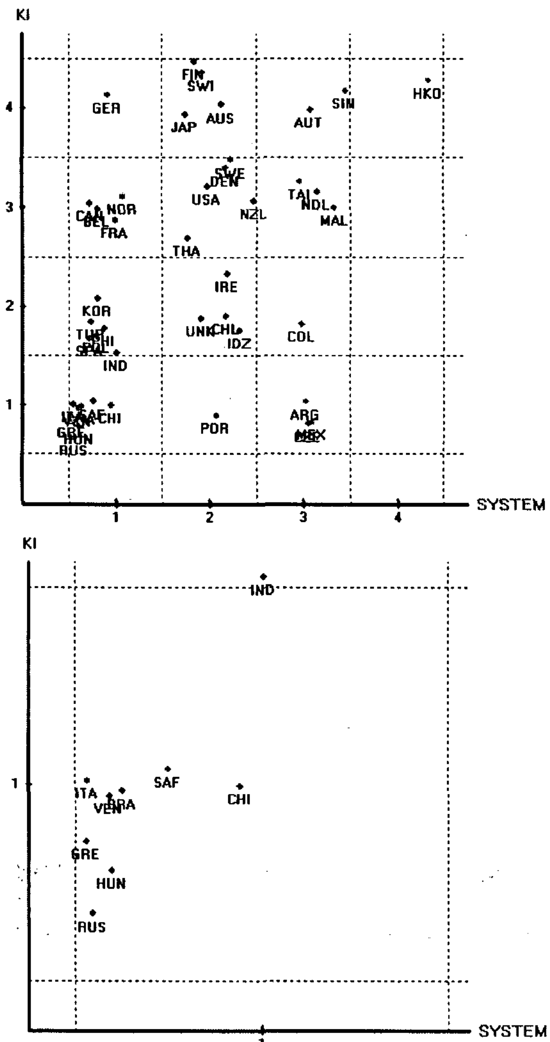


Figure 6: Vredana's graphical representation of the results of the evaluation for Knowledge infrastructure and System model (Figure on the right shows an enlargement of the quadrant KI=1 and SYSTEM=1).

Criteria	USA	Finland
KI	3	4
IT_USAGE	4	4
MANAG_IT	4	4
IT	4	4
EDUCATION	**2**	**4**
C_LIT	**3**	**4**
GEN_EDUCAT	**2**	**4**
EDUC_SYS	**2**	**4**
TRAINING	**2**	**4**
TEC_INFRA	4	4
C_INFRA	4	4
C_USE	4	3
C_PC	4	4
TELECOMM	4	4
TEL_INFR_INV	3	4
INF_REQ	4	4
TEL_INFR	4	4
INVEST	1	2
TELEPHONES	4	4
TEL_LINES	4	4
TEL_COST	3	4

Figure 7: Comparison of criteria for knowledge infrastructure for USA and Finland. The difference between the two countries (3 to 4) can be contributed to the differences of quality of the education (2 to 4), of which the subtree is printed in bold.

	SYSTEM	sel.KI	sel.SYS	GDP/cap
KI	0.452	0.822	0.201	0.658
SYSTEM		0.377	0.754	0.150
sel.KI			0.216	0.730
sel.SYSTEM				0.050

Table 6: Correlation coefficients for ranks obtained from the two socioeconomic models (KI and SYSTEM), selected basic criteria from each model (sel.KI and sel.SYS) and GDP/capita.

uncorrelated a coefficient of 0. The ranks of the two models are found weakly correlated (0.452). Not surprisingly, GDP/capita correlates better with Knowledge infrastructure than with System ($0.658 > 0.150$). As expected, the outcome of the two models best correlate with the ranks derived from the two averaged selected criteria, *i.e.*, sel.KI and sel.SYSTEM respectively.

A more focused ways of comparing the countries in Vredana in shown in Figure 8. The user selected four countries (Sweden, Austria, Poland, and Slovenia, and three criteria (political and economical system, and knowledge infrastructure) upon which these countries are compared. For Slovenia, the values of the basic criteria were estimated by local experts. For the analysis in Figure 8 we did not replace the unknown values, so one can observe that for Poland and Slovenia the minimal and maximal value for specific criteria is shown (for example, for Slovenia, the value of political system lies within 2 and 3). The radar charts show that there is a balance among knowledge infrastructure, political and economical system for the two highly developed members of the EU, whereas for the two associated countries in transition Poland and Slovenia it is evident that knowledge infrastructure and economical sys-

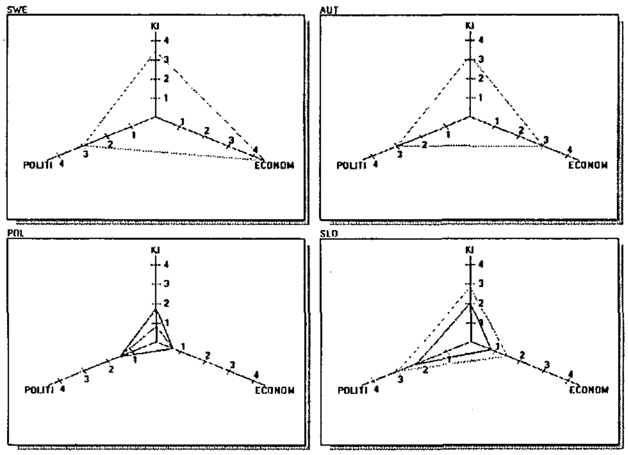


Figure 8: A snapshot of Vredana showing a radar chart that compares four countries with respect to three selected criteria.

tem do not follow yet the positive changes in political system.

4.3 What-if analysis

For an example of "what-if" analysis, we have studied Slovenia through the knowledge infrastructure model. Initially, Slovenia evaluates to "2-3" which ranks it into moderately developed countries in this respect. The question posed to "what-if" analysis is whether its knowledge infrastructure will be improved provided that Slovenia privatizes telecommunications. Namely, at present the Telecom Slovenia is the only telecommunication provider in the country (until 2001), thus holding a complete monopoly. The privatization of telecommunications in the European countries (including those in transition) boosted the development increasing both the quality of infrastructure and services. We have simulated such case and raised the values of basic criteria TEL_INFR and TEL_COST to 4. The two evaluated criteria trees, *i.e.*, the one for original data and the one with adjusted values due to privatization in telecommunications, are shown in Figure 9. According to the model, it is TEL_INFR whose improvement propagates through the intermediate criteria of telecommunication infrastructure all the way up to the target criteria, such that the new value of knowledge infrastructure is 3.

We have additionally attempted to change the value of management and information technology criteria (MANAG_IT). Increasing utilization and familiarity with IT by management is an already undergoing process, so we expect changes it this area in the near future. All other basic criteria being equal, raising MANAG_IT from "2-3" to "3-4" first results in increased IT_USAGE from 2-3 to 3-4, which finally results in improvement of knowledge infrastructure to 3 from previously 2-3.

Overall, we found the "what-if" analysis by DEX as exemplified above a very flexible and useful tool, especially as it provides the explanation through tracing of criteria tree of why and to what degree did the changes influenced the final score. This feature of model's transparency furthermore increases decision maker's confidence to the model and veracity of results.

Criteria	SLO	SLO*
KI	**2:3**	**3**
IT_USAGE	2:3	2:3
MANAG_IT	2:3	2:3
IT	3:4	3:4
EDUCATION	3	3
C_LIT	3:4	3:4
GEN_EDUCAT	3	3
EDUC_SYS	4	4
TRAINING	2	2
TEC_INFRA	**2**	**3**
C_INFRA	2	2
C_USE	1	1
C_PC	3	3
TELECOMM	**2**	**3**
TEL_INFR_INV	2	3
INF_REQ	2:3	2:3
TEL_INFR	**2**	**4**
INVEST	2	2
TELEPHONES	3	3
TEL_LINES	3	3
TEL_COST	**2**	**4**

Figure 9: Original (SLO) and modified (SLO*) evaluated criteria tree for Slovenia considering the pending changes in privatization of telecommunications. The differences are highlighted (criteria printed in bold).

4.4 Advantages and Disadvantages

Another feature of DEX that can support socioeconomic data analysis is the display of advantages and disadvantages for some selected country. Advantageous criteria are considered to be those that have especially positive effect to the value of the target criteria. Criteria that potentially most lower the final outcome are considered as disadvantages.

An example of advantages/disadvantages analysis for Japan using knowledge infrastructure model is shown in Figure 10. One can see that the major advantages of this country are in the area of usage of IT and in education, while the only disadvantage is the international telephone cost. Note that both disadvantages and advantages are shown as the criteria subtrees, so one can easily trace the propagation of positive (negative) effects through the criteria tree. For Japan, we can see that the advantageous criteria propagated all the way up in the IT usage and education subtrees, but these advantages were not strong enough to make the final outcome of maximal grade of the highest grade (the value of knowledge infrastructure evaluates to 3).

5 Conclusion

We have described the DEX paradigm to construction of hierarchical decision-support models and presented a case study to show how it can enable the efficient construction and application of socioeconomic models. In particular,

```
Advantages:
IT_USAGE                4
    MANAG_IT            4

EDUCATION               4
    C_LIT               4
    GEN_EDUCAT          4
        EDUC_SYS        4
        TRAINING        4

        C_USE           4

            INF_REQ     4

Disadvantages:
            TEL_COST    1
```

Figure 10: Advantages and disadvantages for Japan.

- DEX enables an efficient model construction that consist of identification of hierarchical structure and construction of rules for aggregated criteria. Since the original problem (mapping of many basic criteria to final criteria) is decomposed by introduction of intermediate criteria, the aggregation functions include only a few attributes and can be efficiently specified by means of pointwise rules elicited from the experts.
- The use of intermediate criteria not only decomposes a problem of model construction to simpler subproblems, but also makes these intermediate criteria observable — this is specifically useful in application of the model, since it can provide structured explanation and can ease the process of data analysis.
- Once the models are built, DEX can provide further inspection to aggregated functions by means of visualization and of presenting rules in an aggregated way. Moreover, the models can be used to study the overall relevance of the basic criteria.
- Data is provided to DEX models in terms of values for the basic criteria. DEX evaluates the data (derives the values of aggregated criteria) and can additionally be used to answer what-if questions, compare options (data for different countries), and structurally outline the advantages and disadvantages of each option.
- In addition to DEX, a Vredana tool can be used to visualize the data and compare the options.

When constructing and applying the socioeconomic models for knowledge infrastructure and value of political and economical system, we found all of the above advantages of the DEX and Vredana approach very useful. Of specific help was Vredana tool, which we believe should be the tool of the choice for performing what-if analysis and comparative studies. The weakness of the proposed approach is the fact that DEX and Vredana are available only as a separate tools that communicate through common model and option definition data file. It is expected that ongoing work on their integration will not only make data analysis more efficient, but will enable a deeper analysis of the model, such that, for example, the effects of changing the aggregation rules on the values of aggregated criteria for some set of options (countries) could be immediately observed through visualization.

Another possible methodological improvement is a function decomposition technique [18] to model development. Namely, in the case where a dataset exists that gives the values of the target criterion for a number of combinations of basic criteria, the aggregated functions can be automatically induced from the dataset. This data mining approach can potentially shorten the model development time as well as maintain the integrity of the model with some preexisting classified data. A pilot study that used this framework for construction of knowledge infrastructure model is described in [12].

We have proposed two different socioeconomic models, first modeling the value of country's knowledge infrastructure and second modeling the quality of political and economic system in regard to their support of economy and business. There are of course many other interesting socioeconomic models that could be employed in drilling in the country's socioeconomic data, getting insight to its present state and constructing and evaluating its potential future development scenarios. In our further work, we plan to extend the existing and construct new socioeconomic decision support models and correspondingly extend the data base of basic criteria using different sources, including the Yearbook of International Institute for Management Development, World Bank, International Monetary Found, and Institute for Economic Research from Ljubljana, Slovenia. As proposed in this article, these models will be built, integrated in and applied to support decision making and data analysis within DEX-Vredana framework.

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