UNICAP*: Efficient Decision Support for Academic Resource and Capacity Management

Svetlana Vinnik and Marc H. Scholl

Department of Computer & Information Science
University of Konstanz, Box D 188,
78457 Konstanz
{vinnik, scholl}@inf.uni-konstanz.de

Abstract. Growing complexity of the data and processes to be managed, as well as the transition from strict governmental regulation towards autonomy make academic institutions a significant consumer of advanced software solutions. Strategic management requires a comprehensive analysis of large data volumes from heterogeneous sources, often imprecise and incomplete. Our aim is to assist university policy-makers in building strategic action plans in the field of resource distribution and teaching capacity utilization through explicit modeling and testing of diverse development strategies. The proposed decision support system (DSS), called UNICAP (acronym for university's capacity planning), is aimed at optimizing the academic decision making by allowing simulation and evaluation of strategic plans. We conclude by presenting a case study, carried by the planning experts of our university who used UNICAP filled with "real" university's data.

1 Introduction

Universities[1] throughout the world operate with large amounts of data, typically scattered across multiple, non-centralized information systems and applications. Support of administrative decision-making and knowledge discovery from such decentralized data flows require data-unifying OLAP-enabled applications [5] designed with close eye on the specific needs of the academic domain. The emergence of the Internet and other information technologies has been crucial in altering the operational environment of universities world-wide. Being public institutions and as such subject to governmental control, on the one hand, and exposed to globalization and economic accountability and performance challenges, on the other hand, universities turn into a significant consumer of e-government solutions, in particular of *intelligent systems* that provide advice to the policy-makers to assist in strategic and operational decision-making.

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[1] The term "*university*" is used here generally to refer to all types of public higher education institutions.

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1.1 Background

Our research was inspired by the evolving reforms of the higher education system in Germany aimed at improving the performance of academic institutions in changing economic conditions [18]. Since similar challenges are faced by the universities throughout the world, we expect our contribution to be valid for the international academic community. Concerns about the efficiency of higher education have given rise to new models and systems aimed at facilitating strategic decision making, primarily concerned with resource allocation and performance analysis [3], [15]. Rapid globalization of the higher education enables a shift from individual solutions to more general strategic management models which can be appropriately adjusted to serve the needs of a particular institution. International comparative studies [8], [15], [20] have outlined a number of general performance descriptors (e.g. staff per student ratio, teaching load, student retention quote. etc.) which can parameterize such models.

Our proposed DSS is concerned with strategic planning of academic resources, their distribution and consumption. The common economic principle of demand-supply equilibrium builds up the core of the underlying computational model. *Educational supply* (ES) describes the available teaching capacities in terms of the amount of services (i.e., courses, supervision, etc.). *Educational demand* (ED) measures the consumption of those services by students according to their individual curricula.

Prior to the admission of new students, the *admission capacity* (AC) of every program, i.e. the upper bound on the number of beginners it can accommodate, must be announced. Accurate models and systems are necessary to avoid aggravating strategic errors which may lead to wasting expensive resources, long-term misbalance of the university's operation, and the failure to provide the required quality of education.

AC is derived from the educational resources released due to regular ex-matriculation of some portion of the students and is distributed among all offered study programs according to the university's admission policy. Determining the AC from the available resources is called a *supply-oriented* approach as educational capacity is considered to be fixed. An alternative approach, called *demand-oriented*, reverses the computation by allowing the a-priori specification of the desired admission numbers and determining the required educational supply.

In Germany, a supply-oriented admission capacity model, introduced in 1972, is still enforced by the legislation. Its concept, trading-off accuracy and correctness for simplicity and rapid application with no software support, is obviously out-of-date and is being subjected to growing criticism in academic circles. The condition to fully utilize the available capacities implies adherence to the minimum staff-per-student ratios [18] disabling university-specific variations. Ensuring the general compatibility with the current approach, we propose a more flexible computational model.

The focus of our work has thereby been twofold: a) to propose the methodology for admission capacity planning, and b) to implement it in a software product. The remainder of the paper is structured as follows: in Section 2 we present the methodology for determining the admission capacity; Section 3 contains the requirements specification for the UNICAP architecture and functionality; implementation issues are presented in Section 4 followed by presentation of a case study in Section 5. We conclude by a summary of our contribution and proposals for future work.

1.2 Related Work

First efforts to develop academic planning applications go back to the 60-ies, with CAMPUS project [17] being an example of an ambitious multi-parameter simulation model which reached the marking phase in the 70-ies but had to be abandoned due to its overly complicated applicability and high input data requirements.

In the 90-ies, there was a renewed enthusiasm in developing software solutions for the academic domain. Decision support and expert systems were offered in the fields of course/exam/instructor scheduling [7], program assessment [6], resource allocation [3], [11], [15], admission policy [9], [12], managing university funds, academic advising, and strategic planning [2], [10], to name a few.
We expect the next generation of academic applications to increasingly incorporate OLAP and knowledge discovery functionalities and offer user-friendly interfaces in order to be adopted by larger target group of decision makers.

The major provider of academic software solutions in Germany is a non-profit organization HIS[2] [13]. However, HIS applications tend to target distinct administrative areas (e.g., personnel, finance, and facility management) related to the operational rather than to the strategic issues. We see a great potential for DSS with elaborate analysis and visualization techniques in the field of academic strategic management.

As for the computational model, similar approaches to determining educational capacities are apparently used in other countries [1], [2].

2 Methodology

To enable backward compatibility with the current practices for the purpose of “painless” introduction of the UNICAP in the hosting university and elsewhere in German legal environment, we used the official German admission capacity model as a starting point for the new approach. However, our concept has been made more generic by introducing multiple fine-tuning parameters, taking into account international indicators (as defined by authoritative organizations such as OECD [19] and CHEPS [4]) and ensuring the system’s adjustability to varying conditions.

2.1 Basic Definitions

The hierarchal structure of a university is defined as follows: basic division units are the *faculties*, each responsible for one scientific discipline[3]. Faculties dispose of the teaching resources classified into *position groups*, such as professor, associate professor, research assistant, etc. Each position group has a *teaching load* assigned to it, which is the number of academic hours per week invested in curricular activities, denoted *semester periods per week* (SPW). The total of the teaching loads of a faculty, adjusted appropriately in case of special conditions (legal decrements, using external resources) and multiplied with the number of terms per academic year, expresses that faculty's annual educational capacity, or supply, denoted ES_{total}.

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[2] HIS stands for Higher-Education Information System Corp.

[3] Multidisciplinary faculties are divided into sub-faculties to process each discipline separately.

Education is organized into *study programs* (henceforth addressed as *programs*) characterized by a *subject* and a *degree*. Some degree types allow multiple subjects (major and minor ones) to be combined. To account for this division we add a *priority* attribute with the value domain {major | secondary | N/A}.

Each faculty is said to "own" the programs offering its discipline and to supervise the students registered therein. Servicing the supervised students is called *self-contribution* of the faculty whereas services to the students from other faculties form its *exports*. Reversely, the parts of the program's curriculum referring to the services of other faculties form the *imports* of its supervising faculty. The increasingly popular class of *interdisciplinary* programs (i.e., coordinated by multiple faculties) has to be handled separately since the division of their costs is negotiated among the participating faculties. The total amount of services provided to supervised and non-supervised students describes the faculty's total educational demand, denoted ED_{total}.

Abstracting from different admission approaches (e.g., each term or once per year) we speak of the *annual* admission capacity. To determine the admission numbers for the faculty's programs from its ES_{total}, it is necessary to specify the admission scenario, i.e., the portion of each supervised program, called its *partition*, in the total number of the faculty's beginners (for example, 0.5:0.3:0.2 partitioning between bachelor's, master's, and PhD degrees, respectively).

Since most faculties have non-zero exports, it appears impossible to determine their admission numbers without considering the expected admission numbers of all importing faculties as the latter determine the amount of exported services. To balance the entire system one must construct the so-called *interdependency*, or export-import, *matrix* and solve the resulting system of equations.

2.2 Cost Model

We start out by describing balanced resource utilization for any single faculty:

$$ES_{total} = ED_{self-contribution} + ED_{exports} + ED_{interdisciplinary} \quad . \tag{1}$$

$ED_{self\text{-}contribution}$ measured in SPW is the portion consumed by the supervised students. To transform the available SPW into the number of students, $ED_{self\text{-}contribution}$ has to be divided by the costs of educating a student in a particular program, called the *curricular value* (CV)[4]. The CV of a particular program describes the necessary per-student teaching load for the entire duration of the study and can be computed from the program's curriculum. For example, if the curriculum consists of 100 SPW and the average teacher-student relation is 1:50, the resulting CV equals 2 SPW per student. Curricula consist of modules specifying the courses and other activities (internships, team projects, course papers etc.) to be attended or performed. For simplicity, we refer to all curricular activities as *courses*.

A course is characterized by its type *T* (lecture, seminar, tutorial, etc), volume in SPW and a *support relation* which upper-bounds the number of course participants.

[4] In Germany this value is called *standard-curricular-value* as it is assigned by the supervising ministries to ensure inter-university comparability of degrees offered in the same discipline.

The SPW of each course of type *T* are translated into the SPW of the teaching load by weighing the former with an adjustment coefficient adj_T, ranging between 0 and 1. adj_T is defined for each course type and expresses the preparation-intensiveness on behalf of the teaching staff for that type. For example, types such as lecture or tutorial are mapped in a straightforward matter whereas internship or laboratory supervision is multiplied with 0.5 due to expected lower preparation costs.

Curricular modules typically define domains of courses to choose from, not the courses themselves. Some modules are defined in a highly flexible way, for instance, allowing students to choose a lecture or a seminar, or a course of a non-supervising faculty. The costs of such modules will depend on the actually selected courses and may vary from one academic year to another. We suggest analyzing the course attendance and examinations statistics accumulated over previous years in order to make accurate assumptions for such uncertain cost areas.

We can now describe the per-student costs of attending a given course *C* of type *T* with the maximum number of participants *N*, which is the course's *curricular value*:

$$CV_{C_T} = \frac{SPW_{C_T} \times adj_T}{N_{C_T}} \quad . \tag{2}$$

The CV of the entire program results from the sum of the CV of all the courses in its curriculum. Parts of this value, grouped by the supplier faculty, describe that faculty's *curricular quota* (CQ) in the program. The faculty's CQ in any supervised program is considered its *self-contribution quota*; other faculties' quotas are the program's *imports*. The sum of the self-contribution CQs of all supervised programs weighed with their respective programs' partitions produces the faculty's *weighted self-contribution curricular quota* $\overline{CQ^F}$, which is the weighted mean per-student costs of being educated in the faculty's programs.

2.3 Matrix-Based Solution

The AC of faculty *F* is obtained by dividing the self-contribution part of its resources, as defined in (1), by its weighted self-contribution curricular quota:

$$AC^F = \frac{ES^F_{total} - ED^F_{exports} - ED^F_{interdisciplinary}}{\overline{CQ^F}} \quad . \tag{3}$$

The AC of a single supervised program *P* can now be computed as follows:

$$AC^{P\,in\,F} = \frac{AC^F \times Q^{P\,in\,F}}{LF^P} \quad , \tag{4}$$

with $Q^{P\ in\ F}$ being *P*'s partition and LF^P as a *loss factor* (ranging from 0 to 1) to account for the fact that only a subset of the beginners will actually complete their studies while the rest change the program or quit. Division by the LF increases the admission numbers, thus preventing capacity under-utilization due to shrinking student numbers in higher semesters. We adopt the computationally correct *Hamburger Model* [21] for determining loss factors and will give no further explanations due to space constraints.

The problem of computing the admission capacity of a single faculty lies in the inability to evaluate the $ED^{F}_{exports}$ component in (3) as long as the admission numbers of each importing program are unknown:

$$ED^{F}_{exports} = \sum\nolimits_{\forall\ P\ not\ in\ F} \left(AC^{P} \times LF^{P} \times CQ^{F\ in\ P} \right). \tag{5}$$

The value of $ED^{F}_{interdisciplinary}$, however, can be estimated in a straightforward manner since the admission numbers of all interdisciplinary programs are known in advance:

$$ED^{F}_{interdisciplinary} = \sum\nolimits_{\forall\ interdisciplinary\ P} \left(AC^{P} \times LF^{P} \times CQ^{F\ in\ P} \right). \tag{6}$$

We proceed by constructing a system of linear equations which contains an equation for each faculty according to (1). The unknowns are the admission capacities of the faculties so that their number matches the number of equations. For any faculty F_i, i=1, …, N, with N as the total number of faculties, we denote F_i's AC as x_i (x_i, i=1, …, N, are the unknowns of the system) and rewrite (1) into a linear equation:

$$\sum_{j=1}^{N} \left(\sum\nolimits_{\forall P\ in\ F_j} CQ^{F_i\ in\ P} \times Q^{P\ in\ F_j} \right) \times x_j = ES^{F_i}_{total} - ED^{F_i}_{interdisciplinary}\ . \tag{7}$$

This just sets the total expected educational demand of F_i, summarized over all "demanding" programs grouped by supervising faculty, to match F_i's supply.

Within the demand-oriented approach, the desired AC^P is specified for each program P and the required AC of the supervising faculty F_i is determined as follows:

$$AC^{F_i}_{required} = \sum\nolimits_{\forall P\ in\ F_i} AC^{P\ in\ F_i} \times LF^{P}\ . \tag{8}$$

By substituting x_j in (7) with its specified value according to (8) and applying some reductions, we arrive at the computation of the required supply for faculty F_i:

$$ES^{F_i}_{required} = \sum_{j=1}^{N} \left(\sum\nolimits_{\forall P\ in\ F_j} CQ^{F_i\ in\ P} \times AC^{P\ in\ F_j} \times LF^{P} \right). \tag{9}$$

$ES_{required}$ of any single faculty can be calculated separately since (9) contains a single unknown.

The last step is to check the capacity utilization ratio for the specified admission numbers, which is the ratio between the required and the available educational resources. Full utilization will result in the value of 1.0 (i.e., 100%); under- and over-utilization are characterized by values less than and greater than 1, respectively. In German practice, a slight under-utilization (down to 80%) is considered even desirable. Generally, some deviation from the optimum can be acceptable. Exact bounds of the utilization tolerance interval should be set by the policy-makers. We suggest the default interval of [0.8, 1.1].

3 Requirements Specification

Among the target group's requirements, the basic one is for the system to be comprehensible and usable even for untrained users, familiar with the methodology, but not possessing any programming, database or other in-depth computer related skills.

The desired output of the program is a report containing the input data, the relevant interim results and the output in a form appropriate for decision support. Users should be able to modify the input and change the report's options in order to simulate various scenarios and to compare them. Decision support is realized by allowing the users to test their proposals "on the fly" and thus become aware of their effects and implications. Fig. 1 depicts the general procedure of creating a report. The two output options *5a* and *5b* stand for the choice between the supply- and the demand-oriented approaches, respectively, whereas simulation mode is realized by enabling repeated modification of the input data for iterating to an acceptable solution.

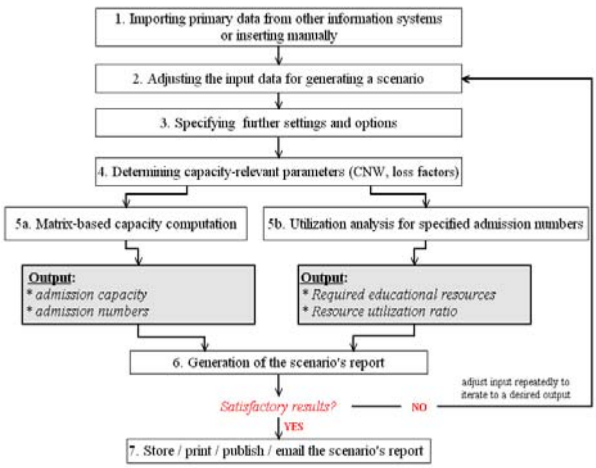

Fig. 1. Modeling the overall UNICAP's functionality

3.1 Data Management

Since the data is expected to be intensively queried and processed for simulation purposes, it is indispensable to back-end our tool with an efficient data management system. The required data originating from multiple sources has to be merged in the model's autonomous database. Once the actual data sources and formats are known, the required data transfer routines can be automated. Data centralization will also allow us to detect and fix contingent inconsistencies.

The relational model, extended to account for some German legislative implications, is shown in Fig. 2. Notice that the modeled data comprises a single computational period (i.e., academic year) which is appropriate for annual planning. To preserve and accumulate the data from previous years, the outdated data sets are placed each into its own database instance building up a data pool for data-mining purposes.

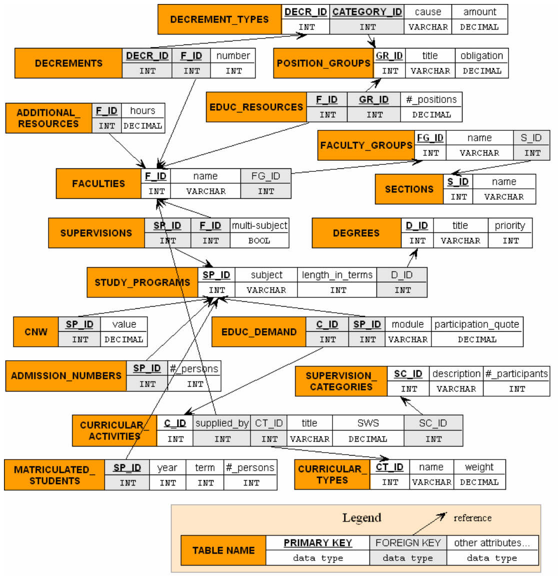

Fig. 2. UNICAP's relational data model

To prevent the central data pool from becoming damaged through unskillful manipulations, modifying access may be granted only to a competent user with administrative privileges. Ordinary users operate exclusively on their local data copies.

3.2 User Management

The target group is rather heterogeneous: the primary users are the experts who generate planning reports for external (supervising ministry and other institutions) and internal controlling; the primary beneficiaries, however, are the administrative policy-makers responsible for strategic planning; another target segment are the officials indirectly involved in capacity planning through related activities (e.g., constructing curricula, setting quality benchmarks, etc.) who altogether represent quite a large portion of the institution's officials.

To enable the heterogeneous user groups we pre-define respective access categories, such as *administrator*, *expert*, *guest*, etc., as well as *Administrator* and *Guest* user accounts in the corresponding categories for the extreme access privileges of full and read-only access, respectively. Other access aspects (e.g., storage limit per user) can be handled by defining new categories or editing the existing ones.

3.3 System Requirements

Multi-user support and database back-end imply network communication between the clients and the server. Data transfer is expected to be secured against unauthorized access. Appreciation of the application could be increased if it is implemented in a platform-independent manner abstaining from any commercial components. Ease of installation, configuration and administration as well as stable and reliable operation are crucial as otherwise the potential users might refuse to adopt the model at all.

4 Implementation Issues

To best fulfill the above requirements we have chosen a popular web-enabled client/server solution with database connectivity which offers a number of convincing advantages, such as availability of open-source platform-independent solutions, ease of installation and configuration, server-side maintenance and administration, etc.

Decision support is realized by efficient and interactive analysis of large heterogeneous data volumes. Typical operations are querying and manipulating the data as well as application of analytical tools and visualization of the results. Similar functions are imposed on OLAP applications [5]; therefore we opted for OLAP's (simplified) architectural scheme, as shown in Fig. 3. At this point, we leave out the employment of any OLAP tools for future work.

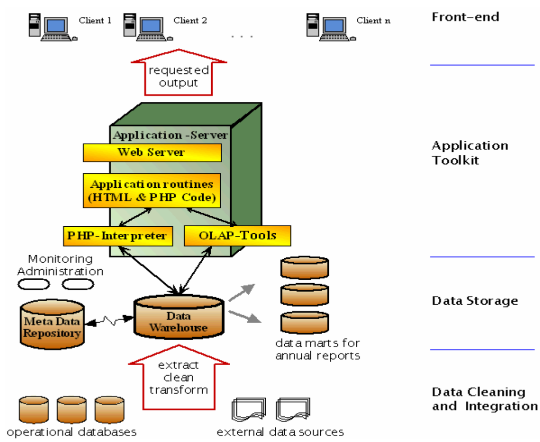

Fig. 3. Multi-layered software architecture

4.1 Database Back-End

The DBMS at the back-end manages two types of data: a) input data integrated from multiple sources into a centralized consistent set, and b) temporary data and interim results generated during simulations.

Compliant with the *data-warehouse* approach [14], the primary data is to be extracted, checked, transformed for migration, and, finally, transferred into the UNICAP's stand-alone database prior to any analyzing activities. *Data-cleaning*, i.e., bringing it into a consistent state, is essential for ensuring correct analysis results. Aware of the semantic constraints, we can incorporate integrity provisions directly into data manipulation routines. We have provided warnings against frequently occurring data conflicts as well as options as to how a specific faultiness should be handled.

4.3 Graphical User Interface

User interface is represented by a website front-end which displays the dynamically generated contents in a user-friendly form. Interactive elements enable the user to get acquainted with the computational concept, evaluate various scenarios and iterate to the desired output. The user is lead through the sequence of preparation, fine-tuning, simulation, and analysis steps, with context-specific assistance being offered throughout the interaction. To produce an impression of an application, every site follows the same layout with each functional area being at its fixed position, as shown in Fig. 4.

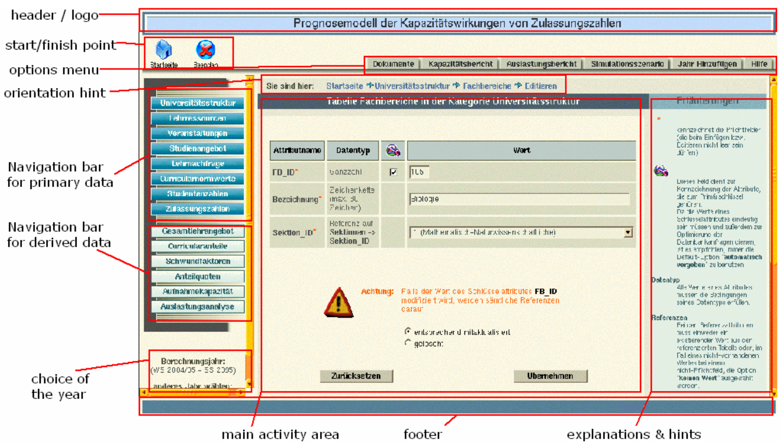

Fig. 4. Application's structural areas

Last not least, there is a separate user interface for the model's administrator which allows intuitive and comfortable monitoring and management of model's resources.

5 UNICAP in Action

To demonstrate the intuition behind using UNICAP we produce a fragment from one of the conducted case studies.

Task Definition. The Faculties of Biology (FB) and Computer Science (FCS) are setting up a new interdisciplinary Master's Degree in Bioinformatics with 30 beginners per year. Check if this plan can be supported with the available resources under the default capacity utilization tolerance interval of [0.8, 1.1].

Solution. We first generate the capacity utilization report for the initial data state. The overview in Fig. 5 (left) shows FB to be under-utilized with the ratio of 0.7647 whereas FCS is nearly balanced with the ratio of 1.0430. Having created our own simulation scenario, we adjust the input to accommodate the new program, its curriculum and the desired admission number. Analysis of the new state reveals FCS's incapability to service the desired number of beginners, as shown in Fig. 5 (right).

Testing the same setting with the admission number reduced from 30 to 20 (not shown here) leads to the utilization ratios of 0.81 and 1.0928 for FB and FCS, respectively, which are now both tolerable.

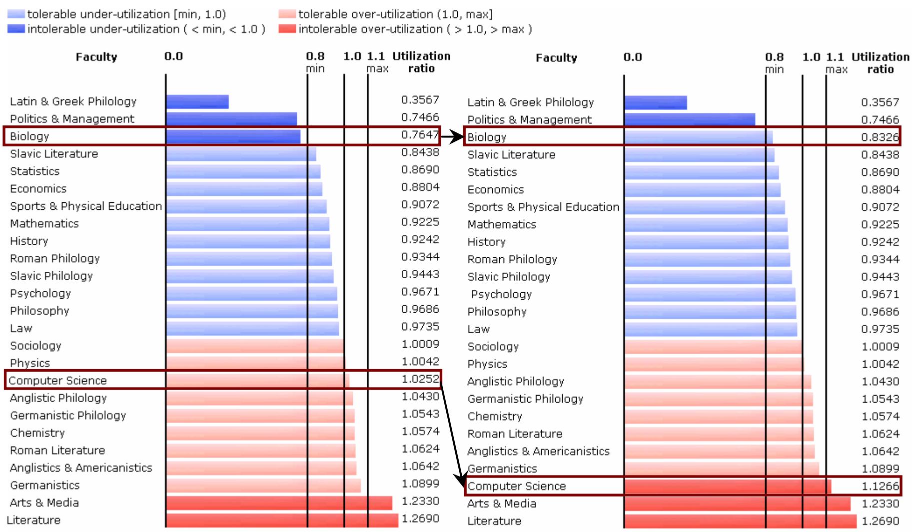

Fig. 5. Evaluating a user-defined scenario with UNICAP (fragment)

6 Conclusion

The presented UNICAP model is realized as a DSS for planning educational capacity in universities. The system integrates data from heterogeneous sources and allows users to interact with it in order to test various development strategies and become aware of their quantitative implications. Explanatory power of the user interface is assured by providing orientation aids, detailed instructions, graphical support and leading the user through the computation. Visually enhanced presentation of the output facilitates its perception and interpretation.

We consider UNICAP to be a starting point in building a more comprehensive DSS with OLAP functionality, designed with a close eye on the academic management needs. Such system should be helpful for optimizing the organization's internal process flows, but also for delivering an appropriate interface for inter-institutional controlling and knowledge discovery to be carried out by the supervising governmental bodies. Integration of the data from other sources and accumulation of the data from the past build up a base for refining and extending the analysis. Possible extensions would be visual analysis of teaching staff structure, educational supply, export-import relationships, as well as trend analysis from the accumulated historical data.

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