DECISION SUPPORT SYSTEM FOR MANAGING EDUCATIONAL CAPACITY UTILIZATION IN UNIVERSITIES

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Abstract — *Decision-making in the field of academic planning involves extensive analysis of large data volumes originating from multiple systems. Academic workload management is concerned with distributing teaching resources in order to adequately support the university's educational framework (faculties, degrees, courses, admission policies, teaching workload etc).*

We propose a methodology for assessing educational capacity and planning its distribution and utilization in universities. The approach has been implemented as a decision support system allowing simulation and evaluation of various proposals and scenarios. The system integrates the input data from relevant sources into an autonomous data warehouse, while the client front-end ensures adequate output presentation to the user so as reveal significant details and dependencies.

Applying the system as an "on-the-fly" decision-support facility for the policy-makers has resulted in significant acceleration of planning procedures, raised the overall awareness with respect to the underlying methodology and, ultimately, enabled more efficient academic administration.

Index Terms — academic Decision Support System, educational capacity utilization, teaching workload management, academic resource planning.

INTRODUCTION

Academic resource planning is a highly complex administrative procedure based on extensive analysis of the entire data related to the educational framework, such as teaching resources, offered degrees, course structure and curricula, enrolment and retention, etc. "State-of-the-art" decision-making within most universities around the globe has the form of an argumentative pie-cutting barely backed up by any solid quantitative analysis. However, the emergence of advanced information technologies has altered the operational environment of universities world-wide offering them an opportunity to move on towards more systematic and efficient management of their assets.

Accurate computational model, comprehensible methodology, complete and consistent data basis and a friendly output presentation are of paramount importance for advanced decision support. Frequently experienced problems include unavailability of the data in an appropriate form and lack of tools and approaches for its evaluation.

From the early days of information systems administrative academic processes such as effective resource distribution, teaching personnel management, automation of student admission and registration, student performance, retention and dismiss, to name the major ones, have been among the "hottest" educationalist issues. First attempts to implement simulation models for handling educational resource management go back to the 60-ies [12] with renewed enthusiasm in the 90-ies apparently encouraged by the overall advancement of information technology.

In the 80-ies the academic decision theory focused mainly on formulating the general principles and approaches of the model-based decision support systems (DSS) for academic environments [10], [14].

Various academic DSS for resource allocation [1], [8], performance assessment [4], course scheduling [6], admission policy [7], advising [13], student profile evolution [2] and strategic planning [1] have previously been proposed. More recent attempts circle around the *data warehouse* approach which enables data collection across decentralized applications necessary for solving of complex administrative problems [9].

The goal of our research is to contribute to the next generation of academic DSS based on the data warehouse technology with incorporated data mining and knowledge discovery functionalities. Decision-making is supported primarily by means of intelligent information presentation and by providing options for its explorative analysis. Focusing on the exploration rather then on generating ready-made solutions has the advantage of ensuring the model's adaptability and applicability for a wide range of problems.

Our DSS targets to support the administrative task of planning the university's educational capacity in terms of the number of students its courses can accommodate under the specified resource constraints. Decision-makers are able to evaluate various strategies and generate forecasts running simulations and experimenting with the input data.

To keep the model manageable and intuitive as well as to avoid functional explosion we opted for a single bottle-neck resource of the educational capacity, which is the teaching staff. From experience, staff availability is by far the most crucial resource constraint, expensive and hardly adjustable in the short-term compared to other resources involved, such as facilities, budget, appliances, materials etc.

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Our contribution is basically twofold: 1) to propose the methodology for assessing the educational capacity and 2) to design its adequate data warehouse implementation. The paper is structured as follows: Section 2 introduces the university data model followed by the educational capacity methodology in Section 3; in Section 4 we elaborate on the implementation issues; interactive and explorative aspects are discussed in Section 5. We conclude by a summary of our contribution and proposals for future work.

MODELING THE UNIVERSITY STRUCTURE

Universities world-wide tend to have a hierarchical structure consisting of faculties, degrees, and courses. *Faculties* are the basic administrative units, each responsible for normally a single scientific discipline in terms of offering study programs and courses related to it. Multidisciplinary faculties, in case their disciplines were grouped for merely administrative reasons, can be further divided into sub-faculties, called *units*, to process each discipline separately. Provision of both the administrative (faculties) and the scientific (units) decompositions enables clear distinction between interdisciplinary and interfaculty relationships.

Let us consider the academic processes in terms of educational supply and demand relationships, with faculties as *suppliers* of educational services and students as their *consumers*. Obviously, resource utilization is fully balanced if the per-faculty supply corresponds to its demand. Since faculties/units are the main actors in the process of resource allocation, we proceed by substantiating the concept of educational supply and demand on a per-faculty basis. Most curricular activities (lectures, tutorials, exams), henceforth referred to as *courses*, span one semester or can be mapped accordingly, so that semester appears to be an appropriate timeframe unit for resource utilization analysis.

Educational Supply

Educational supply measures the available teaching capacities in terms of the volume of services the faculty's staff provides to students. Teaching resources are classified into *position groups* (e.g., professor, research assistant, etc.) with a specific *teaching load* assigned to each group by respective legislation. Teaching load defines the number of academic hours per week, denoted *semester periods per week*, or *SPW*, to be invested in teaching. Thereby, the potential supply results from the total amount of available SPW whereas its particular instance consists of the courses actually offered. Figure 1 visualizes the above supply concept using the example of a two-disciplinary faculty.

Educational Demand

Educational demand describes the consumption of the faculty's academic services by the students who attend courses according to their respective curricula.

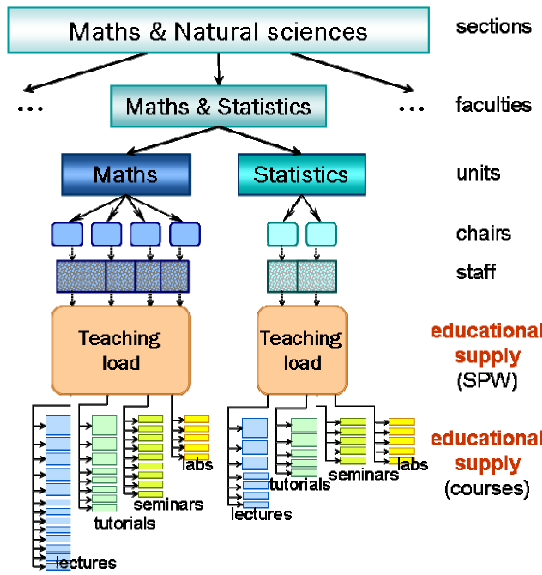

FIGURE 1.
EDUCATIONAL SUPPLY OF A FACULTY.

Faculties are responsible for study programs in their respective scientific discipline and as such supervise the students enrolled therein. Each study program is characterized by a *subject* and a *degree*. In case of composite degrees each *major* and *minor* subject has to be processed separately since they normally have different supervising faculties. Even another case is an increasingly popular class of *interdisciplinary* programs whose very subjects are composite (e.g., Bioinformatics). Such programs are thus supervised by more than one faculty. Figure 2 shows the composition of the demand at the example of two faculties.

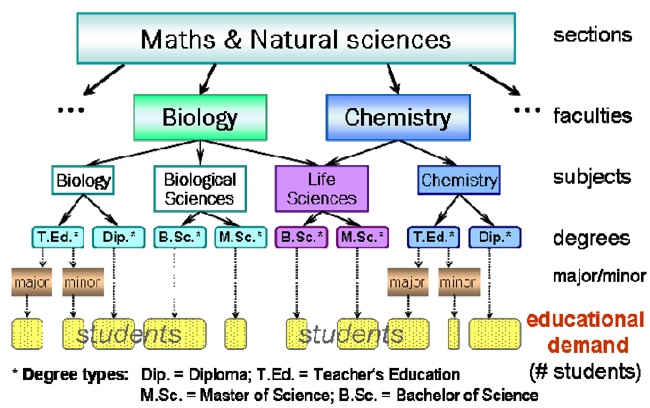

FIGURE 2.
EDUCATIONAL DEMAND OF A FACULTY.

Cross-Faculty Relationships

So far both the supply and the demand have been presented as having prevailingly hierarchical structures (most faculty's sub-trees do not overlap). In case of strict hierarchy each faculty would manage exclusively its own available resources and supervised study programs. However, in reality there exist diverse cross-faculty dependencies on the part of both the supply and especially the demand. These intensive interrelations make isolated per-faculty optimization of capacity utilization unfeasible.

Major interdisciplinary issues and cross-faculty interactions arise at the following levels:

- *Courses*: some courses with complex subjects are offered as a joint effort of teaching staff belonging to different faculties.
- *Study programs*: study programs having an interdisciplinary subject are typically jointly supervised by multiple faculties responsible for respective sub-disciplines (as in Figure 2).
- *Degrees*: Those degrees with subdivision into major/minor subjects (e.g., teacher's education degree) frequently encourage combination of non-related subjects. Students enrolled in such degrees are registered within multiple faculties.
- *Curricula*: Curricula of most study programs contain blocks of courses offered by non-supervising faculties, thus declaring their dependency on "imported" services.

Examples of the cross-faculty interactions listed above are presented in Figure 3.

Cross-faculty teaching services can be described as exports-imports relationships of the faculties. From the point of view of a single faculty, awareness of its expected exports volume is indispensable in order to account for it when estimating the capacity available for servicing its own supervised programs. Let us now proceed with the methodology for measuring educational supply and demand.

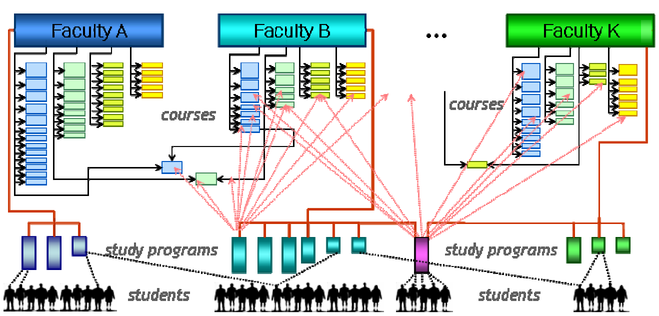

FIGURE 3.
MAPPING CROSS-FACULTY DEPENDENCIES (SIMPLIFIED FRAGMENT).

METHODOLOGY

As presented is Section 2, the academic capacity utilization is all about providing and consuming curricular activities. The overall educational capacity is the total of the capacities of all offered courses. Each course is characterized by the *volume* measured in SPW and the *support relation* upper-bounding the number of participants. Additionally, course types can be weighted differently depending on the preparation-intensiveness on behalf of the teaching staff. Thereby, the teacher-hours-per-student cost of some course C of type T with support relation N, called the course's curricular value (CV), can be estimated as follows:

$$CV_C = \frac{SPW_C \times weight_T}{N_C} . \qquad (1)$$

Curricular value of some particular degree is thus the total of the CVs of all the courses specified in the respective curriculum. It thus represents the necessary number of teacher periods per-student necessary for completing that degree. Table I shows an example of estimating the CV from the degree's curriculum.

TABLE I
CURRICULAR VALUE OF A STUDY PROGRAM (FRAGMENT)

semester	Course title	SWS	support relation	offered by faculty	CV
1st	*Introduction into CS I*	6	150	Comp. Sc.	0.04
	Operating systems	4	50	Comp. Sc.	0.08
	Maths for Programmer	6	100	Maths	0.06
	...	...	...	...	...
2nd	*Algorithms&Data Struct.*	6	100	Comp. Sc.	0.06
	Statistical Methods	4	200	Statistics	0.02
	...	...	...	...	...
3rd	*Information Systems*	6	100	Comp. Sc.	0.06
	Inform. Managemen	6	100	Comp. Sc.	0.06
	...	...	...	...	...
...					
6th	*Practical Assignment*	4	20	Comp. Sc.	0.5
	Project Management	4	50	Economics	0.08
	Patent Law	2	100	Law	0.02
Total Curricular Value (*B.Sc. in Information Engineering*)					**3.85**

Summing up the course CVs grouped by the servicing faculty (rows of the same color in Table I) in the curriculum of degree d yields the per-student demand within d for each involved faculty. Such per-faculty portions in the total degree's CV are called *faculty's curricular contributions* (*CC*) within a degree.

Intuitively, a convenient and compact way of displaying all faculty/degree interactions is by arranging the CCs into a matrix with faculties as columns and degrees (clustered by supervising faculty) as rows. Each cell *[d,F]* thereby describes faculty F's CC in degree d, as shown in Table II.

Deriving faculties' CC from the curricula, however, may be rather aggravated if the latter are defined in a flexible manner, i.e. allowing students to individually select courses following some general selection rules. Our proposed solution is to synthesize a "representative" curriculum by combining formal curriculum definition with the analysis of the actual recent course attendance statistics.

For a single semester, the per-student demand value in any matrix cell *[d,F]*, divided by the length of degree *d* in semesters and multiplied with number of enrollments in *d* in that semester, describes *d*'s educational demand within faculty *F*:

$$demand_d^F = \frac{CC_d^F}{\#semesters_d} \times \#enrollments_d \,. \tag{2}$$

Summarized vertically, those values produce the total required resources of faculty *F*. The ratio between the total demand towards *F* and its available teaching resources in SPW shows the faculty's teaching capacity utilization:

$$CapUtilization^F = \frac{\sum_{all\ d} demand_d^F}{TeachingLoad^F} \,. \tag{3}$$

TABLE II

EXPORTS/IMPORTS RELATIONSHIPS OF THE FACULTIES (FRAGMENT)

	Faculty/Degree	Maths	Inf. Sc.	Biology	Economy		TOTAL
Maths	Maths, Dipl.	1.80	0.30		0.02		3.20
	Maths, T.Ed., 1	1.10	0.05				2.45
	Maths, T.Ed., 2	0.55					1.82
Inf. Sc.	Inf. Eng., B.Sc.	0.04	2.33		0.03		2.60
	Inf. Eng., M.Sc.		1.41				1.85
	Comp. Sc., T.Ed., 2	0.04	1.80				2.25
Biology	Biology, Dipl.	0.30		5.11			6.44
	Biology, B.Sc.	0.17	0.02	2.97		...	4.02
	Biology, M.Sc.			1.85			2.25
Economy	Economics, Dipl.	0.92	0.02		2.43		3.40
	Economics, T.Ed., 1	0.74	0.01		2.11		2.74
	Economics, B.Sc.	0.80	0.04		2.56		3.05
	Economics, M.Sc.	0.06			1.40		1.74
interdisc	Inf. Manag., B.Sc.		1.72		2.12		2.84
	Inf. Manag., M.Sc.		0.90		1.65		1.50
	Life Science, B.Sc.	0.05	0.02	2.78			4.55
	...						

Further computational details and model parameters are omitted here due to limited space. The introduced methodology can be applied for solving a wide range of problems related to academic capacity planning, such as:

- determining the faculty's admission capacity for a specified degree setting (presented in [15]);
- locating the bottle-neck faculty when modifing the degree structure;
- computing the necessary adjustment of teaching resources for supporting a certain szenario;
- checking whether there are any discrepancies between offered degrees and courses.

Other tasks can be easily enabled by defining the respective reporting structure (input, options, output).

IMPLEMENTATION

Our chosen solution is a database-enabled web-application since it best fulfils the requirements of a DSS with high availability and a differentiated multi-user access. The system runs completely server-side (dynamic content is generated by PHP scripts, complex visualizations are implemented in Java) so that all a client needs to access it is just a web browser and a network connection.

The major challenge is the pre-processing phase in which the entire input data has to be identified, collected and integrated into the data warehouse. Depending on the types of the systems involved, the quality of the data (e.g., consistency, completeness, and format) and the legal data access constraints this process may take up to several months. Fortunately, the model can operate on incomplete data for solving less complex tasks. In case of missing data, the user is prompted to specify a let-out (e.g., to use default values, generate assumptions or aggregate over historical data) or even to manually fill the gaps in the required input.

Expert knowledge of the users is generally a valuable asset and a significant contribution to the system's reliability since it is hardly feasible to ensure complete and faultless automated data extraction and analysis.

Simulation mode is realized by means of creating a copy of the data subset required for solving the specified task and allowing the user to manipulate that input and generate the desired reporting documents. Both the underlying data and the reports of simulation scenarios can be stored, reloaded, re-processed and shared among multiple users.

SIMULATION AND VISUAL EXPLORATION

The system's graphical user interface has been designed with the objective to encourage both *strictly guided* as well as *freewheeling* user interaction modes. Most decision processes require combination of both approaches anyway - the expert would first use their intuition to explore potentially relevant data and would then apply particular analytical tools for assessing particular problem areas.

Guided interaction mode is implemented as an analytical toolbox with output report generation for a pre-defined set of academic problems and contains the following steps:

(1) select one of the predefined tasks from the list;
(2) select the type of report to generate;
(3) select the report options (level of detail, aggregations, assumptions, error reporting, input inconsistency handling, etc.);
(4) adjust default values and assumptions;
(5) specify the input data requirements and options;
(6) adjust the input data to map the desired scenario;
(7) run the scenario and generate the output report;
(8) interactively explore the output (using zooming, aggregating, details-on-demand and other techniques);

(9) repeat steps (6)-(8) to iterate to a satisfactory result or to collect the information required for decision-making.

We conclude our presentation by producing some fragments from the system's report generated for studying the effects of introducing a new interdisciplinary degree on the educational capacity utilization. The screenshots in Figure 4 display the data in a top-down fashion, starting from the whole university overview to a single degree.

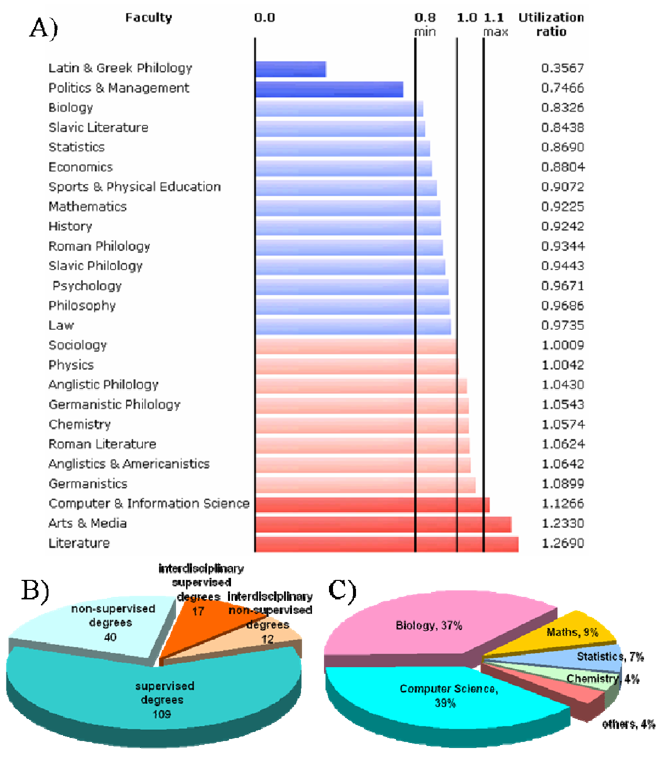

FIGURE 4.

EXPLORING THE RESULTS OF A USER-DEFINED SCENARIO (FRAGMENTS):

A) PER-FACULTY CAPACITY UTILIZATION RATIO

B) EDUCATIONAL DEMAND DISTRIBUTION WITHIN A FACULTY

C) CURRICULAR VALUE COMPOSITION OF A DEGREE

CONCLUSION

We have focused on the problem of offering reliable decision support to the process of balancing educational demand and supply in universities. We first introduced the concept of the academic structure and the methodology for assessing the educational capacity based on correct and accurate mapping of cross-faculty dependencies.

The model has been implemented as a group DSS for online construction and evaluation of academic scenarios. The system integrates data from heterogeneous university systems. Decision support functionality is realized by offering reporting tools for solving particular capacity-related tasks as well as by allowing users to navigate through the data, query it, generate interactive visualizations and explore those for retrieving interesting details.

Our future work will be directed towards improving the data integration routines and enhancing the user interface to enable intuitive and flexible interactive visual exploration of the accumulated data with incorporated data mining techniques for expert trend analysis.

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