A Meta-model approach to the construction of decision support systems in health economics

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Abstract

The system described in this paper provides different types of health care professionals with a set of tools for building, using and sharing decision support systems for resource allocation. The system addresses selected areas, namely the choice of diagnostic tests, the therapy planning and the instrumentation purchase. Decision support is based on decision-analytic models, incorporating an explicit knowledge representation of both the medical domain knowledge and the economic evaluation theory. Application models are built on top of meta-models (there is a meta-model for each addressed area), that are used as guidelines for making explicit both the cost and effectiveness components, as well as the responsibility of different decision makers for different decision variables. The proposed approach improves the transparency and rigour of the collaborative decision-making process. In addition, reusing the results of a particular economic evaluation in different settings is facilitated by a standard representation of both the underlying hypotheses and the results themselves. The system is designed as a service accessible through the internet.

1. Introduction

How best to allocate limited economic resources is an ever increasing problem in health care. Studies in this field aim at comparing alternative options, one of which may be the null alternative, i.e. "Do not do anything", in terms of both efficacy and resource allocation. Despite the exponential growth of related literature in recent years, methods of gathering and synthesizing data on health care outcomes (costs and effectiveness), are underdeveloped, as are systems of providing the available recommendations to physicians, patients and health care organizations. Some confounding factors, that often impair both the study design and the result interpretation, concern 1) the outcomes choice and measurement, 2) the point of view and the time horizon of the analysis, that dramatically change the cost components to be taken into account, 3) the consideration of individual preferences and 4) the account for financial factors, such as the discount rate for future outcomes. From several parts, a need of some standardization in the field is claimed. For example, the Task Force on Principles for Economic Analysis of Health Care Technology [Task Force 1995] is an international effort whose purpose is to provide guidelines for carrying on a correct economic evaluation study. As another example, scientific medical journals have published editorials for declaring their constraints policy about the publication of economic evaluation papers [Kassirer 1994, BMJ Working party]. Drummond [Drummond 1993] outlines the need for common terminology and methodological standards in order to improve the result comprehension and transferability.

This paper shows how the above problems can be faced through a formalized, model-based approach. Modeling is not the only way to design an economic evaluation study of health care interventions. Several analyses have been based on observational studies or randomized controlled clinical trials. In a recent paper, Sheldon [Sheldon 1996] enumerates the advantages and the drawbacks of each method, and in particular he warns about the misuse and abuse of decision models, concluding that models must be used only when direct observation of the phenomenon is not available and cannot be collected in a reasonable time. We agree on this claim and also on the fact that published decision models often contain errors, such as invalid syntax, actions based on unobservable states, incorrect modeling of diagnostic test results and of treatment outcomes. In addition, results provided by decision models often lack of a proper dispersion and sensitivity analysis. On the other hands, it must be recognized that in some cases modeling is the only way to provide a rationale for a decision, a tool for simulating different possible scenarios, a mean for highlighting the key uncertain variables.

The main purpose of the proposed system is to provide a framework for the correct use of modeling in health care economic evaluations. The system has been designed as a "service", delivered through the WEB, in such a way that information sources can be maintained and updated in the opportune sites. The prototype is available at:
(http://medea.unipv.it:9900/hcrema.html)

2. Economic evaluations in health care

We start this section by clearing terminology up, since conflicting terminology is one of the causes of confusion in interpreting literature reported studies. We adopted a precise, widely agreed-on classification of economic evaluations [Drummond 1987, Weinstein 1980]. Four types of analysis are recognized:

1. Cost Minimization (CM) - Options to be compared are supposed to have the same consequences, thus the choice is based only on the cost evaluation;
2. Cost/Benefit Analysis (CBA) - Consequences, as well as costs, are expressed in monetary terms. In this case it is possible to calculate the 'net economic benefit' (i.e. benefits - costs) in addition to the cost/benefit ratio;
3. Cost/Effectiveness Analysis (CEA) - Consequences are expressed in physical, non-monetary units (i.e. gained life years, number of identified diseases, etc), while costs are expressed in monetary units. In this case, results are given as cost per unit of effect;
4. Cost/Utility Analysis (CUA) - Consequences are usually measured by Quality Adjusted Life Years (QALYs), or any other measure that incorporates the quality of life.

Another source of confusion is represented by the point of view of the analysis. As a matter of fact, the same decision problem may have different solutions, according to the perspective used, i.e. the perspective of the patient, of the society, of the third payer, of the health care provider, and so on. The perspective determines the cost components to be considered for the study. Our system incorporates the cost classification suggested in [Drummond 1987], that distinguishes between direct and indirect costs. Direct costs are due to organizational efforts, time spent by health care professional, material used, purchased instrumentation, and costs sustained by patients and their families. Indirect costs derive from loss of productivity caused by patient hospitalization or disability.

Thus, the difference among the possible categories of economic evaluations lies on the measure of the consequences and costs. It is then feasible to develop generic models of economic evaluation problems, which can be specialized into one of these categories by defining the needed measure of consequences and costs, without changing their main structure. As a matter of fact, the starting point of our work is the consideration that it is possible to individuate both general structures of models for economic evaluation on different classes of problems and general structures of models for cost evaluation in different contexts. The precise specification of these general structures will make the development of economic evaluation models more rigorous - e.g. it will become more difficult 'to forget' some important predictive variable - and will encourage the presentation of results according to standard, predefined formats.

3. The system architecture

Figure 1 shows the functional architecture of the system.

The system components are:

- an ontological description of both medical and economic concepts
- a set of meta-models, each one describing the "general" decision model for a given application area.

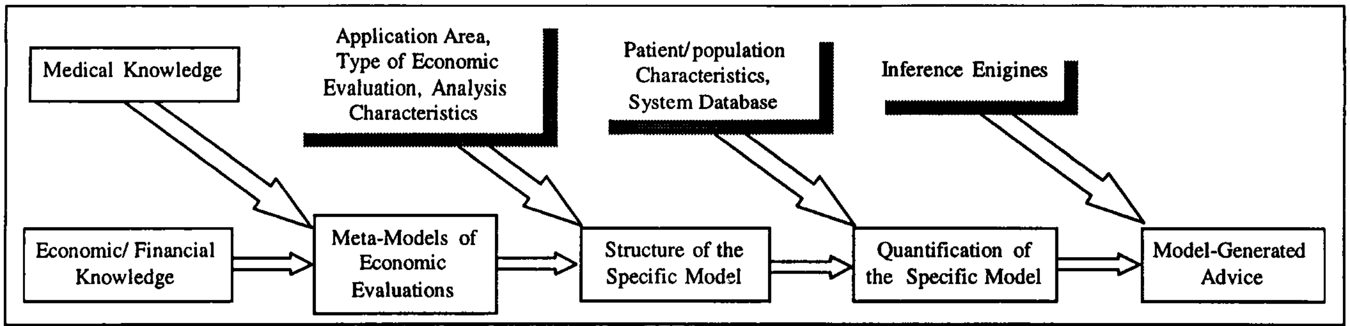

Figure 1: The system functionality: medical and economic/financial knowledge is used to provide general models, that are tailored by the user according to the specific analysis. Tailoring (shadowed blocks) is performed by specifying the target population or patient, and the analysis characteristics, that can be general, such as the point of view, and specific, such as the particular diseases and tests to consider for a screening program. The system provides a database with information about diseases, treatments and diagnostic tests.

- a database storing some basic information that is generally useful in economic evaluation studies. Data concern prevalence and incidence (including cost), population statistics, etc. ;
- a library of statistical models that can be used to assess some probabilistic parameters in particular application domains
- a library of models for calculating cost of common procedures
- a set of inference engines for running the decision models

In the following, these components are described.

3.1 Ontology and meta-models An ontology that defines the entities and the relationships among entities in the domain of health care economic evaluations has been built. A common ontology will guarantee that the produced models will be easily shared among different users as well as user-tailored in the appropriate contexts, for example by adopting a different quantification of some parameters. The description of the whole ontology is beyond the scope of this paper, and can be found in [Quaglini 1996] . At highest levels, this ontology describes the medical concepts (diseases, treatments, diagnostic tests, life expectancy, QALYs, etc.), the economic concepts (direct costs, indirect costs, interest rate, etc.) and some combinations of them, such as the cost/effectiveness, cost/benefit and cost/utility ratio. The lowest level of this ontology is a set of meta-models, i.e. very general models, exploiting the concepts described in the highest levels. There is a meta-model for each of the selected health care economic evaluation domains. Each specific application model will be generated on guarantees its correctness. In other words, a meta-model is a framework designed to assist the decision-maker in building decision-analytic models, that is to define the cost and effectiveness components for a given problem, according to the context in which the analysis must be carried on. The result will be a model in which each component is well-documented, i.e. it has a sound ontological definition, and it may be linked with data sources for its own quantification. For example, let us suppose that "population life expectancy" is a node of a belief network; the meta-model contains the very general knowledge that "life expectancy" may be linked to "life tables", where survival is given as a function of age, sex and race; while building his specific model, the decision maker will be "invited" to refer to a particular life table, for example of a given country, or a given sub-population (the system offers facilities to store or access databases).

3.2 The meta-models As previously mentioned, every problem can be characterized in terms of both cost and efficacy components, but these vary depending on the domain. For example, instrumentation purchase implies to take into account cost components such as capital investment, management costs, and amortization, while the cost components for a screening program include items such as the cost of the screening tests, and eventual therapies performed as a consequence of the screening results. The measure of benefits also may vary among domains: even though all programs in health care aim at improving life expectancy and/or the quality of life of the population, often some surrogate outcomes are considered, which are easier to measure and predict. According to the domain, these surrogate outcomes may be the increased number of examinations performed with a new instrument, or the number of correct diagnoses obtained by a screening. The aim of the meta-models is just to assess the type of variables and the conditional dependencies among them, for each application area. Once the area has been selected, the corresponding meta-model becomes a guide for the user to build his specific decision model. This gives two advantages: first, both syntax errors and forgetting of some important variables are prevented because, instead of building his own model from the beginning, the user "instantiates" a general model, by assembling one or more "building blocks" provided by the system; second, conceptual errors concerning inconsistency between the model and the analysis characteristics (point of view, time horizon, etc) are also prevented, because the meta-model embeds this kind of methodological knowledge. Figure 2 illustrates the meta-model for the selected area "diagnostic testing". The influence diagram formalism has been adopted: squares represent alternative choices, circles represent general categories of medical and economic chance variables and diamonds represent objective functions to be optimized.

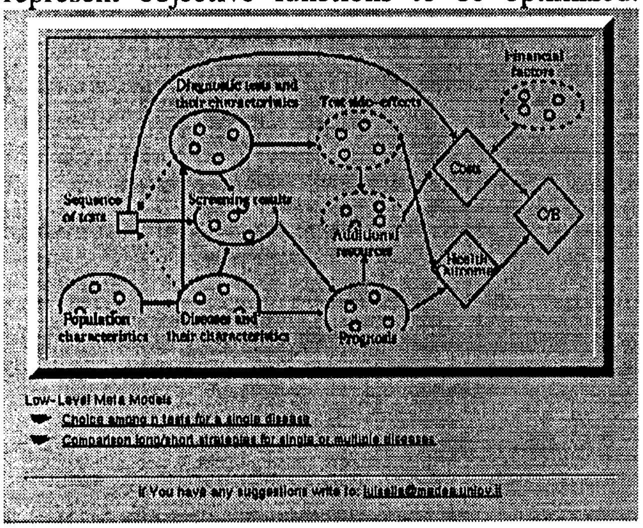

Figure 2: The meta-model for the diagnostic testing problem, as shown by a WEB page of the system prototype.

Thus, in a diagnostic testing problem, the decision will be a sequence of tests, i.e. the choice consists in selecting and scheduling one or more among several possible tests. The health consequences may be the test result, the test side effects, the disease prognosis. Financial factors, typically the interest rate, are necessary to relate present and future costs. At the moment of the decision, the disease(s) to investigate, the tests available for each disease and some patient or population characteristics are known. Some disease characteristics, such as prevalence and risk of death, depend on the target population (age, sex, ...). The result of the investigation depends both on the disease prevalence and on the tests used, more precisely on their specificity and sensibility. Some tests are invasive and may cause side effects, that's why the health outcomes depends not only on disease prognosis, but also on the test consequences. Costs depend on tests, additional resources necessary to treat test side-effects, and they can be affected by financial factors. Finally, costs and outcomes, estimated separately, can be combined in order to perform the various kinds of economic evaluations.

Other meta-models have been designed, namely for therapy planning and instrumentation purchase.

3.3 The system database- ORACLE™ rdbms has been used to build an information repository, describing some entities that are usually needed when performing economic evaluations in health care. In particular, it incorporates 1) the ICD9-CM classification of diseases, 2) the population life tables, where expected survival is given as a function of sex, age and race (at present the italian table), 3) the disease prevalence and incidence (at present only for neoplasms), as a function of sex and age, 4) the survival in case of early and late diagnosis for each disease, 5) the diagnostic tests associated to each disease, with their characteristics (sensibility, specificity, risk, cost, mean time spent by the patient to perform the test). It is important to note that these tables represent "certified" sources of information. As a matter of fact, they are gleaned either from official institutes of statistics (such as the italian institute for statistic ISTAT), or by accurate search procedures in the literature; in the latter case the references are reported in the database together with the data.

3.4 Library of models- The system embeds some models that may be shared by different applications for some common purposes. For example, for assessing the indirect cost of a procedure, the model is simply a formula that calculates the lost salary, starting from the mean time spent by a person submitted to that procedure and the mean salary for a person belonging to the target (sub)population. Another model computes the direct cost of a radiological test starting from a weight, assigned to each test by the Italian Radiologist Society, and a unitary cost, that is an attribute of each hospital: of course this model is valid for italian health care organizations, and the idea is that each country will maintain a library of its own models, in addition to the general ones. The system also provide statistical models for assessing some useful probabilities: for example, there is a logistic regression model that computes the most probable cause of a urinary tract infection, among several possible bacteria, starting from the data about infection onset and patient clinical conditions. This is very useful when empirical antibiotic treatment must be assessed [Andreassen 1996]. Again, each country should provide its own tables of drug costs, in order to customize the application.

3.5 Inference engines-. The system adopts the two most widely used formalisms for decision analysis, namely decision trees and influence diagrams. Existing software packages are exploited in order to implement the 'inference engines' of the models (i.e. to make computations according to decision analysis theory). They are: Hugin (Hugin™ is a product of Hugin Expert A/S) which is based on influence diagrams, and DATA (DATA™ is a product of Tree Age Software, Inc.) which is based on decision trees. Thus, an interface that translates the developed models in a format suitable for each package is provided. In addition, for some particular models, LISP procedures have been written to exploit the model structure in order to make computation more efficient. Java applets are used to show graphical layout of both the models and the results.

4. Running the system

The computational architecture of the system is shown in Figure 3.

As explained above, certified sources of information have been used to fill a database with data commonly needed for health care economic evaluations. In addition, the same database contains user tables for storing the parameters of the actual consultation session. ORACLE Web Server™ is the kernel of the interactive system allowing the user to create a specific model. Java Applets are used to show some particular models. ORACLE Web Server also calls the opportune inference engines through CGI (common Gateway Interface).

The following diagnostic problem will be used for illustrating the system performances:

"It is known that patients with idiopathic deep

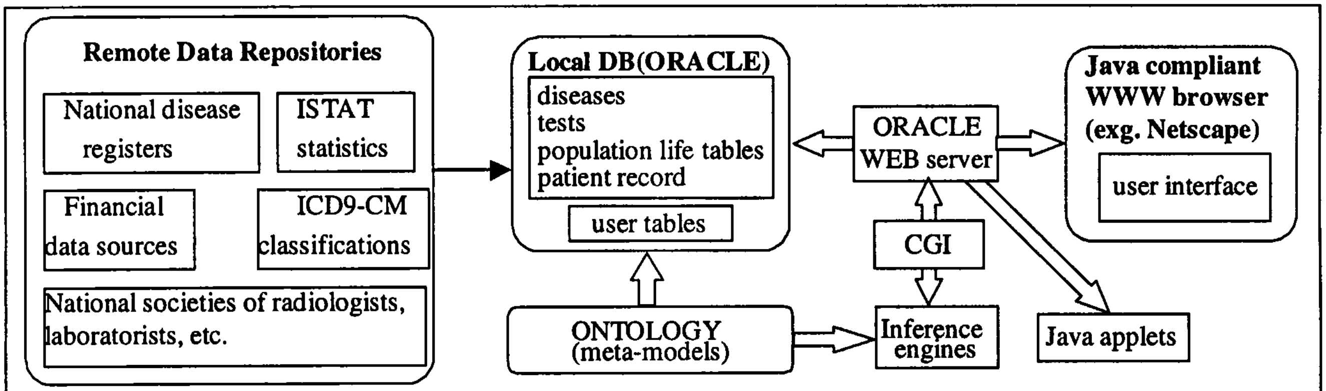

Figure 3: The computational tools of the system

venous thrombosis (IDVT) show an increased risk, with respect to the general population, of manifesting a cancer within an interval lasting about from six months to two years after IDVT diagnosis. This suggests that IDVT may be caused by an occult cancer. Given the relatively old age of these patients (median age is 64 years), and given that there is not a preferred tumor site, the question is ``is it worthwhile, in terms of survival, submitting these patients to a screening for occult cancer, how many types of cancers have to be searched for, in which sequence, and by which tests? Which is the cost per each life year gained, if any?"

Effectiveness of screening programs depends on several variables, for example prevalence of the diseases, benefits of early diagnosis, test availability. The choice of the tests sequence is one of the main problems to face when more than one test is available for investigating a disease. As a matter of fact, tests differ for invasiveness, cost, sensitivity and specificity, thus their sequence may affect the final outcome. When the screening program concerns multiple diseases, as in the case proposed here, the sequence of their investigation is another choice variable. In this paragraph, a service session about the above problem is illustrated. The first page, not shown for lack of space, provides a summary of the project characteristics and the access to the subscription form, necessary for using the prototype. At the page bottom, a suggestion box is open, and users may send messages to the system administrators to give suggestions or ask questions. The interaction starts by showing the possible medical problems for which meta-models are available: they are the diagnostic testing, the therapy choice, and the instrumentation purchase. WEB pages have been designed as self-explaining as possible, thus they report some theoretical background and explanation. By choosing "diagnostic testing", the meta-model for the screening problem (see Figure 2) is shown. While it is not impossible to generate a specific model directly from a meta-model, the system provides an intermediate level, called low-level meta-model, that bounds the application field and that is easier to instantiate.

Concerning the diagnostic problem, there are several situations, again general enough to be modeled by a low-level meta-model, for example: "testing for a single disease with one among several possible tests", and " diagnosing one among several possible diseases with different sequences of tests".

Let us consider the second option. The system shows the kernel of the model consisting, for each disease, of three different strategies: 1) no testing; 2) performing a preliminary, non invasive test and continue only if positive with a more invasive test and, eventually, a biopsy (long strategy); 3) skipping the preliminary test and directly starting with a more informative test (short strategy). The patient may die from the test procedure, or survive. Test may be either positive or negative, in every case the patient may either be ill or healthy. Every path is quantified according to the chosen payoffs, for example the 5 years survival and the total cost associated to the path. Given that, in our clinical problem, the cancer sites to investigate are more than one, the first decision node will represent the decision "which site to investigate first?". For each site, the three above strategies will be considered. When a path ends without a diagnosis, a further decision node will represent the question "which site to investigate next?". The system will automatically build a decision tree with this structure, according to the user provided information, as shown in the following.

The meta-model is a guide to the information acquisition from the user: the different portions of the meta-model are shown, page after page, as a motivation of the information required.

4.1 Assessing the utility model

The payoffs are chosen as shown in Figure 4. For the diagnostic problem, life expectancy and number of correct diagnoses have been implemented as suitable payoffs, but in the future the system will be able to consider every payoff described in the economic evaluation ontology. Figure 4 also shows how to choose the point of view of the analysis (that can be of the patient, of the society, of a third payer, of the health care provider), and the discount rate for future costs and benefits. In addition there is the possibility of considering a risk factor, that will multiply the

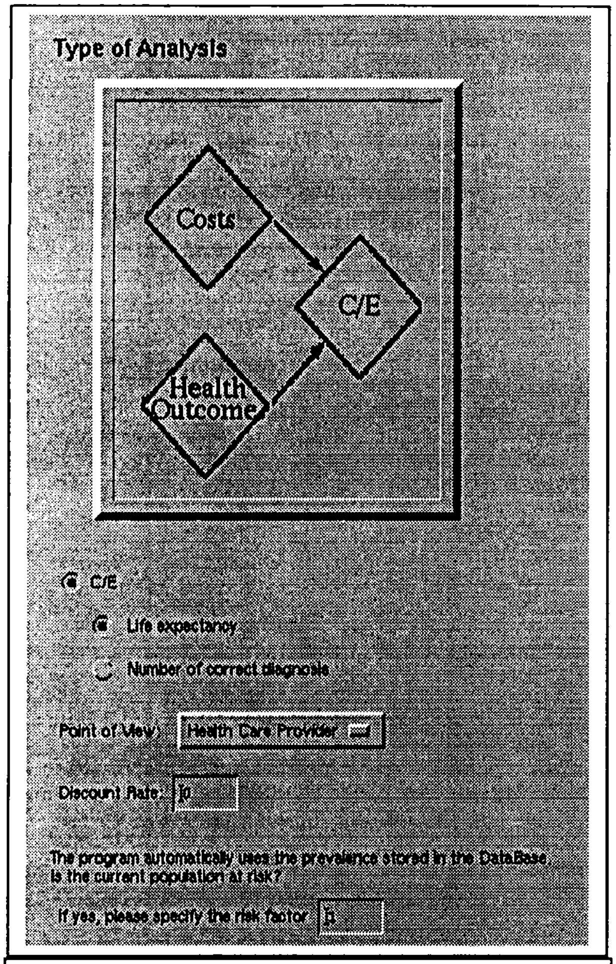

Figure 4: Choosing the characteristics of the current analysis

baseline disease prevalence stored in the database (this could be useful when the sub-population to be screened is known to be at risk for a certain disease). Keeping trace of the type of analysis is very important in order to understand and share the results.

4.2 Tailoring the analysis to the population

The system needs the specification of the population characteristics, necessary to retrieve some population-related parameters, such as the prevalence of a disease. The system asks for sex, age (point value or interval) and race. Then the diseases to be screened must be indicated. The ICD9-CM international classification has been chosen, which is hierarchically organized. The user can navigate through different pages, starting from the page of the general disease classes, to find the specific disease. For example, starting from "Neoplasms", one may reach and choose "Malignant Neoplasm of Colon": Figure 5 shows data retrieved from the HC-ReMa database about that disease (prevalence for the specified age class, early diagnosis survival, late diagnosis survival, lead time). One interesting feature of the system, shown in the Figure, is represented by the pointers to reference literature.

4.3 Test selection

After choosing the disease, the system shows the possible tests available for diagnosis. Test are classified as "preliminary", "secondary", and "confirmatory". The user selects a test for each category; for each test, its characteristics (sensibility, specificity, death probability and direct cost) are retrieved from the database. These values may be changed by the user, but this will affect only the current analysis, and not the "official" database. The user may also choose "other" from the list, and then describe a new test not present in the database yet. But also in this case, the new test will be stored in a private table for that user, and will not affect the "official" database. Finally, a battery of test may be composed by choosing two or more tests: the battery is intended as a new "composite test", that is considered positive when at least one of the combined tests is positive, and negative if all tests are negative. In this way the battery will minimize the false negative results. These information acquisition procedure continues until all the diseases and the corresponding testing strategies are described. For example, if two cancer sites must be investigated, two preliminary tests, two secondary tests and two confirmatory tests must be indicated.

4.4 The tree construction and solution

When all the information have been provided the system shows a summary of the user choices. The decision tree is automatically built and quantified starting from the introduced parameters. Appropriate models for computing costs are applied to this purpose, according the user analysis specification. For example, in this case, the point of view is that of the "health care provider", thus only direct costs are considered. In the case of the "society" point of view, also indirect costs are taken into account, derived by computing the loss of productivity associated to each screening program. An inference engine is

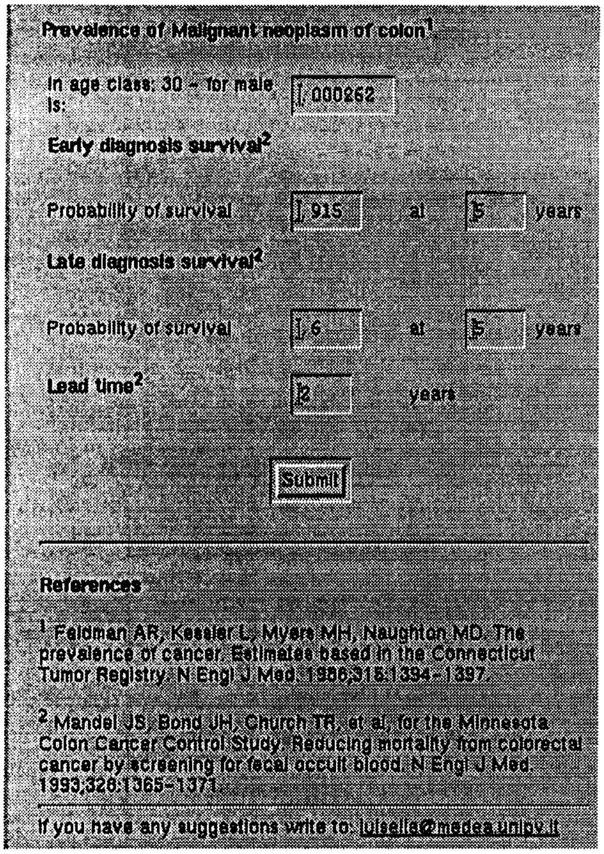

Figure 5: The system retrieves information about the specified diseases

called, and the results are shown (see Figure 6). The most and the least effective, and the most and least expensive strategies are evaluated and compared. In this case, it would be impossible to show the effectiveness and costs for all the possible options, because the number of combinations of diseases to be screened and of test sequences are hundreds. In addition, not only the expected value of the payoffs are shown, but also the dispersion diagrams. This allows to better evaluate the difference among options and to evaluate if the (optimal) suggested decision also complies with the risk attitude of the decision maker. On the user request, the system is able to show dispersion diagrams of the probability distribution of the outcomes.

5. Discussion

Physicians must incorporate costs into their decisions, they unconsciously make hundreds of cost-effectiveness decisions in daily clinical practice. For example, the DRG (diagnosis related groups) based method of hospital funding, which is becoming more and more diffuse around the world, forces physicians to be more concerned about health-care costs than they were in the past. There is a need for integrating tools for cost-effectiveness analysis into the hospital information system, which will make it easier for physicians and administrators to consider these issues in a more rational way. As a by-product of these tools, physicians and administrators will be provided with a common and unambiguous language for communicating their expertise, and sharing their knowledge and data. How to introduce decision models in the hospital information systems? A number of commercial products for performing decision analysis are nowadays on the market, but they are limited to produce 'stand-alone' applications: models built within these systems cannot share any knowledge or data source with other models, nor can make use of common meta-models. More important, these tools do not provide the user with methodological knowledge for building sound models. In recent years, other authors addressed the issue of helping the decision maker to build a correct decision model in the medical area. MIDAS [Sonnenberg 1994] is a system that exploits a knowledge base of the medical domain and a set of rules that guides the selection of the knowledge base items for their insertion into a decision model; unlike our system, it does not contain any pre-built decision model structure, and the size of the final model depends on the completeness of the knowledge base.

Another approach was proposed in [Egar 1993], where a graph-grammar provides assistance for modeling of decisions: the system "accepts an unordered list of terms that together describe a dilemma, and produces an initial influence diagram". To this aim, it embeds a description of medical concepts (whose terminal symbols are partially drawn from standard vocabularies) and their relationships, represented as grammar rules. Unlike our system, the aim of this one is to build only the qualitative structure of the decision model, leaving every quantification to the user. Both these systems do not put the emphasis on economic evaluation, at most considering direct costs of some interventions. On the other hand, they impose fewer constraints to the model structure, that in our system is bounded by the low-level meta-models. Finally, our system is conceived as an internet service. A similar service is COST[1], that differs from ours because it provides very specific models, for some selected diseases, that cannot be tailored by the user, except from the patient characteristics

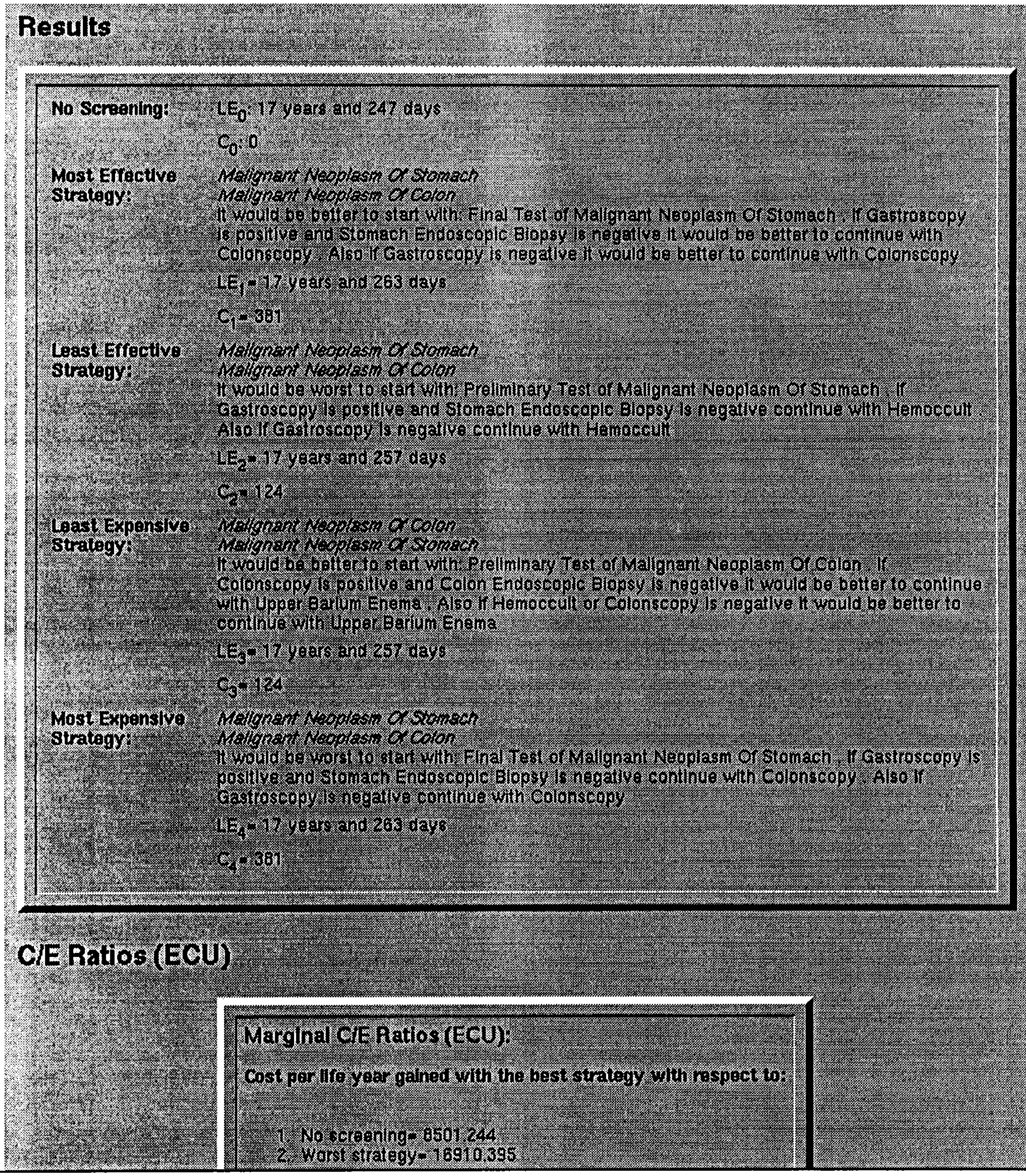

Figure 6: Results provided by the inference engine

[1] COST is a product by Pharmacon Int. Inc., New York

instantiation [Arnold 1996].

While it was not our aim to propose new products for decision analysis, we faced the need for a tool which a) could integrate existing technology for decision analysis with other technologies, such as data base management and knowledge engineering, and b) could provide predefined decision structures addressing the multi-user and multiple-views aspects of cost-assessment and cost-effectiveness applications in health-care. Given this architecture, possible improvement of our system may consist on both the assessment of additional meta-models and the extension of the database. At the moment, these tasks are performed by domain experts (physicians and knowledge engineers), and we believe this leads to the development of *reasonable* models. Of course, it should be very useful to allow skilled users to participate to the system extension, but this requires additional facilities for ensuring both security and reliability of the proposed updating. Future work will consider both these aspects and the system validation.

Acknowledgements

This work is part of the HC-ReMa project, supported by the European Commission within the Health Telematics Program. The authors whish to thank the partners of the HC-ReMa Consortium for helpful discussion about the system architecture. They are: S.K. Andersen and S. Andreassen from the Aalborg University (DK); E. Motta and J. Domingue from the Open University, Milton Keynes (UK); and G. Schreiber from the Amsterdam University (NL). In addition, the authors thank G. Barosi and M. Marchetti for providing data to implement the clinical exemplar.

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