# "VISUAL INTERACTIVE MODELLING AND INTELLIGENT DSS: PUTTING THEORY INTO PRACTICE"

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# VISUAL INTERACTIVE MODELLING & INTELLIGENT DSS: PUTTING THEORY INTO PRACTICE

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The development of *active* but nevertheless *user-centered* systems is a key issue of decision support. Our contribution to this research area is reported here by a new system: An *intelligent* DSS (-generator) for decision-making in a geographical context. This paper describes the major characteristics of the system and the design principles underlying the development of its highly visual, object-oriented modelling environment and of its expert component, which interacts with the user "by example".

**1. Introduction.** Decision Support Systems aim to change the paradigm for providing computer support for managerial tasks[(1)]. The change process can be characterized by the following list of technical attributes:

From data processing to iconic visual information processing.
From formal analysis to interactive modelling.
From algorithmic manipulation to direct manipulation.
From problem solvers to context-sensitive modelling environments.
From "passive" support systems to intelligent cooperative systems.

The main goal is to provide the users with tools for interactively exploring, designing and analyzing his decision situations in a manner compatible with his mental representations[(2)]. Since we have elaborated these cognitive aspects in another paper (Angehrn et al., 1988), herein we will not deal with it in more depth. What we would like to present are some basic guidelines for designing and developing DSS which have shown to be applicable and appropriate in practice. In particular we will focus in the next section on two basic and elementary design principles resulting in the development of user-centered, active decision support systems. In section 3 the abstract concepts described in section 2 are exemplified and illustrated by the system called *Tolomeo*, an intelligent DSS (-generator) supporting decision-making processes in a geographical context.

**2. Modelling Environments and Symbiotic Systems.** From a functional viewpoint, a DSS is characterized by three components: a language system, a knowledge system, and a problem processing system (figure 1). Briefly put, the user initiates and establishes the problem communication with the system by using the expressive power (semantics and syntax) of the language provided. Conforming to the user's requests the problem processing component activates the available functionality of the system and communicates the appropriate response (information, methods, knowledge) to the DSS user.

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(1)"Development of approaches for applying information systems technology to increase the effectiveness of decision-makers in situations where the computer can support and enhance human judgement in the performance of tasks that have elements which cannot be specified in advance" (Sol, 1983).

(2)"On working with people, we establish domains of conversations in which our pre-understanding lets us communicate with a minimum of words and conscious effort. We become explicitly aware of the structure of conversations only when there is some breakdown calling for corrective action. If machines could understand in the same way people do, interactions would be equally transparent" (Winograd et al., 1986).

Based on previously formulated conceptual models (Holsapple and Whinston,1987; Arnoldi,1989) and taking into account the paradigm sketched in section 1, the functional and technical requirements for each component of a DSS like *Tolomeo* are summarized in figure 1.

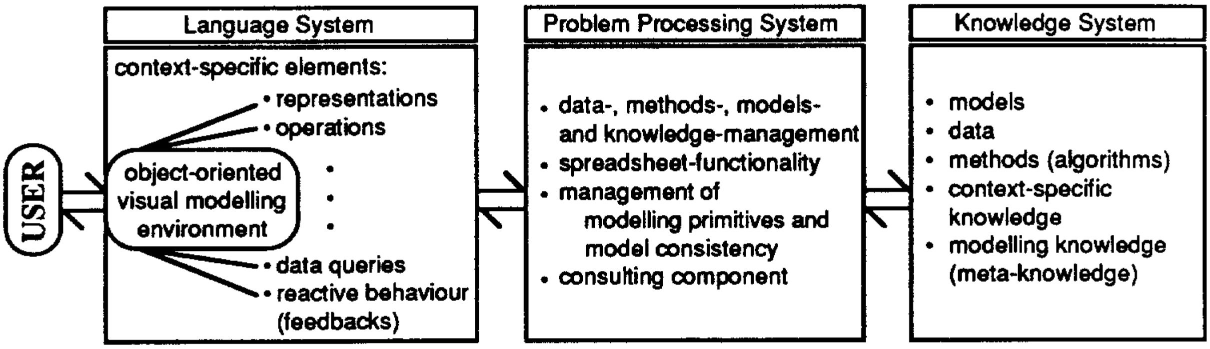


Figure 1: DSS structure and requirements.

For the DSS user, the interface (the language system) is "the System". The provided interaction language does determine the usability of a rich system with respect to its functionality. If its function is not transparent to the user, he or she will either reject the system or use it incorrectly.
This is often an underestimated fact in traditional system development, where the identification of a well-defined problem and the development of algorithms play the major role. In figure 2 this classical "method"-/"data"-centered approach - whose focus is on delivering functionality - is compared with a "user"-centered one (Angehrn,1989). This "user"-centered view adds the integration of a suitable functionality into the system at the end of the development process, emphasizing the importance of first designing an environment the user can effectively work with. We are not questioning here the value of the "method"-centered approach, but we are stressing that only *usable* methods are really effective! Thus our first design principle emphasizes *"Usability prior to functionality"*.

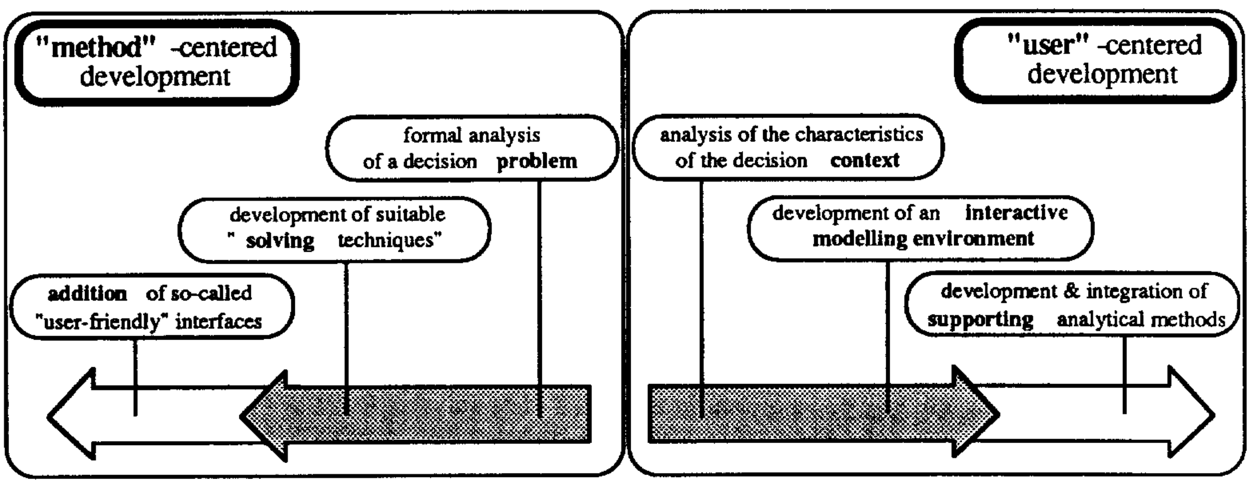


Figure 2. Development approaches

The method- and data-centered development sketched in the left diagram of figure 2 is still recommended in the framework of automatic planning, allowing precise task specification (and delegation!) and hence facilitating the use of suitable and reliable design instruments and techniques. The situation changes when the user must design a large part of his application himself. The emphasis of the system development then shifts to analyzing the so-called *decision context*, determining an appropriate language

and form of communication, identifying notions, concepts and operations familiar to the user and which correspond to his specific knowledge of the problem and experience (Angehrn et al.,1988).
In order to perform the next step of implementing an interactive modelling environment, two technical elements should be carefully studied: Well-established rules for designing *visual languages* (Chang, 1986) and *object-oriented principles* for supporting the modelling process (Brodie et al.,1984). Proceeding in this way necessarily leads to the identification of fundamental constructs supporting *Visual Interactive Modelling* (VIM).

In *Tolomeo* we have identified three such basic items, called "modelling primitives":

- *objects*, i.e. concrete or abstract entities (cities, ambulances,...) with a set of specific attributes (population, accidents,...),
- *relations* and functional *dependencies* (streets, shipments, regions, costs,...), and
- *constraints* on attribute values (e.g. population less then 100,000)

As it will be described in section 3, these generic modelling primitives are made available to the user in such a manner that a human-like form of interaction is simulated through direct association between abstract problem entities and manipulative objects so that a natural, incremental "modelling" of his or her problem perspective is supported.

Furthermore, cooperative teamwork between the human and the computer is only possible when both sides are *active* in the problem-solving process. This presupposes that the system itself can also offer its functionality to suit prevailing conditions in that the available methods can be smoothly interlaced in the modelling process. The second design principle is thus the *"Principle of Active Cooperation"*: While the human divides the complex planning job into partial tasks and assigns some problems to the machine to resolve, the system takes over the role of an "advisor" or "facilitator" (Angehrn,1989). During the decision-making process it stimulates and supports the application of analytical methods as well as other techniques for deducing relevant information through procedural suggestions.

In summary, in the pursuit of these two basic design principles - "usability prior to functionality" and "active cooperation" - we find realistic means of creating so-called *symbiotic* systems which are based on complementing human skills through computer technique "...so that a job which neither man nor computer could or would want to perform alone, can be carried out together." (Fischer and Gunzenhäuser, 1986).

Essentially the user can now perform the following functions independently:

- He can analyze his decision situations according to his personal style and knowledge.
- He can construct and compare various quantitative models.
- In turn he can adapt these to changing external conditions.
- He can evaluate his scope of activity according to different aspects and by employing different means.

**3. VIM and Intelligent DSS: Putting Theory into Practice.** In this section we will use a specific example to show how it was possible to operationalize the design principles mentioned above. For this purpose we will use the DSS-generator *Tolomeo*, an interactive system we have developed for supporting planning tasks in a geographical context. This system illustrates the described user-centered approach, the support of visual interactive modelling as well as the idea of "Modelling by Example" as a means for enhancing an active man-machine cooperation.
We first provide a small educational example which serves as a framework for the system description. Based on this example, part 4 illustrates more in detail the man-machine interaction during a decision process.

*An example: Modelling communication networks.* Figure 3 shows the model of a planning task, in this case the design and the analysis of a communication network, and how a planner can describe it within a short time using the *Tolomeo* system[3]. This model of the situation to be examined/decided on reflects the planner's problem view at a specific phase of the decision process. Apart from the background - showing a map of the planning area - the model consists basically on two main components: nodes and switching centers. Aiming at modelling an existing network the user has introduced some *nodes* (sending/receiving stations, symbolized by ) and some transmission channels (the elements of the *basicnet* through which messages can be transmitted from one *node* to another). Starting from these two components, the user can now explore different alternatives for a qualitative network improvement. Here, the planner is particularly interested in examining the introduction of *switching centers* () to serve as collecting points for message distribution. In this case the *switching centers* are interconnected by a superimposed net (a *hypernet* represented by the bold lines).

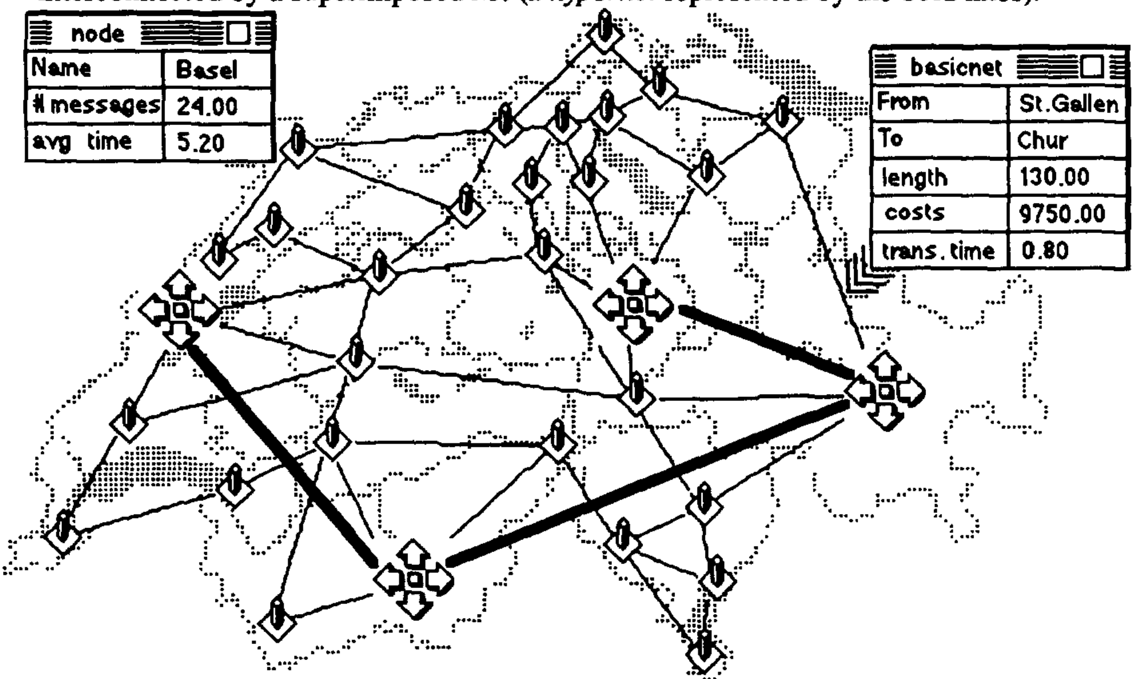


Figure 3: An example.

This small model already enables the user to explore different alternatives for the choice of a specific number of *switching centers*, their location on the map and for the design of the *hypernet*. For supporting his task of alternative generation and evaluation, the user has attached some quantitative information to the single model components. The two tables displayed in figure 3 illustrate how, in *Tolomeo*, every single element of the model can "carry" some dynamic information in the form of user-defined properties whose values can be typed in, extracted from a database or calculated by formulas. The first table (left side of figure 3) shows the properties of the *node* called "Basel" (24 messages sent with an average transmission time of 5.2 seconds). Displaying the second table the user can see the data describing the *basicnet* connection between the *nodes* "St. Gallen" and "Chur".

(3) Note that this kind of planning task is only an example. Tolomeo can be applied in a broad range of decision situations having nothing in common with the example used in this paper. Furthermore, even in this small example, we do not start from a well-defined problem specification. This aspect underlines the often neglected reality that "well-structured problems" usually appear only as partial components in a decision process and are seldom available a priori in an objective form. They only come to light in the flow diagram process stemming from a decision-maker's subjective feeling.

**4. Decision support through Visual Interactive Modelling.** A system like *Tolomeo* can be appropriately described along the following four important dimensions:

(I) End-user (decision-maker) *modelling*.

(II) Modelling as a *concrete*, *visual* and *incremental* process.

(III) *Reactive* system behavior.

(IV) *Smooth integration* of system functionality (especially analytical methods) during the decision process.

***4.1. End-user modelling.*** According to section 1 and 2, one of the most important objectives of DSS development is the design of flexible tools which can be individually employed by users during their decision processes. Modelling, interpreted as the incremental process of converting internalized mental concepts into explicit and hence analyzable representations, is a crucial activity in every formal decision process. One of the most interesting issues in DSS research is the development of concepts and tools supporting decision-makers in performing the modelling process by themselves.
As many of today's DSS mainly focus on problem *solving* rather than supporting the *modelling process*, users are often limited by a fixed scope of action predefined by the system designer. Systems like *Tolomeo*, on the other hand, supply a flexible modelling environment enabling users to develop their own models interactively, starting from their individual views of the decision situations at hand.
This flexibility is based on a clearly arranged set of "primitives", i.e. some basic modelling tools fulfilling the following two requirements:

(i) They are general enough (*expressive power*).
(ii) They are provided in such a way that even end-users can master them without great effort, allowing them to concentrate on the task and not on the tools employed (*usability*).

Accordingly, the main characteristic of *Tolomeo*'s modelling environment is that every operation (definition, modification, representation and organization of model components) can be performed interactively by direct manipulation of *visible* and *tangible objects*.
This design principle, applied to the development of the man-machine interface, permits the avoidance of abstract structures (like command languages) and the realization of a concrete modelling style based on context-specific elements and representations. This can sustantially facilitate the description of complex decision models, whose components are functionally and structurally related in a non-trivial way, and make them more accessible to a wide class of users.

Figure 4 illustrates the original model (depicted in figure 3) enhanced by some new elements: Four *sectors* partitioning the planning area and supporting the user in finding a balanced distribution of the planned *centers*. Using the visual- and graphic-based modelling environment of *Tolomeo*, the introduction and specification of such new model components simply take place by drawing the desired objects (in our case: 4 polygons) on the map displayed on the screen. Once an object has been described graphically, the user can choose a suitable representation and attach different problem-specific properties to it. In the example of figure 4 the user has attached three specific pieces of information to the *sectors*: the properties "#messages" (total number of messages starting from *nodes* within the *sector*), "#centers" (number of switching *centers* contained in the *sector*'s area) and "avg. time" (average transmission time for the *nodes* within the *sector*).

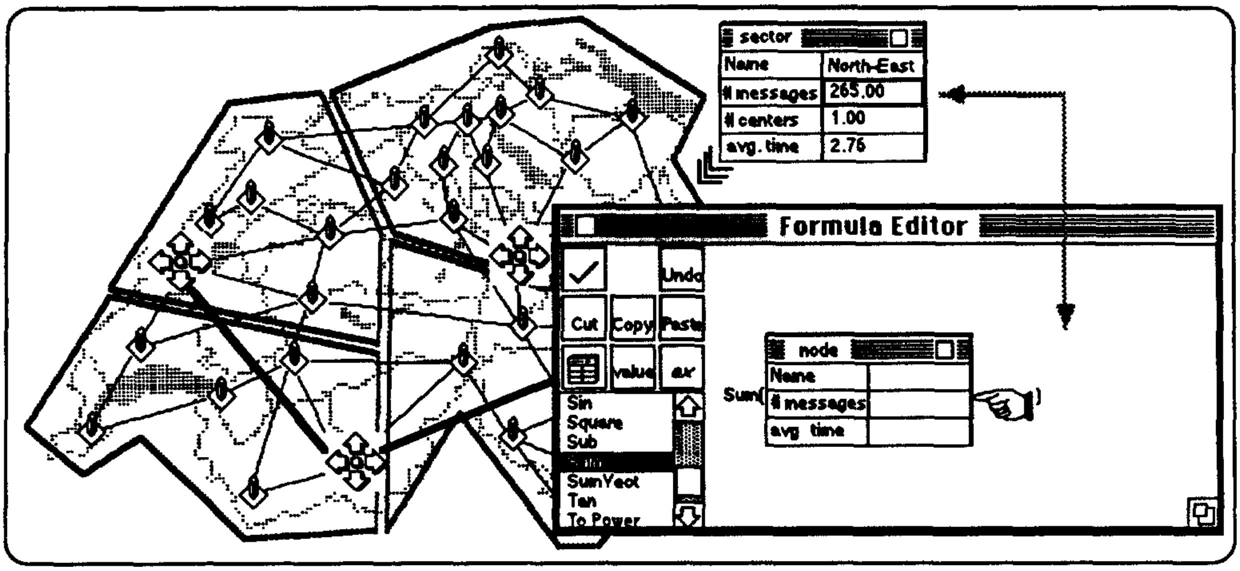


Figure 4. Interactive specification of new model components.

The definition of functional relationships is another important modelling "primitive", which is supported in *Tolomeo* by a graphic-based formula editor. In our example (see figure 4), this editor has been used for attaching a formula to the property "#messages": The user simply adds up the property "messages" for every *node* contained in the *sector*.
This brief example demonstrated how this kind of environment can support users in interactively creating or modifying a model of complex decision situations, allowing them to experiment with various decision alternatives and *see* their impact in a graphical, even dynamic form (Turban and Carlson.,1989).

***4.2. Modelling as a concrete, visual and incremental process.*** The supply of suitable modelling primitives in *Tolomeo* is mainly based on object-oriented concepts (Stefik and Bobrow, 1986). Hence every model can be formally represented as a collection of object-classes characterized by the entities, the properties and the relationships (objects, formulas and hierarchical structures) which the user describes interactively during the decision process. Nevertheless the user is not obliged to explicitly deal with an abstract model representation as in programming. He can perform every operation on his models by manipulating objects, leaving to the system the task of managing the underlying formal structure.
The resulting modelling style presents two main advantages: First, interacting with a system by manipulating significant and concrete objects/symbols gives the user the feeling of *directness* (Hutchins et al., 1985). Second, the direct association "object ↔ information" offers, even occasional users, a natural structure for understanding existing models and for expressing their views of a decision situation according to their own cognitive style.

Beside concreteness, visualization is the second important characteristic of *Tolomeo's* modelling environment. Supporting and facilitating the choice of suitable symbolic or graphical representations is often an underestimated issue. It has, however, a crucial importance in supporting DSS users in:

(i) gaining new insights into the structure of their problems through generating different views of the decision situation under investigation, and
(ii) exploiting their own visual skills in order to recognize meaningful alternatives and strategies during the problem solving process.

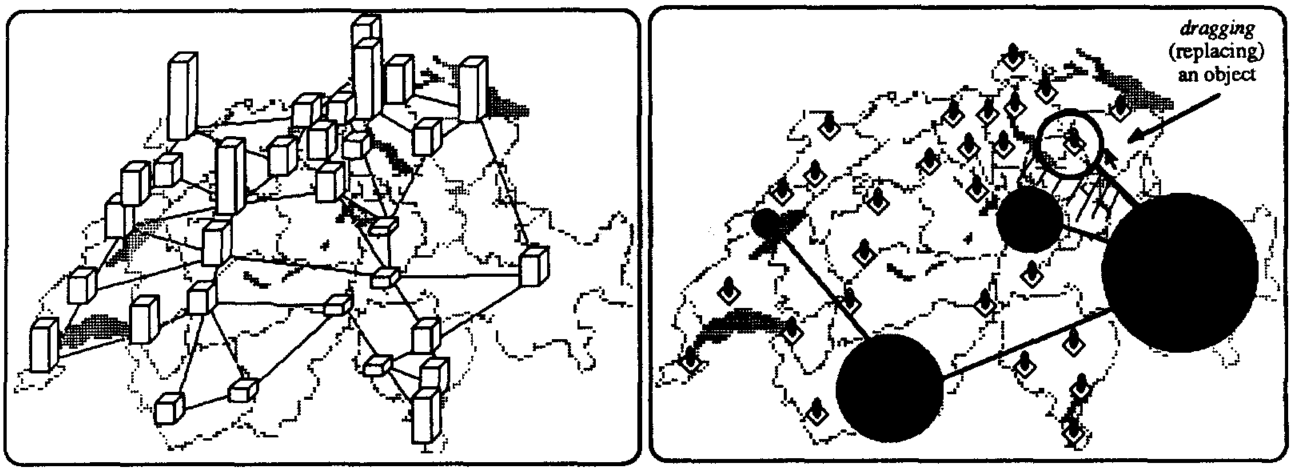


Figure 5. Individual problem visualization.

Figure 5 illustrates two ways in which the representation-kit of *Tolomeo* can be employed for generating different model views. As shown on the left screen, views can be even based on one specific property of some model components. In our case, *nodes* are represented by histograms whose size depends on the value of the property "messages". Moreover the user can create *selective* views and visualize only the model components he is really interested in. In figure 5, for instance, the same model is displayed twice: In the left figure only the *nodes* and the *basicnet* are visualized whereas in the right one the *basicnet* is not visible but the switching *centers* (as circles) and the *hypernet* are displayed on the screen and can be manipulated independently from their current graphic representation.

The support of modelling as an *incremental process* is the third basic characteristic of the "Visual Interactive Modelling" -style achieved through the development of *Tolomeo*. Allowing the user to incrementally build, complete and test his models not only makes the man-machine interaction much easier and concrete, but as the modelling process mainly stimulates *learning* about the unstructured situation under investigation, an important benefit also results from directly involving the decision-maker in this phase and thus supporting a gradually evolving learning process.

***4.3. Reactive system behavior.*** An effective man-machine cooperation is mainly based on the system's capability to complement the user's activity with suitable feedbacks. In a modelling environment such as the one described so far, the reactive behavior is strongly connected to the modelling primitives employed by the user in different situations. In *Tolomeo*, for instance, three conceptually different feedback types can be distinguished:

(i) A recalculation mechanism (*spreadsheet functionality*) operating on the functional relationships (formulas) introduced by the user. The supply of this first kind of feedback accompanying the user's modelling efforts has 3 major advantages:
   - Model consistency is guaranteed at every stage.
   - Incremental model development is supported (the user can always see and work with an updated model).
   - What-If analysis and alternative comparison can be performed interactively.

(ii) Other types of modelling primitives made available by the visual modelling environment of *Tolomeo* are the so-called "constraints". Their role is to support the introduction of semantic information into a model: Using constraints the user can explicitly and dynamically express his own preferences (goals) by attaching specific requirements to any model component. In the network example he could express his concerns regarding fast communication by simply attaching a constraint

to the property "average transmission time" (e.g. these values should not exceed 2.5 seconds for each *node*).
Thus, the second type of reactive behavior realized in *Tolomeo* aims at showing the importance of control mechanisms processing different types of user-defined constraints. In *Tolomeo* such a mechanism dynamically checks the existence of constraints, tests if the conditions are fulfilled and advises the user through a visual feedback. The system indicates to the user those model components which do not achieve certain targets (defined by the user interactively) and supports in this way a kind of "visual optimization": The user immediately - visually - recognizes the quality of the decision alternatives he has designed, and at the same time he obtains useful indications for improvements.

(iii) A third important feedback which should be supplied in visual modelling environments concerns the control of structural consistency. Building models of decision situations, the user will always employ the available modelling primitives for defining structural relationships between different model components. A typical example in our network model concerns the *switching centers*, whose location can be structurally confined to places where a *node* already exists.
As discussed in the above paragraph (ii), it is again up to the system to guarantee consistency and to react in case one of these implicit rules is broken by the user during the modelling process.

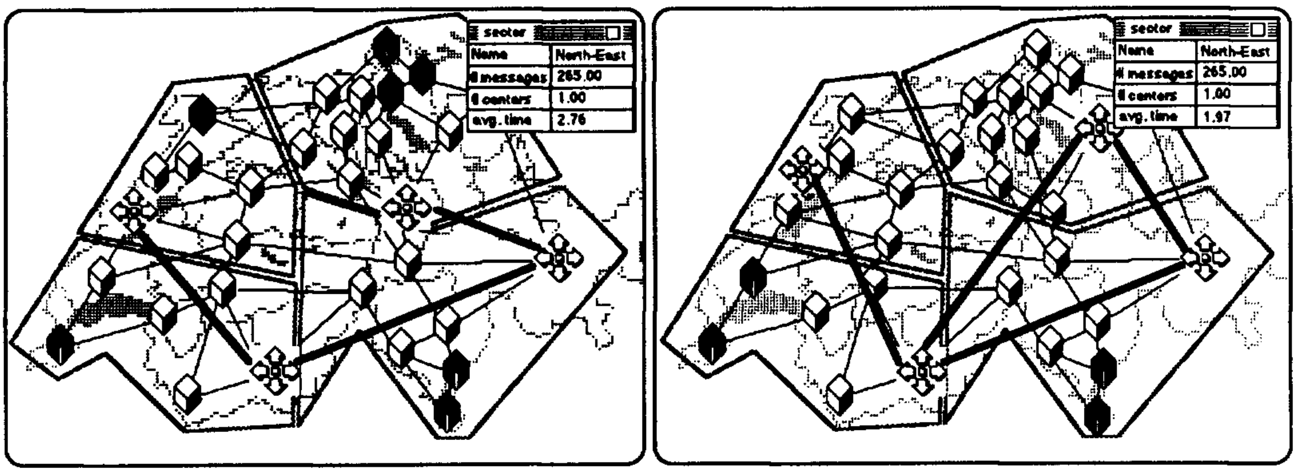


Figure 6. Design and evaluation of alternatives.

Figure 6 illustrates the most important feedback types implemented in *Tolomeo*. The pictures show two different alternatives for the location of the *switching centers* and for the design of the *hypernet*. The user can test the quality of each alternative (i) in a visual way, and (ii) by looking at the property-tables displaying the current property-values by double-clicking the corresponding object/symbol.
By this means the user can immediately see the differences in the network structure and for instance find out, that the "average transmission time" of the *sector* called North-East is much lower for the alternative displayed on the right screen. Furthermore figure 6 illustrates the effect of the visual mechanism operating on the constraints. Given that a constraint like "< 2.5" has been attached to the *stations'* transmission times, the system shows in both cases which the "critical" *stations* not meeting this requirement (the dark cubes) and supports the user in exploring better solutions.

*4.4. Smooth integration of system functionality during the decision process.* The concepts described so far, as well as their realization in the decision support system *Tolomeo*, are mainly oriented to supporting the *user's active involvement* in the process of designing and analyzing decision alternatives. But what about the *system's* activity? Apart from the reactive behavior sketched in the last section, the system role remains quite "passive" (*reaction* is not equal to *action*, and further discussions about the emerging *active* role of DSS are articulated in (Keen, 1986) and (Jelassi et al.,1987)).

In the following we shortly describe an approach developed for supporting decision making processes in a more "active" way. We will focus on the smooth integration of analytical tools as a new component enriching the visual modelling environment described above.
The supply of active support consists in extending the system with the capability of a "consultant" which should be able to

(i) understand/interpret the decision situations described by the user,
(ii) dynamically formulate suggestions, and
(iii) support the ad-hoc application of different techniques.

The main idea underlying this interactive consulting activity consists in letting the system communicate with the user through an exchange of concrete "examples" (as human experts usually do).

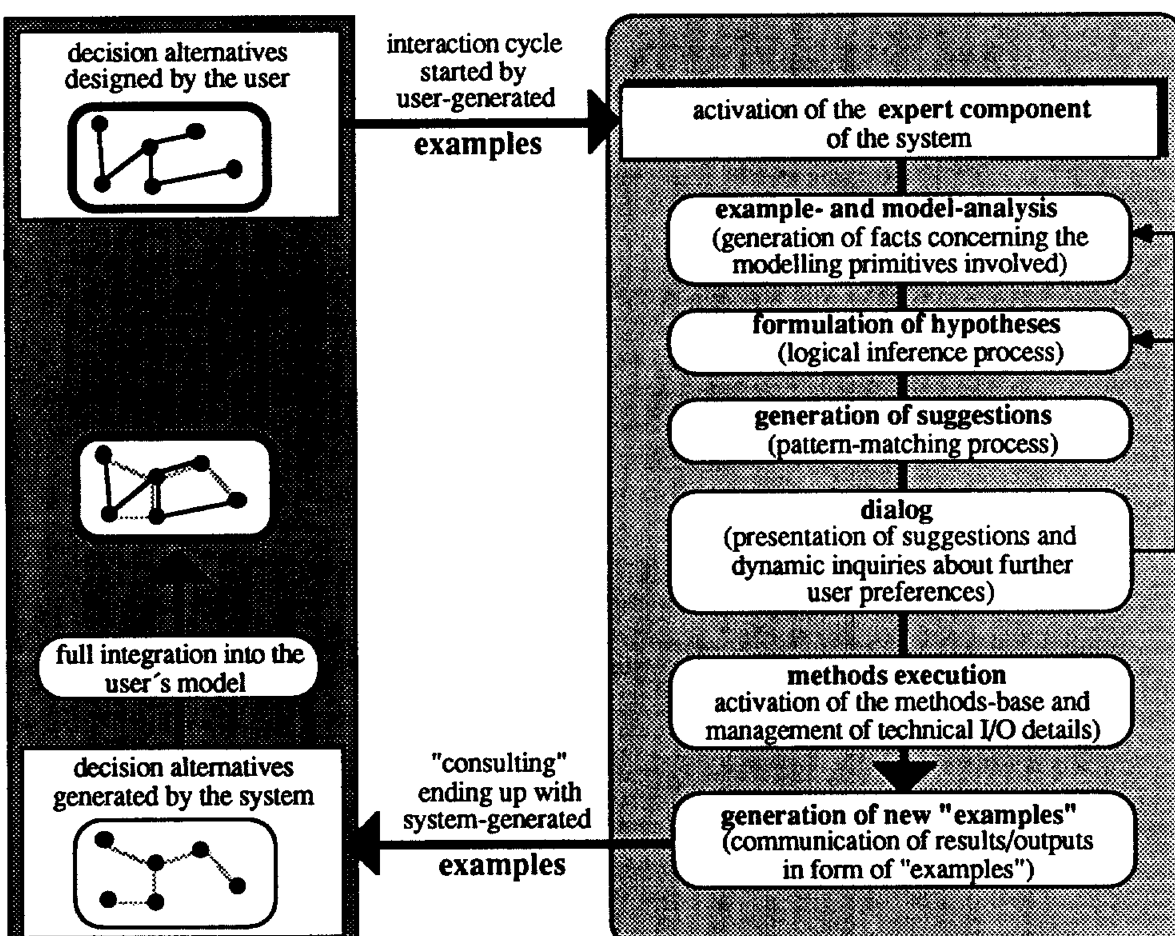


Figure 7. Active system support "by example" (schematically).

The "Modelling by Example (MbE)" -scheme shown in figure 7 has been applied in *Tolomeo* to support the flexible utilization of complex methods (mathematical tools and other significant information processing techniques) within visual interactive modelling environments. One of the main benefits of this unconventional, direct way of delivering "expert" support (*by example*) results from supplying the system functionality (model- and knowledge-base) *smoothly*, i.e. without obliging the user to interrupt his decision process or to reformulate his models (by switching from a *descriptive* to a *normative* "mode"): The same decision alternatives which the user designs and analyzes manually in a What-If mode serve directly as "examples" for the expert component of the system. As shown in figure 7, the user can simply *hand over* his alternatives to the system and activates in this way an inference mechanism, which usually concludes, after a dialog, with some suggestions for generating new and "better" alternatives.
Without going into the technical details of the realization of the MbE-approach[4] sketched in figure 7, it can be summarized that the idea of using "examples" as a form of communication between user and system enables *Tolomeo* to support end-users and "experts" in taking advantage of powerful mathematical methods as for example optimization algorithms and heuristics applicable to routing, transport, allocation and clustering problems. In addition, their utilization during the decision process takes place in a concrete and flexible way, conforming to principles well-suited to visual interactive modelling.

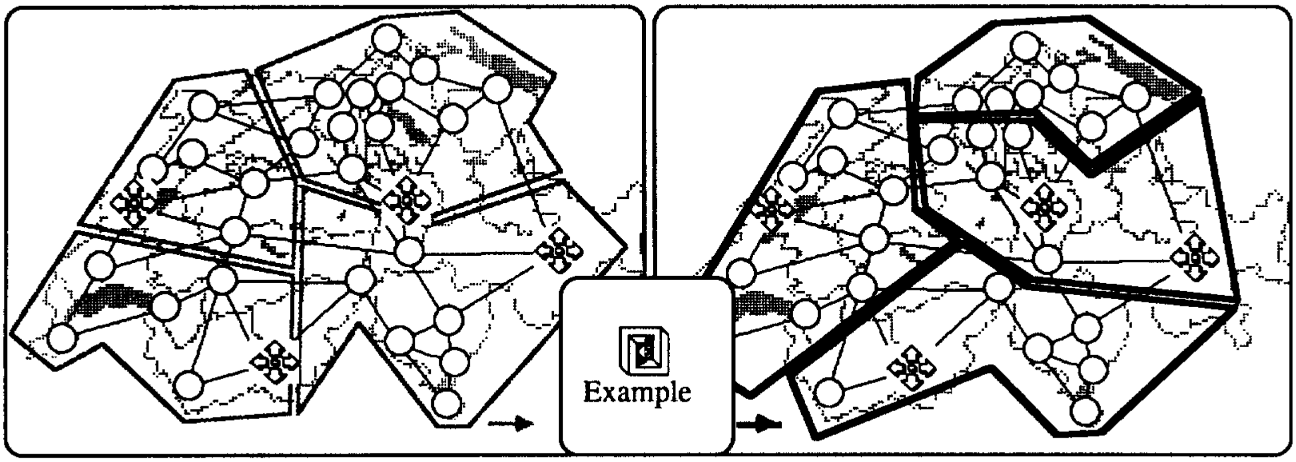


Figure 8: Clustering "by example".

Figure 8 illustrates how the developer of the network model can activate the consulting component of *Tolomeo* by simply "handing over" his self-designed *sectors* as "examples" of what he is looking for (dragging them on the special desktop icon ). After an analysis of the structural characteristics of the user's example, the system will generate a dialog presenting graphically the deduced suggestions (by example, again) and allowing the user to express further criteria and preferences. With the agreement of the user, the system will then select a suitable method, will extract the needed input parameters from the user's model and will finally generate a new "example". As shown in figure 8 (right), such a system-generated "example" corresponds to a new set of *sectors* clustering the planning region and showing some "optimality" characteristics, as e.g. a balanced distribution of the message quantities or flows in the different *sectors*.
As the decision alternatives generated by the system are fully integrated into the user's model, they are immediately available for further explorations (e.g. through What-If

[4] Tolomeo has been implemented on a MacIntosh II using the procedural language *Modula2* and the declarative language *Prolog*. For more information concerning the inference process, see (Angehrn,1989).

analysis). For instance, the new *sectors* can be immediately used for supporting the user in designing new locations for the *switching centers* (one *center* per *sector*).
Even for this allocation problem the user can exploit the MbE-approach implemented in *Tolomeo*: As illustrated in figure 9, the *centers* , which have been previously planned by the user, can now serve as "examples" (figure 9, left). In this case the system analyzes the new examples and makes some suggestions for achieving a better allocation of the *switching centers*.

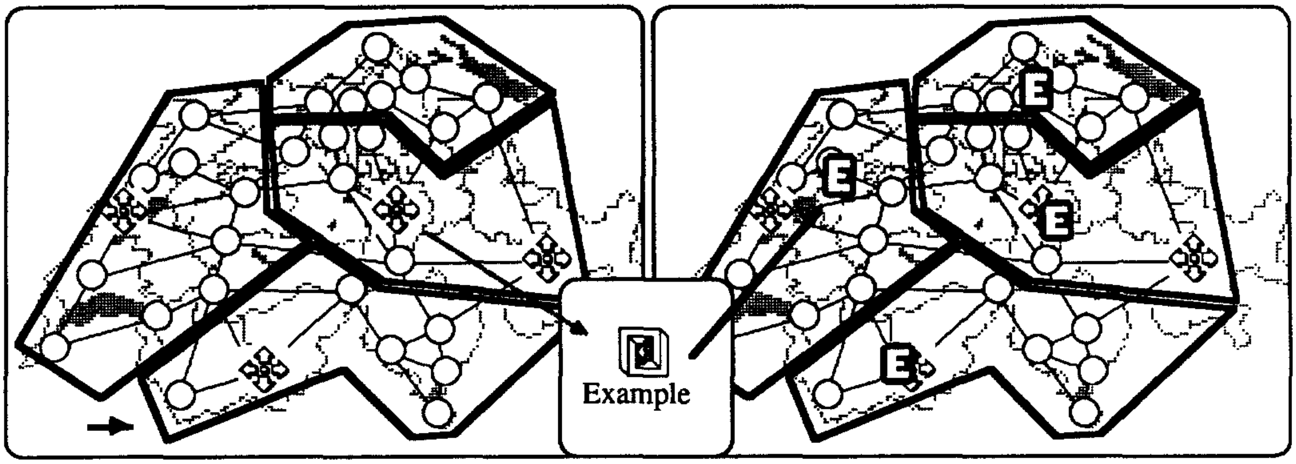


Figure 9: Allocation "by example".

The man-machine cooperation leads again to the introduction of new model components: The new objects , visible on the right hand side of figure 9, correspond to the system-generated alternatives for the location of the *switching centers*.
This example also shows another important advantage of the MbE-approach. As the communication takes place on the basis of concrete "examples", the decision-maker is no longer obliged to "battle" with input preparation or output representation. It is up to the system to take over these technical tasks and allow the user to operate at the high-level of his descriptive model views. Furthermore, in the above example, the clustering generated by the system serves as input for the allocation problem. As the output of mathematical methods is automatically represented in form of "examples" (generated by the system using the user's "examples" as a model), the MbE-approach also supports a flexible linkage of different techniques that combine human skills and computing power.

**5. Conclusions.** The "VIM"-principles and the "Modelling by Example"-approach presented in this paper offer concrete guidelines for the development of user-centered DSS (generators) like *Tolomeo*, exploiting the advantages of visual modelling and supplying an *active* decision support through a proper integration of AI techniques.
We are convinced that human-computer interaction still remains a central issue in the DSS-domain and that further research efforts are needed for realizing a high-level man-machine cooperation in problem-solving and decision-making.
Beside *Tolomeo*, which has been developed for supporting decision-making in a geo/demographical context, other tools based on the same design principles but acting in a different decision context are under development. They will provide a broader basis for evaluating and empirically testing the application of the guidelines described in this paper.

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