THE ROLE OF MODELING

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Summary

Following a brief four-dimensional morphological taxonomy of models (Section 1), two surveys of modeling are presented, covering modeling as a mental activity (Section 2) and mathematical modeling (Section 3). Consideration of the mental activities involved in modeling serves to deepen insight into the ongoing mental processes dealing with internal and external models. The human brain only deals with models, rather than with the immediate reality. All individuals' models differ, due to individuals' differing mental "internal stages." This insight is important to understanding why certain explicit models (particularly mathematical ones) are accepted or rejected by different individuals.

Mathematical modeling will be considered from the specific aspects of operations research and management science (OR/MS). With respect to the objects to be modeled, five types of modeling will be distinguished. After a brief taxonomy of the most

important OR/MS models, their similarities with relational database structures will be outlined, and the availability of standard software for model design and model management in OR/MS will be surveyed.

1. Introduction: Morphology of Models

The term "model" is of central relevance to most branches of science. Models, as well as modeling (in the sense of processes applied to models), play a fundamental role not only in research, but also in the ways people cope with problems, both personal and professional ones. In other words, models are crucial to understanding reality as well as to decision making.

Models shall be classified here according to properties related to four attributes (Table 1):

- With regard to *maturity*, *internal (tacit)* models shall be distinguished from *external (explicit)* ones (Sections 2.1 and 2.2). Internal models are more or less unstructured representations of reality in our brains: pictures of our "images" or "internal stages." In contrast, external models are explicit and serve the additional purpose of communication.

- With regard to *abstraction*, *analogous* models shall be separated from *symbolic* ones. Analogous models—like photographs—relate directly to an original and require little imagination to be acknowledged and accepted; they look (or sound, or smell, or taste, or feel) similar to the original. Symbolic models, however, are abstractions in which elements of reality are represented by symbols. Symbolic models can consist of language as well as of mathematical terms (Section 3).

- With respect to *operationality*, a distinction is suggested between *descriptive* and *responsive* models. Descriptive models are essentially reports on reality, portraits, illustrations, and even definitions. They are not suitable for any kind of algorithmic operation: i.e. they are not responsive. In contrast, responsive models are designed to accept questions and to answer them; frequently they are presented in mathematical notation (Section 3).

- With respect to *purpose*, models that help to develop theory shall be distinguished from those that help to support *practice*. Models for theory aim to provide a better understanding of the world and its parts. Models for practice are to assist problem analysis and decision making: in other words, they are involved with practical action (Sections 2.5 and 3).

Attribute	Attributive Properties	
Maturity	Internal (Tacit)	External (Explicit)
Abstraction	Analogous	Symbolic
Operationality	Descriptive	Responsive
Purpose	Theory	Practice

Table 1. Condensed morphology of models

Many more attributes and attributive properties of models are considered in the relevant literature, but this morphology (Table 1) covers the most important ones for the purpose of this paper. Use of the term “morphology” to attain “total field coverage” was suggested by Zwicky (1898–1974), and this aims at fullest possible comprehension of all possible instances.

This contribution is rooted in the field of Operations Research and Management Science (OR/MS); therefore, emphasis will be placed upon *external*, *symbolic*, and *responsive* models in the service of *practical* aims. However, the interdependence between *internal (tacit)* and *external (explicit)* models will be considered in some detail, because the interaction between internal and external models is the key to the acceptance of external models in the professional practice of OR/MS.

Some consideration has already been given to models in the field of OR/MS. Churchman, Ackoff, and Arnoff (1957) were among the first researchers to do so, dedicating a whole chapter of their OR textbook to the term “model.” The term “model” stems from the Latin term “modus,” and its diminutive “modulus.” Among its contemporary meanings are “a hypothetical description, often based on an analogy, used in analyzing something” (Webster’s *New World Dictionary*, 1990 edition: US), and “a thing from which something else is to be derived; a basis” (Chambers *Pocket Dictionary*, 1992 edition: UK). In this contribution, the human brain’s continuous modeling processes will be considered first (Section 2). This survey will be followed by a consideration of mathematical modeling as practiced in OR/MS (Section 3).

2. Modeling as a Mental Activity

Modeling is an ongoing mental activity. The brain deals continuously with internal and external models (Section 2.1), and internal models are in continuous interdependence with external ones (Section 2.2). The role of modeling can be traced back through history, and many of its roots lie in Greek philosophy (Section 2.3). Modeling is sometimes understood as intentional activities (Section 2.4), which serve the purpose of theory or of practice (Section 2.5).

2.1. Internal versus External Models

The human brain is always occupied with modeling activities—with the design of models, their interpretation, and their storage and retrieval, as well as with their usage. These are *internal*, mental models. They are related to “tacit” knowledge in the terminology of Nonaka and Takeuchi. We do not literally hold reality as such (trees, dogs, cars, roads, enterprises, nations, heaven, other individuals etc.) in our brains; instead our brains deal with our internal (i.e. tacit) models, which represent both, objects from external reality and objects of our own imaginations.

Contrasting to some extent with these internal models are *external* ones, corresponding with “explicit” knowledge in the terminology of Nonaka and Takeuchi. These are based on agreed “meta-model” formats and standard terminology—in other words, on rules of syntax and semantics.

While internal models assist our individual (intrasubjective) understanding of the world, and our personal abilities to cope with it, external models also serve in communication between humans. They help to develop shared views of the world and support collective understanding of it. External models (and our perceptions of them) influence our internal models continuously.

Internal modeling processes are like an ongoing play on our "internal stage," which is different in form and content from one person to another. A related term to the "internal stage" is "image," as used by Boulding. Everybody has an individual "image" of the world. This develops continuously under the influence of received messages, and some messages may even be intended to change the receiver's image. The terms "internal stage" or "image" shall here be understood as the totality of mental individuality; the term "internal model" shall be understood as a single picture, a scene from the internal stage, or a single glance at it.

The differences between individuals' internal stages depend on a great many factors. These may be condensed into three groups:

- The individual's knowledge (the result of education and experience),
- The individual's psyche, and
- The individual's value system.

An accountant, for example, understands an enterprise through its balance sheet and a salesperson through its products, due to their different knowledge. Mintzberg illustrated this with reference to an interaction between a planner and a manager. A planner (or an analytic researcher) may perceive isolated problems and try to solve them by analytic reduction; a manager may perceive disorder and chaos (and his or her duty to resolve it), due to their different psyches. Members of different religions, political parties, competing enterprises, and other entities have different perceptions of the processes going on in their own group and those going on in others, due to their different value systems: their loyalties, attachments, and group memberships.

Communication may be understood as an exchange of pictures between individuals' internal stages. In order to make communication between people possible, external (i.e. explicit) models are needed. They are based upon commonly-agreed "meta-model formats," including natural languages (with their syntax and their semantics), formal languages (like mathematics and computer programming languages), and body languages, as well as any other kind of symbols, icons, and signs (such as those used in construction plans, traffic systems, computer interfaces, or musical composition). Such meta-model formats are necessary to enable exchange between different internal stages: they are frames, generalizations, and rules.

External (i.e. explicit) models are instances of meta-model formats, and depend upon agreement between people. A cock's crow, for example, is modeled "cock-a-doodle-doo" in the English language, "kikeriki" in German, "cocorico" in French, and "quiquiriqui" in Spanish. Cocks of different nationalities do not crow very differently;

the differences lie in the commonly agreed meta-model formats adopted by humans. While the cocks are independent of national languages, their cry is modeled by humans. The “cock-a-doodle-doo” has a place on the internal stage of anybody with English as their first language, “kikeriki” on that of anybody with German as first language, and so on.

This can be taken further. Anybody who is familiar with linear programming (LP) models has an LP facility (i.e. an LP meta-model format) on his/her internal stage. Anybody who is familiar with chemical structures keeps a chemistry suite on his/her internal stage. Anybody who is used to a particular programming language creates programs of any algorithm in this language on his/her internal stage. When we reflect on any external model, we interpret them against the scenery of our internal stages; at the same time they influence, change, and enrich our stages. The agreed meta-model formats help us understand certain types of external model.

The term “meta-model format” is important in working with models. The layouts of a balance sheet and a profit-and-loss account are examples of meta-model formats. This kind of format is the foundation on which individual balance sheets for a certain enterprise in a particular year can be understood. The meta-model format is the frame for understanding the individual cases: it enables our internal stages to perceive the individual models. The form and content of the meta-model formats are the bases for understanding the structure and the terminology of model instances. Individuals who share a meta-model format can communicate about model instances of the same format; the shared meta-model format is the entrance to mutual understanding.

There is a continuous interaction between an individual’s internal models and the external models. Everyone is steadily bombarded with external models but perceives and accepts only those which find acceptance on his/her internal stage, or might adapt the received external models to fit the structure of his/her own stage. On the other hand, we all continually develop external models of our selected internal models, partly in order to gain deeper insight into a situation, partly to communicate with others. Both directions depend upon the individually-accepted meta-model formats that are the components of everyone’s internal stages.

2.2. Interdependence of Internal and External Models

Modeling - or the design, interpretation, storage, and retrieval of models as well as their usage - is a continuous, and at least partly subconscious, mental process. It is structured by cognitive science in many different ways, for example as a framework of six activity groups:

- *Activity group 1: first imagination*. Reality and external models are continuously bombarding all individuals. The models are perceived, consciously as well as unconsciously, by the individuals’ senses and transformed into internal models. Some of these internal (tacit) mental models never reach consciousness; others do. It is even an open question as to whether perceptions that do not become conscious should be termed “models” at all.

- *Activity group 2: reflection.* Those internal mental models that reach consciousness act as triggers for reflection. The individual becomes aware of, and perhaps even interested in, the models and starts to give thought to them.

- *Activity group 3: design.* The individual may select certain internal models and begin—instinctively and/or purposefully—to design his/her own explicit models of them.

- *Activity group 4: comparison.* The model designer develops internal models of the new external models which he/she is constructing. He/she compares his/her new internal models of the new external models with his/her own (former) internal models of reality.
- *Activity group 5: acceptance.* The results of these comparisons are of central importance. Only if the former internal models correspond with the new internal models will the modeler accept their own external model.

- *Activity group 6: implementation:* Should the external (explicit) model be accepted, it will be implemented in the sense that the model user replaces reality with the external model: in other words, the user now interacts mentally with the model instead of with reality itself.

The activities of the six groups are not necessarily consecutive phases; instead, they are interlinked in many ways. They may be illustrated by the following example.

1. A product manager visits an industrial fair and sees thousands of products offered by hundreds of enterprises.
2. Only certain products catch his attention - particularly a prototype of a new product that will compete with one of the products of his or herown enterprise.
3. Despite a lack of printed information he/she begins to model the prototype: to draft technical drawings and a bill-of-material list, to calculate R&D and production costs, and to estimate the market price, possible demand, and so on.
4. The product manager will compare his/her image of the competitor's prototype—possibly continually—with his image of his drafts and computations (which act as external models).
5. In cases where both images correspond, he/she will accept his external models.
6. Finally, he/she will use the new external models and (for example) communicate them to colleagues, managers, and/or staff. Since none of the information receivers may have had the chance to see the prototype, their own imaginative processes would start using the product manager's external models.

Communication by means of external models depends upon agreed meta-model formats. The drawing of the prototype may only be understood by those who are used to technical drawings, and the bill-of-material list can only be communicated between those who are familiar with this kind of information format. The same holds true for calculation schemes, and so on. In general, acceptance of somebody else's external models involves overcoming cognitive differences in terms of *knowledge* between the individuals involved.

Acceptance of somebody else's external models must also overcome cognitive differences with respect to the psyche of the individuals involved (Section 2.1). As explained by the "brain split theory," people (at least the right-handed ones) control their analytical, logical, and convergent thinking with the left hemisphere of the brain, but their holistic, pictorial, and divergent thinking with the right hemisphere. Both hemispheres exchange information via the *corpus callosum*. For instance, the term "square" would be understood by the left hemisphere, which is also in control of the mathematical rules regarding the square. The perception of the graph of a square, however, would be controlled by the right hemisphere. Usually one hemisphere is dominant: possibly the left hemisphere in a planner's brain and the right hemisphere in a manager's brain, as suggested by Mintzberg. People with a "left" dominance may prefer symbolic models, and those with a "right" dominance analogous ones (Table 1). A "right"-side dominated manager may have difficulties from his or her first engagement with an external model designed by a "left"-side dominated planner.

2.3. Greek Roots of Modeling

Modeling (Table 1), particularly the design of *explicit* models, helps people understand the world better (through more advanced theory) and cope with it more effectively (by means of better decision making). The design of explicit models—those lying beyond language—has a long history, and many of its roots may be traced to Ancient Greece.

It was Empedocles (483–424 BC) who first proposed the scheme of the four elements out of which everything is composed: water, air, fire, and earth. This was after Thales (ca. 625–545 BC) had suggested that water was the original substance, Anaximenes (ca. 585–525 BC) had assumed that a "cosmic air" was the fundamental essence of the universe, Heraclitos (ca. 544–483 BC) had considered fire as the prevalent matter, and Parmenides (ca. 540–480 BC) had postulated earth as the decisive material. The meta-model format of the four elements was kept alive through many centuries, and shaped the understanding of the Western world at least until the end of the eighteenth century and even beyond.

Pythagoras (ca. 580–500 BC) stated: "All things are numbers," and suggested that mathematics (and numbers) hold the key to the secrets of nature and its harmony. This was an early plea for mathematical modeling. Some 2100 years later the three "planet laws" of Kepler (1571–1630), published in a book with the characteristic title *Harmonices Mundi* ("Harmony of the World") in 1619, are prominent examples of the Pythagorean approach—natural harmony represented by mathematical models.

Hippocrates (ca. 460–377 BC) developed the doctrine of the four temperaments (sanguine, choleric, melancholic, and phlegmatic), a meta-model format of bodily and mental personality that is still alive on many people's internal stages.

Plato (427–347 BC), in his famous "Parable of the Cave" (chapter 7 of *The Republic*), taught that we have no sensual access to (real) reality; instead we perceive only "shadows" of real things. The "ideas"—the central core of reality—tend to remain hidden in the shadows. If we follow his "theory of ideas," we can only model the surfaces of reality: Plato's shadows.

Plato’s doubts may lead to the still-relevant question of whether modeling means *discovery* or *creation*. Discovery is based on the doctrine that reality has a given structure. Our brains try to reveal the structure of reality and express it in our own terminology (language, mathematics etc.). In contrast, creation starts from the standpoint that reality is amorphous and that any structure is human-made, artificial, and subjective. Does reality itself have structure? Alternatively, is any real structure provided by humanity? There is no final proof of either of the doctrines. Supporters of the former may refer to the apparently clear evidence for the structures we perceive with our senses: stars, mountains, trees, water, earth, and creatures, as well as manufactured goods and other items. Yet how reliable are our impressions if we can only perceive their surfaces—in other words, Plato’s shadows? Supporters of the latter doctrine may refer to Theodor Lessing (1872–1933) and understand “science as structuring the structureless reality.” For example, do our models of matter portray the real atomic structure, or are they human representations of matter in our imaginations?

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Biographical Sketch

Heiner Müller-Merbach is Professor of Information Systems and Operations Research at the University of Kaiserslautern, Germany. He received his Diploma degree in Management and Engineering and his doctoral degree in Management Sciences from the University of Darmstadt. He held chairs of Business Administration at the University of Mainz (1967–1971), Management Sciences at the University of Darmstadt (1972–1983), and Information Systems and Operations Research at the University of Kaiserslautern (since 1983). Dr. Müller-Merbach has served in several positions in German OR societies, was Council member of the Institute of Management Sciences (1985–1987), and served as Vice-President (1974–1976) and President (1983–1985) of the International Federation of Operational Research Societies (IFORS). He has published twelve books and more than 400 articles in scientific journals. Since 1986 he has been a member of the Technology Advisory Committee to the State Administration of Rhineland-Palatinate, one of the sixteen states of Germany. Dr. Müller-Merbach belongs to the advisory boards of more than ten scientific journals, and has served as Editor-in-Chief of German scientific journals such as *Unternehmensforschung* (1970–1978) and *Technologie & Management* (1985–1997).