The Structured Systems Approach for the Design of Optimisation and Simulation Models

Heiner Müller-Merbach
Universität Kaiserslautern
D-6750 Kaiserslautern, Germany

Abstract: The structured systems approach integrates the **design** of computerised **models** and **information systems** with comprehensive **relational data bases.** It can be applied to any kind of optimisation and simulation models including system dynamics. In addition, the structured systems approach supports the model design **process** and its **documentation**; it stimulates the **interdisciplinary** and **interpersonal** participation in the model design process.

1. Changed Architecture of Computerised Models and Information Systems

The architecture of computerised (optimisation and simulation) models and information systems has changed in the past and will keep changing in the future. So did and will do planning and modelling procedures.

In the **past**, computerised models and information systems were more or less isolated, single-purpose representations of sections of reality; each model and each information system had its **own** individual data base. Planning and modelling as activities were considered as an **art**, and very little attention was paid to its systematisation.

In the **future**, models and information systems will have to be considered in a broader and **more comprehensive** way. This will be accompanied by a methodological support of the planning and modelling procedures.

The centre of future models and information systems will be **comprehensive relational data bases.** All the models and information systems will take access to central data bases, and the planning and modelling procedures will be carried out in a systematic grammar, again based upon the relational data base terminology. The methodology based upon the grammar of relational data bases shall be called

"structured systems approach".

Conclusion of section 1: The future architecture of (optimisation and simulation) models and information systems is characterised by comprehensive **data bases** in the **centre**, to which any programme (and query) refers. The data bases will be **relational**, and the relational grammar will be constituent for planning and modelling procedures.

2. Relational Data Bases and the Structured Systems Approach

Relational data bases were initiated by Codd (1970), succeeded by numerous contributions since. Many others have contributed to this characteristic of thought, such as Wedekind (1974) with his **"object type approach"** and Chen (1976) with his **"entity relationship approach"**. The **structured systems approach** follows the same principles, but is less closely linked to computer applications and closer to **model design** in general (Müller-Merbach 1981, 1983).

The **structured systems approach** is an extension of many **traditional** forms of the systems approach (for its variety see e.g. Bahm 1981). It is common use in the systems approach to understand the world (and its many mini worlds) as a **system** (or as a hierarchy of systems and sub-systems, respectively) consisting of single **elements**. The elements have certain properties, and each system has **additional** properties which are not properties of their sub-systems. This leads to the traditional, 2,500 years old insight that "the whole is more than the sum of its parts". This has been expressed in different wording by the ancient Greeks, such as Heraklitus (ca. 550 - 480 B.C.), Plato (427 - 347 B.C.) and in particular by Aristotle (384 - 322 B.C.), also by the chinese philosophy of Lao-Tse. They are, indeed, the ancient founders of the systems approach (Müller-Merbach 1988). Examples for thinking in systems:

- A word is more than the sum of its letters. A sentence is more than the sum of its words. A chapter is more than the sum of its sentences. A book is more than the sum of its chapters. An author is more than the sum of his books.

- A bicycle is more than the sum of its frame and its wheels. A wheel is more than the sum of the tire, the spokes, the hub etc., a spoke is more than the sum of its crystals. A crystal is more than the sum of its atoms.

The structured systems approach is based upon this thinking and makes usage of it for design purposes. It works with a notation of six terms: with **elements** and **element sets**, with **relationships** and **relationship sets**, and with **attributes** and **attribute values**.

The **element sets** and the **relationship sets** are the "coat hangers" for information, i.e. for the **attributes**. For each single **element** (of an element set) and for each single **relationship** (of a relationship set) data, i.e. **attribute values**, can be assigned to the attributes.

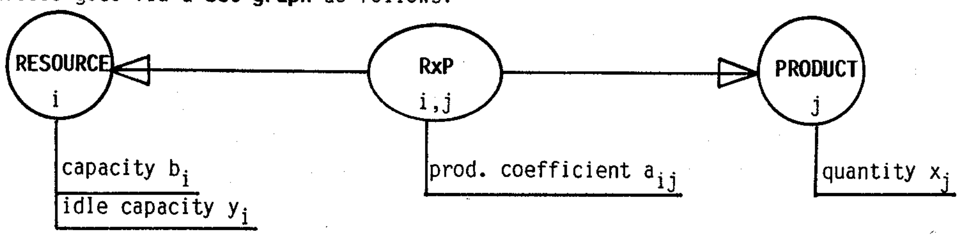
This "grammar" is quite general and in many aspects applicable to model and information system design; in particular, it refers immediately to the notation of mathematical models (Müller-Merbach 1981, 1983): A single **index** specifies a certain **element** of an element set; an **index tuple** specifies a certain **relationship** of a relationship set; any **constant** or **variable** is represented by an **attribute**.

Take, for instance, a standard constraint of linear programming:

$$y_i + SUM_j \; a_{ij} x_j = b_i \quad \forall \; i$$

In this equation, the index i may indicate a single resource of the element set **RESOURCE**, while the index j indicates a single product of the element set **PRODUCT**. The constant b_i may then represents the attribute "capacity" of resource i while the variable y_i represents the attribute "idle capacity". Similarly, the variable x_j represents the attribute "quantity" of product j. The index tuple ij indicates a single relationship pair of resource i and product j; the constant a_{ij} represents the attribute "production coefficient" between resource i and product j.

In the structured systems approach, the process of designing such mathematical models goes via a **set graph** as follows:



Such a set graph is a comprehensive documentation of the information required for a particular model. The element sets are drawn as circles, the relationship sets as ellipses. The corresponding attributes can (in case of not too many sets and attributes) physically be assigned to the sets.

Set graphs do not only support the documentation, they also serve the purpose of communication between the modeller and the problem owner. They can use the set graph to find consensus about the relevant sets and their relevant attributes.

Set graphs can be designed for single purposes and the corresponding models. In general, such single-purpose graphs would be merged with the data base of the institution, e.g. an enterprise. The totality of single set graphs required within any institution constitutes the full data base structure for the institution's comprehensive information system.

Comprehensive information systems come into existence by the continuous extension of its central data base through repeated application of the structured systems approach to all the models of the institution. Any programme or query or (optimisation and simulation) model will eventually refer to the data base. Should any element set, relationship set or attribute not as yet be available, the data base would have to be extended accordingly.

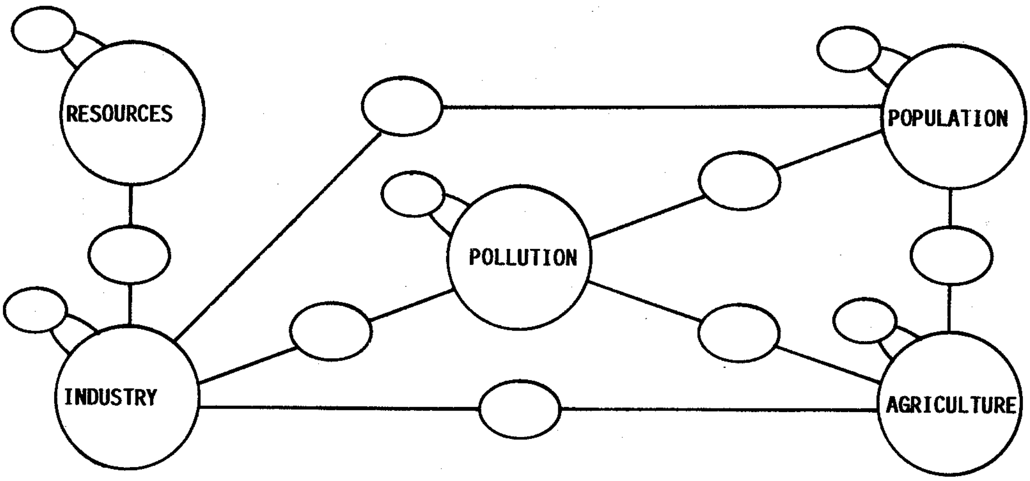
Conclusion of section 2: The structured systems approach would organise the information required in an institution as **attributes** assigned to **element sets** and **relationship sets.** The integration of all the sets and their attributes required would eventually bring about the data base of a comprehensive information system.

3. The Structured Systems Approach for System Dynamics Models

The structured systems approach (or any other relational data base terminology) serves the same purpose for any kind of model, be it an optimisation or a simulation model, including system dynamic models. This is even independent of the fact whether a **comprehensive** data base is being designed or whether the information structure supports the **individual** model only.

Considered be the world model by Meadows at al. (1972). They decided to model the world with respect to five element sets: **POPULATION**, natural **RESOURCES**, **INDUSTRY**, **AGRICULTURE**, and **POLLUTION.** All of these sets accommodate at least one element each, and it is up to the model designer to differentiate between different kinds of population, of resources, of industry etc.

The element sets are presented in the following graph (circles). They are connected by relationship sets (ellipses). A particular property of system dynamics models is the relationship between any particular state of today and the corresponding state of tomorrow. This can be represented by relationship sets which connect an element set with itself.



This graph represents the element sets and the relationship sets and is now ready for the attributes to be assigned to the sets. The attributes can be constants, state variables, rate variables, or any other kind of variables.

The structured systems approach helps to organise the modelling process in that the different levels of design decisions can be separated: What are the relevant **element sets**? Which are the relevant **relationship sets** between the element sets? What are the relevant **attributes** of the element and relationship sets? Many individuals can participate in this process without any specific competence in mathematics and computer sciences.

Conclusion of section 3: The structured systems approach can be applied to **system dynamics** modelling in the same way as to optimisation and other simulation models.

4. The Modelling Process

Models and information systems are the results of design **processes.** These processes require many **decisions.** Models are not just photographs of reality; instead, they are constructions carried out by conscious human minds.

The process of modelling (at least if the model serves a relevant purpose) is necessarily at the same time **interdisciplinary, interpersonal** and **exploratory.** It should be **interdisciplinary** in order to cover **more** aspects than just that of **one** discipline, be it physics, chemistry, electrical engineering, economics, or sociology etc. It should be **interpersonal**, i.e. represent different persons' views, since its results should be acceptable for **groups** of people and not just for a single individual. It should be **exploratory** in that the modelling process itself will open the eyes and provide additional insight into the problem area under study.

Therefore, the model design process itself requires a procedural structure that covers more than just the mathematical model as the outcome. Instead, the modelling process requires a documentation that follows the top down process of design decisions. For this purpose, a five level organisation is being suggested (see Müller-Merbach 1983):

- **Level I - unstructured verbality:** At least - but not only - in the beginning of the modelling process, much unstructured communication will take place. Different ideas and views will be expressed, and dissenting expectations will eventually have to be brought to consensus and/or compromise.

- **Level II - set design:** The relevant **element sets** and the **relationship sets** are being defined and connected to each other in a set graph.

- **Level III - attribute design:** The relevant **attributes** are being defined and assigned to the corresponding element and relationship sets.

- **Level IV - function design:** The **functional dependencies** between the attributes are being defined and transformed into mathematical equalities and inequalities.

- **Level V - data management:** The **attribute values** (data) have to be assigned to the **single** elements and relationships (of the corresponding sets). Some of the data may be available from data bases while others have to be collected somewhere.

Even if there is some internal top down structure from level 1 to level V, the design process need not precisely follow the sequence of the levels. Instead, all the five levels can be accomplished in some parallelity. The levels should be unterstood as **simultaneous components** rather than as **consecutive phases** (Müller-Merbach 1982).

The level structure guides the design process, serves as **top down documentation** and supports the **interdisciplinary** and **interpersonal** communication:

- It guides the design process in that it helps to control the questions regarding the relevant personal views, the relevant sets, the relevant attributes etc.

- It serves the purpose of documentation in that each level brings about its specific documents.

- It helps to communicate in that (i) the unstructured verbality will eventually be mapped in terms of sets, attributes, functions etc. and in that (ii) these records will increase the systematic order of communication.

Thus, the **structured systems approach** may help to stimulate the **participation** in the design of optimisation and simulation models - as well as of comprehensive information systems (see also Geoffrion 1987). This includes experts of methodolgy as well as, in particular, experts in the relevant substance matters.

With the ongoing systematization of modelling processes, the design of models and information systems will more and more become a common skill and will not remain the prerogative of mathematicians and computer scientists etc.

<u>Conclusion of section 4:</u> The structured systems approach will not only **integrate** mathematical models and information systems, but also improve the **documentation** of models and intensify the **communicative design process.**

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