INTEGRATIVE SYSTEMS MODELLING:
Leveraging complementarities of qualitative and quantitative methodologies

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Abstract

The purpose of this paper is to show that a combination of System Dynamics (SD) and the Methodology of Network Thinking (MNT) developed at the University of St. Gallen can help overcoming some of the limitations of both methodologies, and realizing substantial synergies between them.
Insights from an application of this synthesizing methodology, which we call "Integrative Systems Modelling", to a case study, - the RITTS (Regional Innovation and Technology Transfer System)-project in Aachen (Germany), - support our assumption that MNT and SD are highly complementary methodologies.
The experience of this intervention shows that MNT is excellent for eliciting knowledge on complex issues from those who incorporate theoretical understanding and practical experience. It helps in surfacing issues, finding consensual domains and building a communication culture in a team. However, the modelling capabilities of MNT are limited. They do not include formal quantitative modelling of variables and their relationships. Also, the possibilities for simulation and validation are very limited.
To overcome these limitations, SD modelling is the ideal complement. The concept of "Integrative Systems Modelling" is outlined and its main steps of application are illustrated by means of the Aachen RITTS case. Thereby, also the advantages, limitations and complementarities of the GAMMA and ITHINK software packages, in model building, become visible.

1. Introduction.
The separation between the practitioners of the system dynamics community and those with similar interests developing their activities within other systemic approaches has started to be overcome. The convenience of opening system dynamics practice to other related fields where complementarities can be found has already been pointed out elsewhere (Lane and Oliva, 1994).
In this paper we will show how this complementarity was leveraged in a European Commission project entitled "Computer Based Modelling, Simulation and Graphic Representation of Technology Innovation Networks. European Innovation Monitoring System, Sprint DG XIII/D-4". We will demonstrate how the joint application of the Methodology of Network Thinking (MNT) and System Dynamics (SD), as realized in this project, can generate high synergies for dealing with complex issues or problems.
Our paper is structured as follows. First we give an outline of MNT and SD pointing out some of their limitations. Next we identify the aspects of each of these methodologies that may generate synergies when used in combination. Finally we show some of the content of the work made in the Aachen RITTS case where this combined approach has been put into practice.

2. The Methodology of Network Thinking.
The MNT is a methodology developed at the University of St. Gallen (Switzerland) based on the insight that management is regularly confronted with complex issues or problems and a need for decision and action under time as well as information constraints (Schwaninger, 1995). MNT was designed to meet the following requirements simultaneously: 1. Specific dedication to management issues; 2. Channelling and integration of multiple viewpoints; 3. Boundary specification and definition of issues; 4. Combination of qualitative and quantitative modelling; 5. Support not only of modelling but as well of implementation (Schwaninger and Zindel, 1994).

2.1 The MNT intervention process.
The MNT intervention process can be summarized along the following seven steps (Gomez/Probst, 1987; see also: Schwaninger, 1995):
1. Delimiting the problem.
a) Definition of goals and perspectives: Reasons and motivations for the various stakeholders affected by the issue at hand are considered.
b) Definition of the main variables and parameters: Each perspective involved ascribes a purpose to the system-in-focus (i.e. formulates its goals), and then specifies the success factors considered critical for their achievement.
2. Establishing the Network: The complex interrelationships which constitute the issue or problem at hand ("system-in-focus") are visualized in a network.
3. Apprehending the dynamics of the process: Short-, medium- and long-term influences and feedbacks between parameters and variables are identified and represented graphically.
a) Cross impact analysis and classification of variables. The intensities of the interrelationships are roughly quantified. From there, a classification of variables and parameters into four groups is undertaken by means of a cross-impact-matrix: active, passive, critical or inert. This classification as well as its visualization can automatically be achieved with the help of appropriate software packages (see end of this section).
4. Interpreting Potential System Behaviors: For the purpose of exploration, scenarios are constructed, considering in particular the development of largely uncontrollable factors that constitute the future context for any development of the system-in-focus.
5. Ascertaining the Design and Control Possibilities: A distinction between controllable and uncontrollable aspects from the viewpoint of the observer or "controller" helps to identify the levers on which strategies and actions can be built.
6. Shaping Design and Control Strategies: Based on a comprehensive understanding of the problem as well as the possibilities of steering interventions and scenarios concrete strategies are developed.
7. Realizing and further Developing the Problem Solution: The success of "interventions" should be monitored by "strategic controlling". The aim is a continuous development and improvement of the system-in-focus. This is the core challenge enabling for organizational learning and intelligence.

The graphic and simulation software "GAMMA" developed by Unicon Meersburg, Germany (available in German and English) can be used for a quick graphic representation of the network and further classification of variables[1].

2.2 Some limitations of MNT.
From step 3 on several limitations of the MNT become apparent. When trying to understand the dynamics of the situation, it is true that considerable insights from identifying the influences between variables according to different time horizons (short, medium and long term) and intensities, and by classifying the variables in 4 groups (active, critical, passive or inert), can be obtained. These will be of help for guiding interventions. The point is that the information about the behavior over time of the system-in-focus, derived from this procedure is limited. The information about relations between variables (such as: existence of relation, transfer function, intensity and time delay) must be complemented by the exact type of the relationship, and

[1] Another software package with similar capabilities is "Sensitivitätsmodell", developed by Prof. Vester's Studiengruppe für Biologie und Umwelt, Munich, Germany.

especially by differentiating variables in levels and rates[2]. The addition of these two components of information should have a very big influence on the quality of the model.
Another limitation of MNT concerns the validation of the model. A network model obtained through steps 1 and 2, despite the fact of grasping a considerable amount of information, lack specification: the parameters, functional forms, and initial conditions are needed to fully specify and test the model. What the MNT model furnishes is an initial hypothesis about the structure of a system, which still needs to be tested. Simulation, as Sterman (1994) points out, is the only practical way to test these models. Here, SD appears as a necessary tool if we wish to advance in the knowledge of the system-in-focus.
Similar comments can be made in relation to steps 4 and 5. If we wish to know the impact of the different scenarios on our system, and identify the points of intervention, we need a tool which is capable of showing the effects of the changes on the environment, and the sensitivity of the key variables of the system to each of the "controllable" factors we pretend to use for steering purposes. Again, simulations of the model, according to the requisites mentioned before, is the answer.

3. System Dynamics.

3.1 The SD intervention process.

The process of applying the SD methodology can be summarized in the following steps (Forrester, 1994):
Step 1. Describe the System. The main elements of this step are:
a) defining the problem or issue to be studied; b) describing the problematic behavior; c) identifying the causal factors which appear responsible for causing the problem symptoms; d) framing information about feedback relationships between factors; e) formulating policies which transform information into decisions (Lane and Oliva, 1994).
Step 2. Convert description to level and rate equations.
Step 3. Simulate the model.
Step 4. Design alternative policies and structures.
Step 5. Educate and debate.
Step 6. Implement changes in policy and structure.

3.2 Some limitations of SD

The SD intervention process described above, starts with the identification of a problem to be tackled. The selection of "the problem", which will be the focus of the whole process of model building, can be difficult in situations where many viewpoints and interests are present. As Lane and Oliva (1994) indicate "the fact is that the theory of SD rarely touches on practical means of helping participants generate and articulate a richly divergent set of different views which might inspire different issues upon which a model-building study may centre".

4. Integrative Systems Modelling: A tentative synthesis.

After the comments just made about the limitations of both MNT and SD methodologies, we can conclude that these two methodologies are highly complementary. On one hand, MNT is excellent for eliciting knowledge on a complex issue from those who incorporate theoretical understanding and practical experience. It helps in surfacing issues, finding consensual domains and building a communication culture in a team. SD, on the other hand, strives for minimization of inconsistencies and operationalization of the variables, when mapping the model. It offers the power of a rich and flexible simulation tool for testing the model, for identifying the causal structures underlying the behavior of the system modelled, for exploring scenarios and supporting decision-making. We call the combined use of the two methodologies "Integrative Systems Modelling" (ISM). This is a framework for synthesizing qualitative and quantitative modelling, in order to deal with complex issues more effectively than if only using one of both. In figure 1 the main components of this methodology are represented.

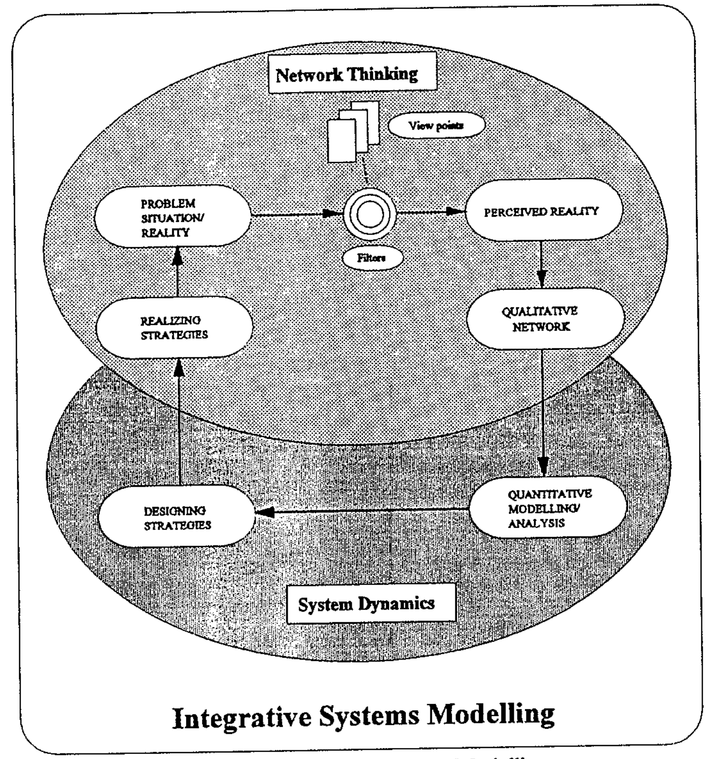

Figure 1. Integrative Systems Modelling

5. The Aachen RITTS case.

The aim of the EC project mentioned in (1.) was examining the suitability of the MNT and SD for dealing with complex issues as well as testing the GAMMA and ITHINK software tools for this purpose. In this context, an application to the Aachen RITTS-project was realized, as were several others to RITTS projects in Germany and Finland. RITTS stands for Regional Innovation and Technology Transfer System. This term denotes network organizations promoted by the European Union, and meant to enhance the global competitiveness of European regions.
The application of the combined methodologies aimed at attaining the following objectives: 1) Elaborating a decision support for the steering committee of the Aachen RITTS-project; 2) Creating a platform for cooperation and fostering contacts among the parties (companies, personalities and institutions) involved in the RITTS project; 3) testing the assumption that MNT and SD are highly complementary methodologies. MNT proved to be an excellent heuristic for eliciting knowledge from an interdisciplinary team, fostering communication and cohesion between its members, who came from different backgrounds. SD on the other hand provided the facilities to build a formal, quantitative model with powerful simulation capabilities. The combination of the two methodologies led to a heuristic named "Integrative Systems Modelling".

[2] Concerning the use of causal loops without a differentiation between levels and rates the following observation by Forrester (1994) seams particularly relevant: "Much of systems thinking uses causal loops-diagrams that connect variables without distinguishing levels (integrations or stocks) from rates (flow or activity). Causal loops do not provide the discipline to thinking imposed by level and rate diagrams in system dynamics. Lacking the identification of level variables, causal loops fail to identify the system elements that produce the system behavior".

We will resume briefly our activities developed in this project.

a) MNT intervention.
In two workshops, key actors of the local RITTS elaborated their own model, therewith developing a shared understanding of the reality they were part of. That way, about 20 persons were involved in the modelling process, which required substantial facilitation skills. The MNT intervention took place through a succession of workshops where the main interests concerned with the Aachen RITTS were represented. The program of the workshops covered mainly: introduction to the methodology, formulation of issues and relevant perspectives (Perspectives/stakeholders; objectives of stakeholders; key factors for each group of stakeholders) and elaboration of the network. This work was followed by an operationalization of the variables; temporalization of the network; determination of the strengths of influences of the variables; attribution of weights to the relationships and analysis of patterns of interaction between the variables. The perspectives and variables incorporated in the network were:

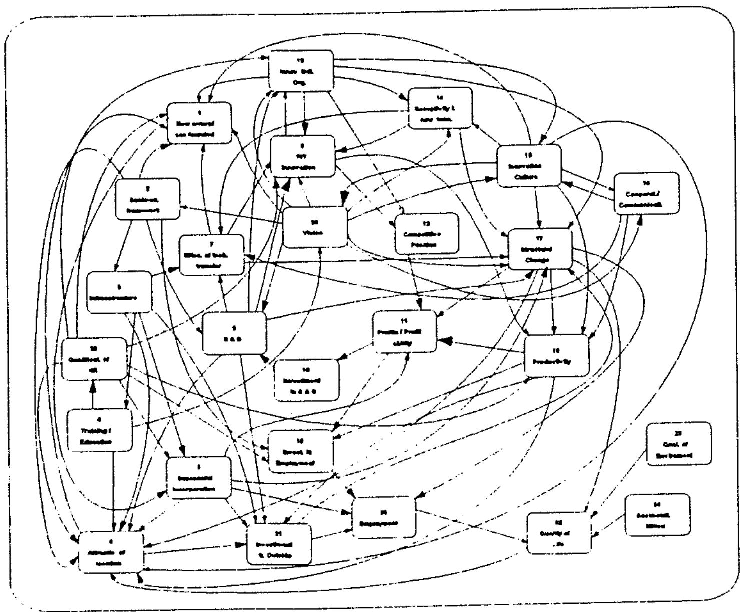

Figure 2. Network (example of MNT application)

<u>*Perspectives*</u> considered for the definition of issues: 1) Companies (Direct and Indirect beneficiaries); 2) Employees; 3) Districts and City of Aachen; 4) External constituencies (Potential Allies, Public in General and Media); 5) Infrastructure ("Software: Technology Transfer Units, Chamber of Commerce, etc" and "Hardware"); 6) Education and Research (RWTH-Aachen Polytechnic); 7) Country of Nordrhein Westfalen (Small Business Department); 8) European Union, Germany (National Level), 9) Natural Environment/Ecology).
<u>*List of Variables*</u>: 1) New enterprises founded, 2) Socio-economic framework; 3) Infrastructure; 4) Training/Education; 5) Successful incorporations, 6) Attractiveness of location; 7) Effectiveness of technology transfer; 8) Research and Development (R&D) expenses; 9) Product/Technology Innovation;
10) Investment in R&D; 11) Profits/profitability; 12) Competitive position; 13) Innovation-friendly organization; 14) Receptivity (for new technologies); 15) Innovation culture; 16) Cooperation/Communication; 17) Structural change; 18) Productivity; 19) Investment in employment (workplaces); 20) Employment (workplaces); 21) Investment from outside; 22) Quality of life; 23) Quality of environment; 24) Socio-cultural milieu; 25) Qualification of Human resources; 26) Vision; 27) Risk capital; 28) Cost structures.
<u>*Network*</u>: In figure 2 we show one of the networks elaborated.

b) SD intervention.
In a later phase, the two authors developed a System Dynamics model with approximately 200 variables. The modelling process proved to be very efficient and effective, to a large part due to the high level of knowledge accumulated in the prior phase of qualitative modelling.
The SD intervention took as its starting base all the materials and understanding generated during the MNT intervention. The assimilation of all this led to a first SD model. This initial version was further revised in an iterative process in collaboration with some of the persons that had participated in the MNT intervention. In this way we increased the possibility of incorporating within the SD model the insights gained during that process. Let us review briefly some content of the SD model.
The SD model named DYNAACHEN-2 was elaborated using the ITHINK software. It consists of seven main sectors: Organization-1; Organization-2; Public sector; New companies from outside; New companies from interior; Employment sector; and Quality of Life sector. The main variables included in each sector are the following:
ORGANIZATION-1. Quality of Human Resources, Vision, Cooperation and Communication, Productivity, Innovation-friendliness, Quality Culture.
ORGANIZATION-2. R&D level, R&D investment. Profits, Product-Technology Innovation, Structural Change, Receptivity to New Technology, Innovation Culture, Competitive Position.

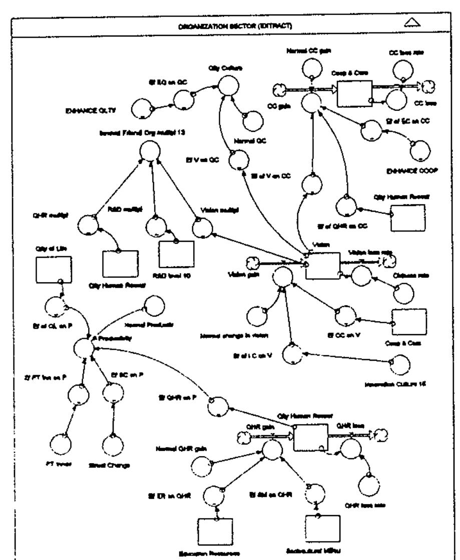

Figure 3. Organization sector (extract of SD model)

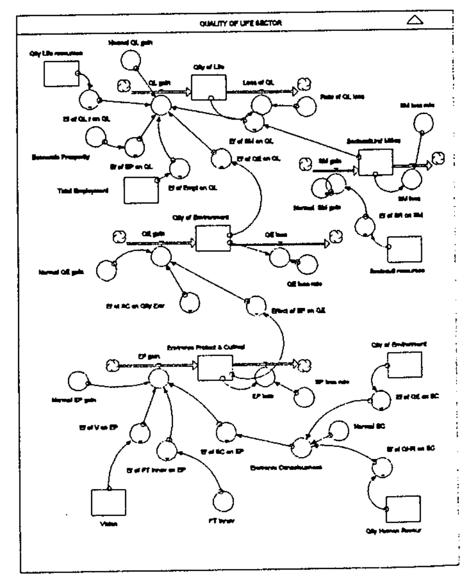

Figure 4. Quality of Life sector (extract of SD model)

PUBLIC SECTOR. Resources Quality of Life, Economic Incentives, Education, R&D, Infrastructure, Sociocultural activities, Public Budget, Cultural Consciousness.
NEW COMPANIES FROM OUTSIDE. New companies from outside, Regional Attractiveness.
NEW COMPANIES FROM INTERIOR. Risk Capital, New Companies due to R&D, New Companies due to Technology Transfer, Number of Technology Transfers, Quality of Technology Transfer.
EMPLOYMENT. Total Employment, Employment loss, Employment from Interior companies, Employment from Outside companies, Economic prosperity, Companies affected by structural change.
QUALITY OF LIFE. Quality of life, Quality of Environment, Environment protection and cultivation, Sociocultural milieu, Environmental Consciousness.
As an illustration of the type of information incorporated within the sectors we present in figures 3 and 4 an extract of the Organization sector and the Quality of Life sector. The details of the whole model, including equations and tables, are documented in Pérez Ríos, 1995.

6. Conclusions.

Applying only one specific methodology (qualitative or quantitative) to the complex problems faced by managers today may often be insufficient. Therefore, a combination of methodologies which offer complementarities is highly recommended. The experience of synthesizing two different methodologies (MNT and SD) to a Regional Innovation and Technology Transfer issue reported here, has revealed significant benefits from transcending methodological "isolationism", achieving synergy from breaking the boundary between quantitative and qualitative modelling.
We propose this combination of MNT and SD (which covers both qualitative and quantitative modelling), named "Integrative Systems Modelling", as a highly useful methodology for dealing with dynamic complex issues where many different viewpoints and interests are involved. It is worth noting, at this point, that ISM raises a series of further methodological issues, on which we plan to elaborate elsewhere (Schwaninger/Pérez Ríos, forthcoming).

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