The University of Linz, organized the first CAST workshop in April 1988, promoted and chaired by Franz R. Pichler, dealing with computer theoretical and practical tools for problems in system science. This meeting demonstrated the acceptance of the concepts by the scientific and technical community. Next, Roberto Moreno-Díaz, of the University of Las Palmas de Gran Canaria joined Franz Pichler, motivated and encouraged by Werner Schimanovich of the University of Vienna (present Honorary Chairman of Eurocast), and they organized the first international meeting on CAST, (Las Palmas February 1989), under the name EUROCAST 1989, which again proved to be a very successful gathering of systems theorists, computer scientists and engineers from most of European countries, North America and Japan. It was agreed that EUROCAST international conferences would be organized every two years, alternating between Las Palmas de Gran Canaria and a continental Europe location, later being decided to host them in Las Palmas. Thus, successive EUROCAST meetings took place in Krems (1991), Las Palmas (1993), Innsbruck (1995), Las Palmas (1997), Vienna (1999), Las Palmas (2001), Las Palmas (2003) Las Palmas (2005), Las Palmas (2007), Las Palmas (2011), in addition to an extra-European CAST Conference in Ottawa in 1994. Selected papers from these meetings were published in Springer’s Lecture Notes in Computer Science series as volume nos. 410, 585, 763, 1300, 1798, 2178, 2809, 3643, 4739, 5717, 6927, 6928, and in several special issues of Cybernetics and Systems: An International Journal.

EUROCAST and CAST meetings are definitely consolidated, as shown by the number and quality of the contributions over the years.

EUROCAST 2013 took place in the Elder Museum of Science and Technology of Las Palmas, during February 6—11. It continued the approach tested in the last conferences as an international computer-related conference with a true interdisciplinary character, in accordance to the nature of modern systems science. There were different specialized workshops devoted to:

1. Modeling Biological Systems, chaired by Nobile and Di Crescenzo (Salerno)
2. Mobile and Autonomous Transportation Systems, chaired by De Pedro (Madrid)
3. Systems Theory and Applications, chaired by Pichler (Linz) and Moreno-Díaz (Las Palmas)
4. Intelligent Information Processing, chaired by Freire (A Coruña)
5. Computer Vision, Sensing and Image Processing, chaired by F. Llorca (Madrid)
6. Computer-Based Methods and Virtual Reality for Clinical and Academic Medicine, chaired by Rozenblit (Tucson) and Klempous (Wroclaw)
Escaping the Linearity Trap:  
Better Simulation Models for Management Support

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Abstract. This contribution aims to show a way towards better models for management support. We compare linear and nonlinear models in terms of their performance. Based on a case study, the respective benefits and shortcomings are fleshed out. A linear spreadsheet model and a nonlinear System Dynamics model are used to deal with one and the same issue: capacity planning in a large telecommunications company. Our analysis refers both to the quality of the models and the process of model building in that firm. The necessity of nonlinear models, when dealing with complex dynamic issues, is substantiated, and strategies for the implementation of such models in organizations are outlined.

Keywords: Linearity, Nonlinearity, Modeling and Simulation, Model-building, Capacity Planning.

1 Purpose

The difference between linear and nonlinear models has important implications for the way we manage organizations and other social systems. Linear models can be misleading as they often do not adequately represent the reality of socio-technical systems. If one is misguided by a model, it is difficult to know that one is. The purpose of this paper is to explore that discrepancy and show a way out of that linearity trap.

Getting caught in linear modeling is common in firms, but nevertheless ineffective in the context of complex situations¹, as will be demonstrated. It is essentially due to flawed or superficial mental models of dynamic systems. In this contribution, we address the limitations of the linear simplicity which abounds in modeling practice, and the benefits of adopting a nonlinear view of dynamic complexity. We will use the methodology of System Dynamics², which hinges on the modeling of systems essentially as webs of feedback loops and delays (Forrester 1961, Sterman 2000).

¹ The prevalence of linear thinking which negates the nature of complex systems with their interrelationships and feedbacks has been observed by prominent authors, in particular Vester (2007), who criticizes the dysfunctionality of that approach.

² System Dynamics is a discipline of modeling, simulation and steering. It stems from Prof. Jay Forrester at the Massachusetts Institute of Technology (MIT).

This contribution shows practitioners new ways of thinking in managerial contexts. Even so, management scientists also may find our paper useful, as it can open new avenues of dealing with complex dynamic issues. We study the following research questions, always with reference to organization and management:

1. What are the weaknesses/shortcomings of linear models?
2. What are the strengths/benefits of nonlinear models?

To give a full picture, we also analyze the benefits of linear models and the shortcomings of nonlinear models. Given the limited space, this is only done in an abridged form.

Our research strategy reverts to the methodology of modeling and simulation which is embedded in a single case study. Single case studies are indicated, among other criteria, if the case at hand is revelatory (Yin 2009). This applies here, as will be shown. We will start with an introduction to the case study. In the following two sections, two planning models used in the firm under study will be described, first linear, then nonlinear. On that basis, we compare the effectiveness of these models in supporting decision-making. We embed these more technical aspects in a reflection of the process which leads to the persistency of linear thinking. Finally, conclusions are drawn about how to overcome the linearity trap to provide more accurate simulation models for management support.

2 Introduction to the Case Study and Problem Description

The case comes from a large European telecommunications enterprise. One of the businesses of that company is attending to the needs of customers who outsource their computer capacities. The leading person from the strategy staff of that unit encountered large discrepancies between the planned volumes of capacity and those actually needed. Either there were redundancies or bottlenecks of available capacity, but rarely a demand and supply in equilibrium. The use of capacity showed an oscillatory behavior which resulted in great inefficiencies. That is, the bottlenecks were a problem, as one is misguided by a model, it is difficult to know that one is. The purpose of this paper is to explore that discrepancy and show a way out of that linearity trap.

The strategist considered the planning method used, and found that it had to be improved. He pondered that a good model had to take into account the feedback effects of high-use levels of existing capacity on the likelihood of acquiring and satisfying additional customers. In search of a better solution, which in his view had to be a nonlinear approach, he contacted the authors. A task force was formed to develop such a model. Under the leadership of the strategist, the capacity planners and operations specialists of the business unit and the authors convened several times. Model development took place on and off the company facilities. The main lines of the model were developed in the plenary on site, while detailed model building was delegated to the authors and accomplished outside.

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3 Linearity – The Planning Model-in-Use

The current method consisted of a sequential calculus of steps along a chain of standard events. Capacity of supply was planned on the basis of a linear algebraic model of demand (Equation 1).

\[
\text{Demand} = \text{demand for connectivity} + \text{demand for direct services} = f(\text{market volume, market share, production lines, capacity utilization})
\]  

(Equation 1)

with \( f \) being a function of the attributes mentioned.

The initial analysis of the model-in-use indicated two main deficits (Figure 1):

1. The demand for capacity was calculated as a function of market share, which was treated as an exogenous parameter which changed over time according to the input of human decision makers.
2. The supply of capacity was taken as a function of the demand, without any consideration of the delays inherent in changes in capacity.

Both of these features of the current model were grossly unrealistic.

The shortcomings of linear models are in that they neglect the characteristics of complex systems, such as interrelationships and nonlinearities. This makes them incongruent with reality. The advantage of linear over nonlinear models is the relatively lower conceptual modeling knowledge which is necessary to elaborate them.

4 Nonlinearity – The New Planning Model

In an attempt to remedy these deficiencies, a suitable methodology was identified for meeting that purpose: A System-Dynamics-Model was constructed, which especially addressed the shortcomings of the linear model:

1. Market share was endogenized (Equation 2). It was determined by the delivery capability, the core attribute of service quality, and a function of the level of capacity utilization (Equation 3). This entails a logically closed structure as shown in the Causal-Loop-Diagram (CLD) in Figure 2.

\[
\text{Market Share} = \frac{\text{revenue of telecommunications company}}{\text{revenue of total market}}; \quad \text{Revenue of telecommunications company} = \text{average revenue for a contract} \times \text{number of contracts}
\]  

(Equation 2)

and

\[
\text{Delivery capability} = \text{normal delivery capability} \times \text{effect of capacity utilization on delivery capability};
\]

\[
\text{effect of capacity utilization on delivery capability} = f(\text{capacity utilization})
\]  

(Equation 3)

2. The capacity of supply was calculated as a function of both demand and the process of building that capacity (Equation 4).
Total Capacity = internal capacity + temporary capacity
= \int_{s=0}^T (\text{finishing rate internal capacity} - \text{depreciation})ds + \int_{s=0}^T (\text{acquisition of temp. capacity} - \text{cutback on temp. capacity})ds

(Equation 4)

where ds is the variable of integration in the interval from 0 to T which is the final time of the simulation.

The CLD in Figure 3 shows the feedback loops which describe the processes that build internal supply and temporary supply (capacity hired from outside).

Based on these qualitative causal structures, a quantitative simulation model was built using the System Dynamics Methodology, implemented with the Vensim Software. The respective system structure diagram of the simulation model is shown in the Appendix in an anonymized version. It shows the important stocks, flows, parameters, and auxiliary variables. Capacity utilization is the variable that connects the two sub-models.

Fleshing out, in this way, the structures underlying system behavior, enhances the understanding of the workings of a complex system. The differences between the two models also visualize the crucial differences between a short- and a long term perspective. For example, if market share may be constant for a short period of time, a longer-term view shows that it is subject to change.

5 Simulations and Insights

The nonlinear model proved to be superior in that the development of demand and supply could be modeled more accurately: the model now accounts for the impact of high utilization rates on the probability to renew or close a contract (demand loop) and for relevant delays in acquisition of the capacity (supply loop). In the following, the results of the nonlinear simulations are compared to the results stemming from the linear model. Figure 4 shows the output of three simulation runs, above for market share, below for capacity utilization (both in percent). The blue line is the result of the linear model; the red line is the result for the nonlinear model with only the demand loop active (Figure 2); the green line is the result for the nonlinear model which includes both demand and supply feedback dynamics (Figures 2 and 3).

The linear model assumes a constant market share of 8% over the relevant time horizon. Since the overall market volume grows at a slow rate of 2%, the capacity utilization increases slightly over time and reaches a value of 97%. Internal objectives for capacity utilization are about 0.86%. The result of the model is unrealistic.

Next, we use the nonlinear model with demand dynamics (partial nonlinear model). Initially, as Figure 4 shows, the market share increases slightly. This is because the relatively low levels of utilization of capacity favor the likelihood to close or renew contracts. However, after more and more contracts have been closed, available capacity is strongly utilized, which reduces the likelihood to have successful closures of contracts. The relevant customers accept contracts only when utilization rates are below a threshold of around 85%. This leads to the curve in Figure 4 which shows the outcome of the non-linear model (only demand side switched on), converging to the value of 85%. Since the total market still increases in size, the market share plunges. This run accounts for demand-side dynamics, but has still the same limitations on the supply-side as the linear model. This simplifying assumption is relaxed next.
The oscillatory lines in Figure 4 show the results of the simulation with both demand and supply dynamics. The market share increases in waves until 12% by the end of the simulation. This is possible since waves of investments in internal capacity are triggered due to increasing utilization rates. Based on the gap for capacity utilization, capital-widening investments are triggered when the gap becomes small. After each delay for the production of capacity, strong reductions in the capacity utilization occur, as soon as the additional capacity comes online (at t=51 and t=91).

We have calculated the monetary benefit which the model is able to generate. We have used the accumulated revenues, i.e., number of contracts with an average size of a contract of 75,000 CHF, over the planning time to compare the three models. A rough calculation shows that the linear model results in a value, for total demand, of 493 Mio CHF, the partial nonlinear model including only demand dynamics results in 446 Mio CHF, and the full nonlinear model including demand and supply dynamics results in 544 Mio CHF. In summary, by representing the business dynamics more accurately, the company is likely to gain 51 Mio CHF in additional revenues over a 10-year horizon.

Strengths of the nonlinear model:

1. The model incorporates the feedback relationships characteristic of complex systems. These are not meaningful at a detailed level. In case a model accounts for many operational details, it can hardly be used for strategic planning purposes: It is neither desirable nor feasible to trace the long-term development of the multitude of details. A higher level of aggregation is required, which facilitates the representation of feedback phenomena, thereby raising internal model validity.

2. The model accounts for important relationships and effects between capacity utilization and probability to renew a contract, which were left out of the linear model. Thus, the nonlinear model has a higher external validity.

3. High generality of the nonlinear model since it is a structural model which accounts for mechanisms generic to situations where capacity is utilized.

One can generalize that nonlinear models of complex dynamic systems, if properly validated, can attain higher internal and external validity which lead to more realistic estimations and considerably more appropriate management decisions. They also have shortcomings, mainly that the expertise and sometimes the cost of elaborating them are higher than in the case of linear models.

6 Process Observations and Reflections

Our observations unveiled a pattern of vehement resistance to change, among the company's capacity planners who were part of the project team. They defended the traditional planning approach inessantly, finding all kinds of excuses why the new model would not improve the situation. Despite logical arguments of the strategist and the authors, which clarified the superiority and higher adequacy of the nonlinear model for the given situation, they succumbed to the illusion of validity (Kahnemann 2011). Repeatedly the following behavior pattern emerged: Up to a certain point these team members showed agreement with our propositions, but then invariably fell back into their defensive routines (Argyris 1990). Even though they accepted the arguments intellectually, they could not get rid of their original prejudice, which for them stayed the valid position.

After some time -- the new model had already been built -- we became aware of the major trigger of that behavior: The capacity planners were concerned with the details of the operations they were part of. These were pictured -- in their view adequately -- in the old model. They showed little interest in a larger picture. Their mentality was short-termist. Long-term considerations such as the gradual changes inherent in a system which is subject to endogenously driven dynamics, was outside their horizon. For example, the feedback-generated dynamics of market share or the building up of capacities were blinded out from their observations. In sum, this problem was essentially in the dominance of an operative orientation paired with a lack of strategic thinking.

If the time we worked on the project with the company (about six months) we have not seen much change of that situation. At least, the new model has triggered debate about the best way of carrying out capacity planning. Obviously, this company is still in a learning process. At the end of our project it was uncertain if the nonlinear model would de facto win out.

7 Conclusions and Outlook

Even though mathematics in general and dynamic simulation in particular are not much used in the management of companies (Behnam et al. 2003), there are plenty of areas where they can be used beneficially.

The analysis in the case under study showed a clear advantage of the nonlinear dynamic simulation model over the linear model. At the same time we discerned tensions in the organizational discourse between the champions of the new model and the defenders of the old one. We assume that both of these observations hold for many other organizations as well. To corroborate that claim, other cases should be studied, to extend external validity of our the empirical results gathered here.

A set of propositions that show a path towards a more effective management support by simulation models can be derived from our study. These propositions do not make up a theory, and they are not cast in stone. They are rather of an indicative type:

1. State of modeling: In companies, linear management models are currently prevalent. Linear thinking negates the dynamic properties of complex systems and is therefore grossly unrealistic.

2. Current Paradigm: Practitioners often have difficulties to accept nonlinear models. They adhere to an outdated paradigm (in the sense of a broadly accepted way of thinking or worldview).

3. Benefits of nonlinear models: Companies could gain very much from the advantages of nonlinear models. These provide more realistic images of system behaviors, enable more realistic scenario analysis, and hence result in better managerial decisions.
4. Short- versus long term: Often the resistance toward nonlinear models is in the divergence of short- and long term orientation. The awareness that the control variables at these two levels are distinct from each other is not widespread yet.

5. Understanding of systems: The understanding of the workings of complex systems is crucial. It can be enhanced by making the underlying structures of system behavior transparent. Therefore, building conceptual and methodological knowledge with model users is an imperative.

6. Overcoming short-termism: The curse of short-termism can be overcome. Clarifying system structures, and in particular, the differences between distinct time horizons is necessary to make the benefits of nonlinear models tangible.

7. Paradigm change: The adoption of nonlinear models requires a change of mindset. In complex, dynamics settings, the assumptions about the structure of the system must be revised. This is requisite for coping with that dynamic complexity effectively, and it relates to a new paradigm.

The discussion of the adequacy of linear and nonlinear models ultimately becomes one of mastering change management.

A discourse is crucial, in which the mental models of the existing planning team are discussed. Also, the planning team must be enabled to adopt a different planning paradigm. This begs for training in conceptual thinking and methodological skills. Do not assume that the planning team will understand and implement. The time investment of the team in the existing model(s) and method(s) is immense. According to the sunk-cost fallacy they are, most likely, not willing to write off these investments.

A nonlinear model, since it is more conceptually challenging than existing linear models, can only have a chance of implementation, when its benefits are accepted by the planning team. It is not enough if the external consulting team perceives the benefits. The barrier to change can in certain cases be prohibitive, so that including different agents in the modeling venture may be indicated.

Nonlinear systems have been discussed in science extensively, but they are only gradually finding their way into managerial practice. As the general landscape of systems changes toward more uncertainty and turbulence, a perspective, which embraces nonlinearity as an ubiquitous phenomenon, will necessarily take over: The new paradigm of nonlinear systems is under way.

References