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Anticipating the Unexpected: Simulating a Health Care System Showing Counterintuitive Behavior

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Abstract. Complex systems often exhibit counterintuitive behavior. They confront us with the unexpected, and the idea of anticipating the unexpected is a challenge to commonsense. The purpose of this contribution is to demonstrate the power of modeling and simulation in discovering the structures that generate counterintuitive behavior in and of organizations. The research question here is if and how these generative "mechanisms" that produce unexpected behavior can be ascertained. If this can be achieved, then unexpected patterns of behavior become amenable to being anticipated as contingencies. If not, system behavior cannot be anticipated, and it remains in the dark. To answer our research question, we revert to a case study of a health-care system that showed unexpected behavior.

Keywords: Dynamic modeling and simulation · Mathematical modeling System Dynamics · Counterintuitive system behavior · Case study Health care

1 Introduction

In organizations, unexpected things happen all the time. It seems paradoxical to claim that one can anticipate the unexpected. Commonsense understanding tells us that we can not. Our claim is that unexpected behavior can be anticipated by good dynamic models with the help of simulation. We apply System Dynamics, a widely used methodology for the modeling and simulation of complex dynamic systems.

A case study is used to underpin our claim. The study was realized in the health care system of Carinthia, a nation-state of the Republic of Austria. The full case study covering 30+ years, is documented elsewhere (Schwaninger and Klocker 2017a). In this piece, we concentrate on the last phase of the case study (2011–2016), and elaborate on aspects pertinent to the purpose of this contribution: to use modeling and simulation for the anticipation of unexpected behavior of complex systems. We are focusing on organizations, but in principle our study is relevant for any kind of social system.

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2 Case Study

This is a long-term, ongoing case from a health organization in which the author has been involved for 30+ years, in an advisory function. He collaborated with the head of that organization, which was developed under their conceptual leadership on the basis of systemic thinking. The scenery of our case study is the Oncological Care System (OCS) of Carinthia, Austria, with its hub at the central hospital of Klagenfurt, the capital. As our focus is on the OCS as a whole, we consider the overall system: it includes the hub and the network of medical services, with several peripheral hospitals as well as local registered doctors from all over the state. In 2010, the OCS showed a record of continual successes, which had been achieved in its history since 1985. However, 26 years after the foundation of the unit, in 2011, the administration of the central hospital announced that it would cut the budgets of all departments, "… to improve the economic situation". The leaders of the OCS expected that such a cut would have severe implications for the success of this unit.

To analyze the situation more closely, a simulation model was built cooperatively: the oncologists contributed the substantive knowledge about the issues under study, while the author (MS) furnished modeling and simulation know-how.

3 Model

In an initial phase, a qualitative analysis by means of causal-loop diagrams ("Qualitative System Dynamics") was carried out, in which a set of reinforcing and balancing feedback loops was identified (documented in detail in Schwaninger and Klocker 2017a). Then all the identified loops were synthesized into a quantitative simulation model. To this end we used the System Dynamics methodology (Forrester 1961, Sterman 2000). The overall picture of the model is shown in the Fig. 1, in the form of a Stock-and-Flow Diagram. That scheme is, to some extent, self-explanatory. For example, Loop B1, - the Finance-Personnel Loop. It shows a connection that is straightforward: the allocation of financial resources enables hiring people, which increases the workforce; the larger the workforce, the higher the cost, which in turn decreases earnings (indicated by the "-" sign) and financial resources available. This is a balancing loop, denoted as "B". The B-loops are normally controlled by a goal or limiting factor. In this case, the personnel budgeted delimits the quantity of personnel.

Compared to this first loop, the second one – R1 – highlights a countervailing relationship: the larger the workforce, the greater the experience and knowledge extant in the organization. The more experienced people are, the less susceptible to stress they become. "Stress" is a proxy for a working climate that enhances the number of exits, which reduce personnel. This Experience-Stress Loop is self-reinforcing (denoted with "R"), leading either to a virtuous or a vicious cycle.

The Stress-Quality Loops R3a and R3b show the causes and implications of both stress and quality of care. A lack of personnel leads to overload and stress, which is a major factor that jeopardizes quality of care. The success of care and the resulting number of cures alleviate the load of patients under treatment, consequently improving the personnel-patients ratio and alleviating stress. Lower stress means higher quality of

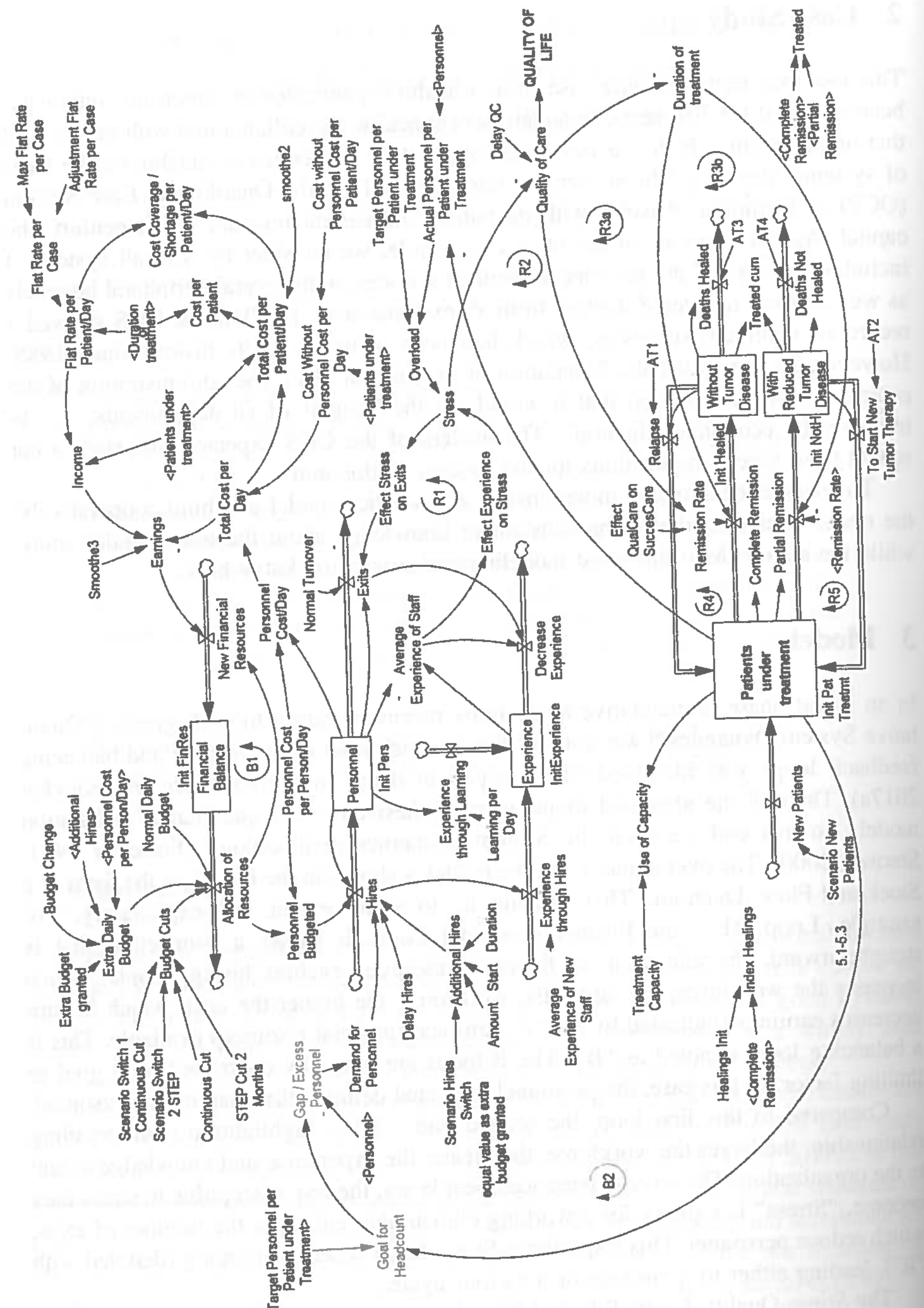

Fig. 1. Stock-and-flow diagram of the simulation model

care and then higher success of care. As loop R3b shows, quality of care – due to better dedication of staff and superior organization – reduces the duration of treatment, which affects the number of cures: shorter duration of treatment results in more healings. Both loops are of the reinforcing type.

The quantitative model is made up of equations, mostly differential equations. It covers a period of three years, from January 1, 2013 to December 31, 2015. It runs over 1095 days, with a small time step, sized 0.0625, to avoid rounding error. The equations have been documented earlier (Schwaninger and Klocker 2017b).

4 Simulations

The Budget Cut Scenario – which is the most important one here - examines the implications of the measures announced by the hospital administration. This scenario assumes a continuous curtailment of daily budgets by 15% over the whole simulation period. We make the simplifying assumption that all budget retrenchments are applicable to staff expenses only, leading to decreases in the workforce.

The graphs in Fig. 2 show that the personnel drops enormously as a consequence of the budget cut. That leads to counterintuitive behavior of the system under study. The decrease of personnel intensity induces overload and more stress, which accelerates the exit of employees, and leads to a lower quality of care. The next consequence is a longer duration of treatments, i.e., people stay in hospital longer, so that the number of patients under treatment and therewith cost are enlarged. What recedes, and dramatically, is the quality of care – a cornerstone and lead indicator of a health care system: growing stress and falling staff experience occur at the price of unsatisfactory treatment of patients.

A second and even more surprising result concerns the economic dimension. The budget cuts appear to be successful in that fewer resources need to be allocated. However, that impression is misleading. It turns out that the flow of earnings, which is positive in the base scenario for 15.7 months, becomes negative already after 8.6 months, in the budget cut scenario. With (−10.8) Mio Euros the cumulated earnings are negative, – twice the amount of the base scenario. In other words, not even the economic quantities respond to the interventions in a desirable way.

Much of the behavior of the model is counterintuitive from the viewpoint of the managers, while it makes sense from the stance of the medical staff. Even so, the working of the "mechanisms" just analyzed was fully understood by the doctors only in hindsight, when they saw the results of the simulations and had observable light-bulb moments.

Among many possible sensitivity analyses we only mention two. The first one to answer the question: "Could changes in the daily budget bring about positive cumulative earnings?" In the maximum budget cut scenario, cumulative earnings already turn negative after 14 months. On the other hand, an expansion of the budget by 15% leads to positive cumulative earnings over the whole period of three years.

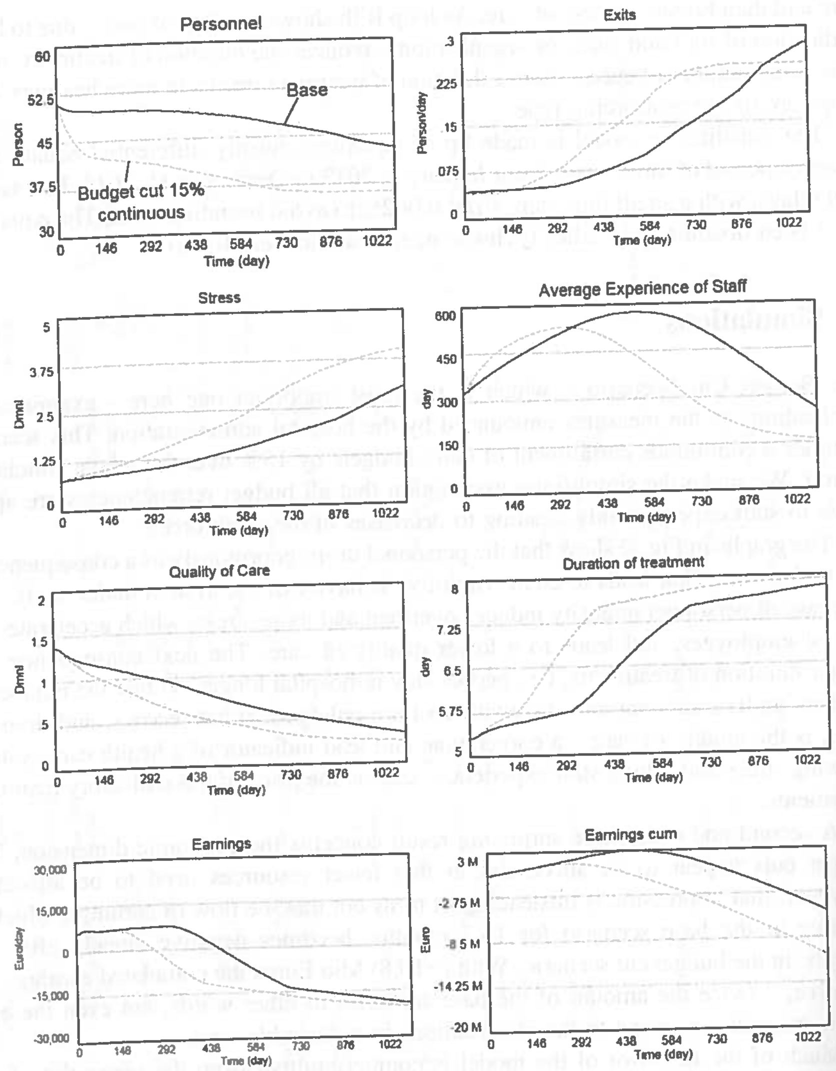

Fig. 2. Budget cut scenario compared to base scenario (based on original model)—Base run (no budget cut); --- Budget Cut 15%, continuous

Second, hiring is a policy test among others examined. The sensitivity analysis shows that recruiting people with more professional experience entails positive consequences throughout: quality of care can be maintained, stress is mitigated, duration of treatment is hardly increased, and earnings remain positive (details are in Schwaninger and Klocker 2017b). The advantages of this policy are obvious, but it is difficult to implement it, as the market for hospital staff in the region has run dry.

5 Validation and Calibration

The model was submitted to a large set of validation tests from the "canon", which is the standard of practice in the System Dynamics Society (for details see: Schwaninger and Klocker 2017b).

In early 2016, as historical data became available, the model was submitted to behavior reproduction tests. The quantitative model was calibrated on the accessible data series of personnel headcount and patient healings (complete and partial remissions). A list with the parameter values is available in Schwaninger and Klocker 2017b. In Fig. 3, the simulation outcomes of the model are compared with the historical data ("real") obtained from the OCS.[1]

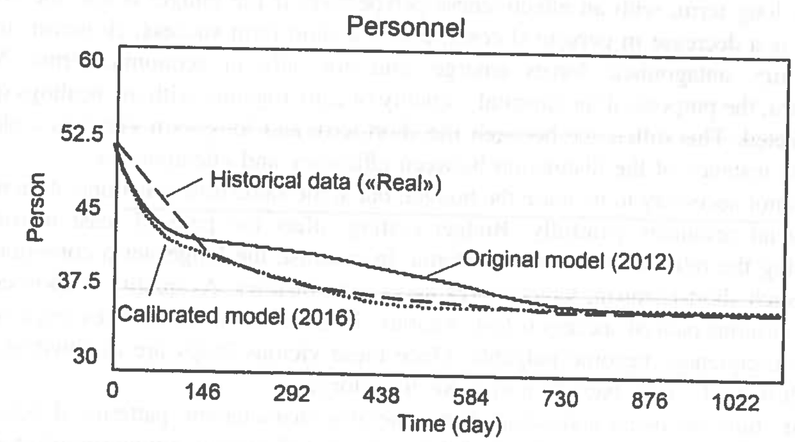

Fig. 3. Behavior reproduction of the model

The correlation between simulated and historical data is close to the maximum of 100%. Values for Mean Squared Error (0.06) and Mean Absolute Percentage Error (0.52) are very low. The analysis of the Mean Squared Error with the Theil Statistics (Theil 1966; Sterman 1984) confirms that the model captures the overall trend in historical behavior (details: Schwaninger and Klocker 2017b). The fit obtained is very high; strong confidence in the model is justified.

6 Results

We have explored dynamic simulation as an instrument, by means of which the counterintuitive, unexpected outcomes of certain policies or interventions can be anticipated. In line with the purpose of this contribution, the power of modeling and

[1] A cut of 15% of the budget is assumed.

simulation in discovering structures that generate counterintuitive system behavior, has been demonstrated.

The better the space of potential system behaviors is understood, the greater is the potential for successful moves. The design of a policy need not meet a discrete objective such as reaching or avoiding a precise outcome. It rather needs building the system for criteria such as robustness (tolerance or resistance to parameter variations) and resilience (response to perturbations that re-establishes equilibrium. In this context simulation can also help to unveil "new parameters" and their consequences. In our analysis, for example "experience" and "stress" were such novel parameters.

The results of the simulations disclosed clear patterns in the OCS's behavior, some of which were unexpected. The model presented amounts to more than a photograph of a system state. It captures the dynamics of both the short run, with the efficiency view, and the long term, with an effectiveness perspective. If the budget is cut, the consequence is a decrease in personnel costs; this is a short-term success. However, in the longer run, antagonistic forces emerge, and not only in economic terms. More important, the purpose of the hospital – quality of care, together with the healings quota - is affected. This difference between the short-term and long-term views is a clearly palpable instance of the distinction between efficiency and effectiveness.

It is not necessary to increase the budget, but at the same time it is imperative not to cut crucial resources painfully. Budget cutting offers the path of least resistance, promising the relief of economic concerns. In contrast, the longer-term consequences refute such short-termism, which paves the way to disaster. As quality erosion creeps in, the virtuous path of success is lost. Vicious circles establish themselves, even before their consequences become palpable. Once these vicious loops are established, it is difficult to find a path back to a virtuous trajectory.

Our study uncovers a structure that generates characteristic patterns of behavior. These conform to the expectations of the medical staff, but are counterintuitive in the logic of the administrators (Forrester 1971). *Our main finding of that kind* – detected ex ante and corroborated a posteriori - *is that the intervention of a budget cut, contrary to the* expectations of the administrators, *led to a decrease in earnings instead of an improvement of the economic situation of the organization.*

The structural features of our model are of a generic type. In other words, they are applicable to multiple contexts, representing a "wider class" of real-world situations (Forrester 1961, p. 208). Hence, their applicability is not limited to public organizations, for our model also covers private firms.

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