INTRODUCTION TO SYSTEM DYNAMICS

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SYSTEMS THINKING

The methods of *systems thinking* provide for better understanding of difficult management problems (environmental, business, human resource, etc). However, they require a move away from looking at isolated *events* and their *causes* (usually assumed to be some other events), and start to look at the problem structure as a *system* made up of interacting parts. System thinking is also closely related to modelling and the following pages will give a short introduction to System Dynamics and modelling.

PATTERNS OF BEHAVIOUR

To start to consider system structure, one first generalises from specific events associated with the problem to considering *patterns of behaviour* that characterise the situation. Usually this requires an investigation into how one or more variables of interest change over time. The systems approach gains much of its power as a problem solving method from the fact that similar patterns of behaviour show up in a variety of different situations, and the underlying system structures that cause these characteristic patterns are known.

The four patterns of behaviour shown in Figure 1 often show up, either individually or in combinations, in systems.

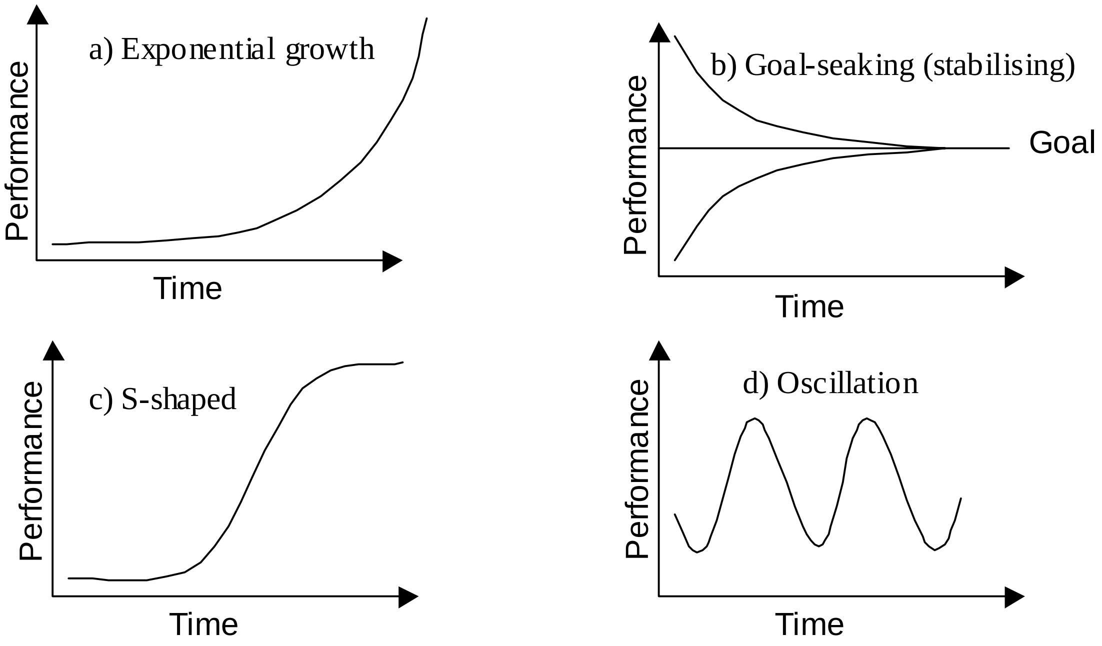

Figure 1. Characteristic patterns of system behaviour

FEEDBACK AND CAUSAL LOOP DIAGRAMS

To better understand the system structure one can use graphical notation (see Figure 2). The diagram shows the relationships between the elements "Tap position", "Water Flow", "Water Level" and "Gap" (i.e. elements necessary for controlling water flow from a tap into a glass). The diagram presents relationships that are often difficult to verbally describe because normal language presents interrelations in linear cause-and-effect chains, while the diagram shows that in actual systems there are circular chains of cause-and-effect. We can see from Figure 2 that the "Tap position" element influences "Water flow", which in turn influences "Water level". Up to this point, this was a linear chain of cause and effect. However, "Water level" influences "Tap position" and the chain forms a closed *feedback loop* or *causal loop*. Another more complex example is given in the Appendix.

If in Figure 2 the tap position is changed (say open further) then the "Water flow" increases (positive sign on the link). Similarly, if the "Water flow" increases, then the "Water level" in the glass will increase (again, positive sign on the link). The next element "Gap" is the difference between the "Desired water level" and the actual "Water level". From this definition it follows that an increase in "Water level" decreases the "Gap" (negative sign on the link).

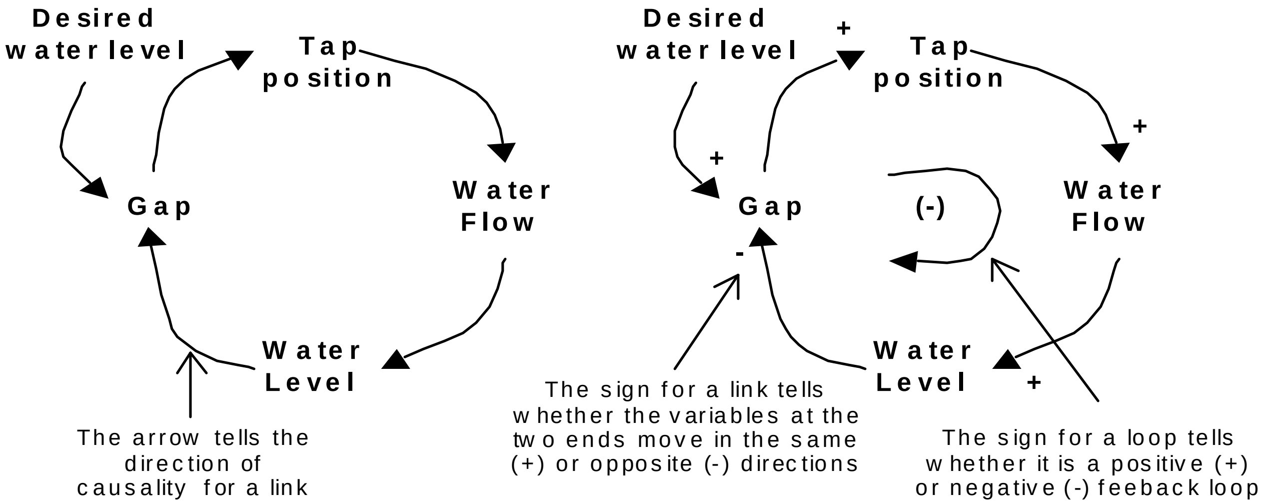

Figure 2. Causal loop diagram (Filling a glass of water) a) links only; b) annotated

LINK BETWEEN FEEDBACK DIAGRAMS AND PATTERNS OF BEHAVIOUR

Figure 3 illustrates a simple, positive (reinforcing) feedback loop-Growth of bank balance.

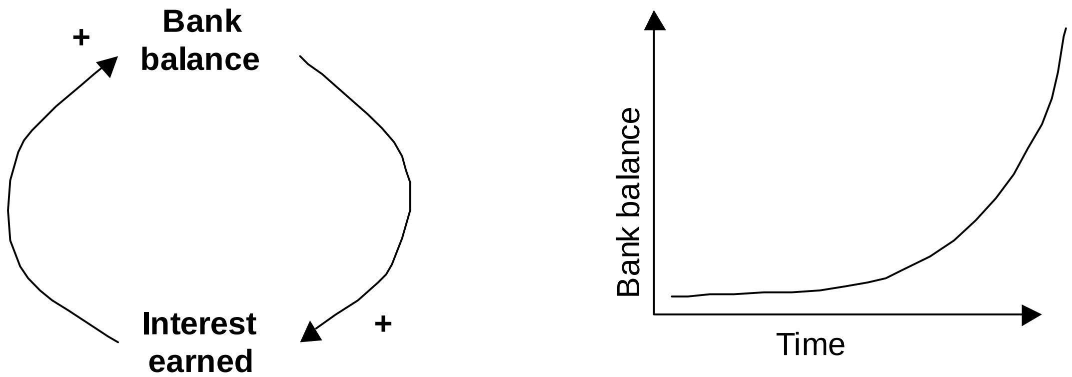

Figure 3. Positive (reinforcing) feedback loop.

This feedback loop reinforces change with even more change. As it can be seen, it results in rapid growth at an ever-increasing (exponential) rate. This type of growth is often referred to as *exponential growth*. In the early stages of the growth, it seems to be slow, but then it speeds up. Thus, the nature of this process can be deceptive – something that will be a major problem later may not be easy to spot early on in the process because it is growing slowly. This is particularly true if the modelled system is complex and there are many interconnected elements with different type of feedback loops.

Opposite to reinforcing loops, there are negative (balancing loops). Figure 4 illustrates a simple, negative (balancing) feedback loop – Regulating an electric blanket.

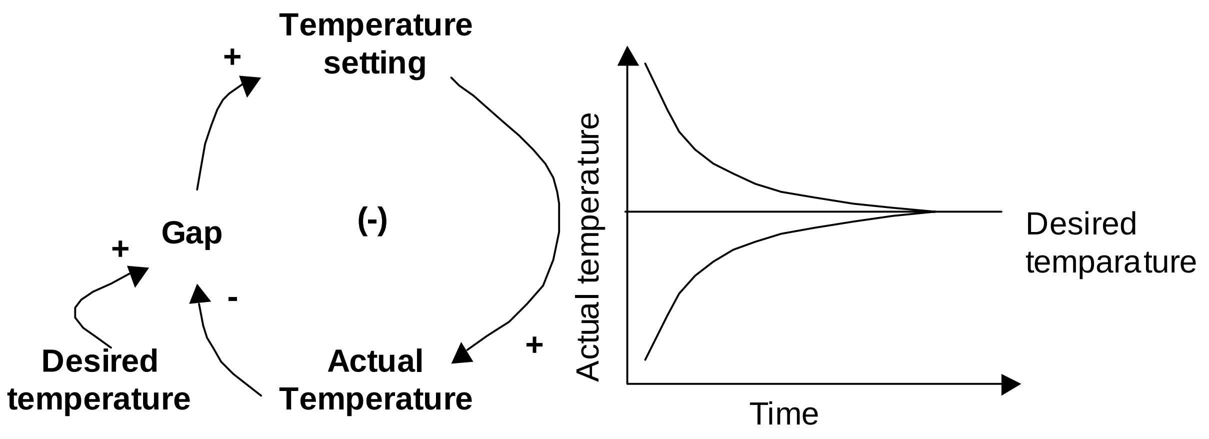

Figure 4. Negative (balancing) feedback loop.

CONCLUDING REMARKS

Just as in any large and complex system (such as business enterprises, watershed estuarine ecology, sewer system of a city, water supply utilities) there are issues such as “limits and constraints” (money, time, talents, political boundaries), “indirect effects” (action in one area leads to diversion of resources and therefore less actions (effects) in other areas), non-linear dynamics (physical and socio-political phenomena), risk, delays, equity considerations (rich stakeholders and welfare-recipients), efficiency, and multiple objectives. It is very difficult to understand such a complex system by one individual or a group of individuals without a model, for which we can use System Dynamics (SD) models and continuously interact with different stakeholders for model refinement and input.

It is important to note that SD models are not engineering models (only), although they can have complex mathematical/engineering relationships built into them. They are more than engineering models as they look at the bigger picture (generalised or strategic models) - but they are also less than engineering models because they ignore the details. To illustrate this we can use the story of the 6 blind men - and the task of a SD person is to be a non-blind person looking at the elephant **from a distance**. This is rather different from the 6 blind (very smart) people feeling the elephant up close and coming up with different (though detailed) description of elephant parts.

SD model is often used in complex negotiations as a collective view of a system developed by managers and stakeholders, used to facilitate plan development, maintenance, implementation and public (stakeholder) participation. These models can be incorporated into the decision-making process at an early stage and attempt to include economic and non-physical measures.

Systems thinking and system dynamics and their applications to societal, technical, managerial, and environmental problems have a long history and the following is just a crude classification of some application fields:

- Industrial and economic dynamics
- Urban and public policy dynamics
- Limits to growth and other global models
- SD for management: firm and market models
- Economic models
- Modelling for learning: systems thinking and organisational learning
- Decision making
- Negotiation

SELECTED APPLICATIONS

Levin, G., G. B. Hirsch, & E. B. Roberts. 1975. The Persistent Poppy: A Computer-Aided Search for Heroin Policy. Cambridge MA: Ballinger.

Examines the interactions within a community among drug users, the police and justice system, treatment agencies, and the citizens. Analyzes policies designed to restore the community's health.

Levin, G., E. B. Roberts, G. B. Hirsch, D. S. Kligler, N. Roberts, & J. F. Wilder. 1976. The Dynamics of Human Service Delivery. Cambridge MA: Ballinger.

Presents a generic theory of human service delivery, with case studies and examples drawn from mental health care, dental planning, elementary education, and outpatient care.

Cooper, K. G. 1980. Naval Ship Production: A Claim Settled and a Framework Built. Interfaces 10 (6): December.

An SD model was used to quantify the causes of cost overruns in a large military shipbuilding project. One of the first and most successful applications of system dynamics to large-scale project management; initiated a long line of related project modelling work.

Jensen, K. S., E. Mosekilde, & N. Holstein-Rathlou. 1985. Self-Sustained Oscillations and Chaotic Behaviour in Kidney Pressure Regulation. In Laws of Nature and Human Conduct, ed. I. Prigogine & M. Sanglier. Brussels: Taskforce of Research Information and Study on Science.

Presents a system dynamics model of the dynamics of rat kidneys. Experimental data show previously unexplained oscillations, sometimes chaotic. The model explains how these fluctuations arise. Excellent example of SD applied to physiology.

Homer, J. B. 1985. Worker Burnout: A Dynamic Model with Implications for Prevention and Control. System Dynamics Review 1 (1): 42-62.

Explains how knowledge workers can experience cycles of burnout through a simple system dynamics model. Avoiding burnout requires that one work at less than maximum capacity.

Homer, J. B. 1987. A Diffusion Model with Application to Evolving Medical Technologies. Technological Forecasting and Social Change 31 (3): 197-218.

Presents a generic model of the diffusion of new medical technologies. Case studies of the cardiac pacemaker and an antibiotic illustrate how the same model can explain the different diffusion dynamics of successful and unsuccessful technologies.

Gardiner, L. K. and R. C. Shreckengost. 1987. A System Dynamics Model for Estimating Heroin Imports into the United States. System Dynamics Review 3 (1): 8-27.

Describes how the CIA used SD to estimate the illegal importation of drugs to the US.

Ford, A. & M. Bull. 1989. Using System Dynamics For Conservation Policy Analysis In The Pacific Northwest. System Dynamics Review 5 (1): 1-15.

Describes the use of an extensive SD model of electric power generation with endogenous demand. The model is used to evaluate strategies for conservation and new generation capacity. Includes discussion of implementation and integration of the SD model with other existing planning tools.

Sklar Reichelt, K. 1990. Halter Marine: A Case Study of the Dangers of Litigation. (Working Paper No. D-4179). System Dynamics Group, Sloan School of Management, MIT, Cambridge MA.

A case-study illustrating the use of system dynamics in litigation. Suitable for classroom teaching.

Abdel-Hamid, T. K. and S. E. Madnick. 1991. Software Project Dynamics: An Integrated Approach. Englewood Cliffs NJ: Prentice Hall.

Integrated SD model of the software development process. The model covers design, coding, reviewing, and quality assurance; these are integrated with resource planning, scheduling, and management of software projects. Includes full documentation, validation, and policy tests.

Sturis, J., K. S. Polonsky, E. Mosekilde and E. Van Cauter. 1991. Computer Model for Mechanisms Underlying Ultradian Oscillations of Insulin and Glucose. American Journal of Physiology 260 (Endocrinol. Metab. 23): E801-E809.

New experimental data show that the human glucose/insulin system is inherently oscillatory. An SD model explains these dynamics. The model is validated against detailed physiological data.

Naill, R. F. 1992 A System Dynamics Model for National Energy Policy Planning. System Dynamics Review 8 (1): 1-19.

Naill, R. F., S. Belanger, A. Klinger, & E. Peterson. 1992 An Analysis of the Cost Effectiveness of U.S. Energy Policies to Mitigate Global Warming. System Dynamics Review 8 (2): 111-128.

Reviews the 20 year history of the SD energy models used by the US Dept. of Energy to forecast and analyze policy options for national energy security, including the impact of US policies on global climate change.

Homer, J. B. 1993. A System Dynamics Model of National Cocaine Prevalence. System Dynamics Review 9 (1): 49-78

An excellent model of the interacting dynamics of addiction, policy-setting, and enforcement.