國立臺北大學自然資源與環境管理研究所
103 學年度第二學期『環境系統分析專題』

課程講義(07-08)：系統動力學簡介

Introduction to System Dynamics

System Dynamics Society (http://www.systemdynamics.org)
Software Packages: Vensim (Ventana Systems); STELLA (isee Systems); PowerSim
Sterman (2001): System Dynamics Modeling: Tools for Learning in a Complex World (Chinese)
第五項修練 (http://valuechain.inde.fcu.edu.tw/file/Systematic.pdf)

- INTRODUCTION TO SYSTEM DYNAMICS (http://www.systemdynamics.org/what-is-s/)
  - Overview: System dynamics is a computer-aided approach to policy analysis and design. It applies to dynamic problems arising in complex social, managerial, economic, or ecological systems -- literally any dynamic systems characterized by interdependence, mutual interaction, information feedback, and circular causality.

    The field developed initially from the work of Jay W. Forrester. His seminal book Industrial Dynamics (Forrester 1961) is still a significant statement of philosophy and methodology in the field. Within ten years of its publication, the span of applications grew from corporate and industrial problems to include the management of research and development, urban stagnation and decay, commodity cycles, and the dynamics of growth in a finite world. It is now applied in economics, public policy, environmental studies, defense, theory-building in social science, and other areas, as well as its home field, management. The name industrial dynamics no longer does justice to the breadth of the field, so it has become generalized to system dynamics. The modern name suggests links to other systems methodologies, but the links are weak and misleading. System dynamics emerges out of servomechanisms engineering, not general systems theory or cybernetics (Richardson 1991).
  - The system dynamics approach: The system dynamics approach involves:
    - ⇨ Defining problems dynamically, in terms of graphs over time.
    - ⇨ Striving for an endogenous, behavioral view of the significant dynamics of a system, a focus inward on the characteristics of a system that themselves generate or exacerbate the perceived problem.
    - ⇨ Thinking of all concepts in the real system as continuous quantities interconnected in loops of information feedback and circular causality.
    - ⇨ Identifying independent stocks or accumulations (levels) in the system and their inflows and outflows (rates).
    - ⇨ Formulating a behavioral model capable of reproducing, by itself, the dynamic problem of concern. The model is usually a computer simulation model expressed in nonlinear equations, but is occasionally left unquantified as a diagram capturing the stock-and-flow/causal feedback structure of the system.
    - ⇨ Deriving understandings and applicable policy insights from the resulting model.
    - ⇨ Implementing changes resulting from model-based understandings and insights.
  - Modeling and Simulation: Mathematically, the basic structure of a formal system dynamics computer simulation model is a system of coupled, nonlinear, first-order differential (or integral) equations,

    $$\frac{d}{dt}x(t) = f(x,p)$$

    where x is a vector of levels (stocks or state variables), p is a set of parameters, and f is a nonlinear vector-valued function.

    Simulation of such systems is easily accomplished by partitioning simulated time into discrete intervals of length dt and stepping the system through time one dt at a time. Each state variable is computed from its previous value and its net rate of change

$x'(t)$: $x(t) = x(t - dt) + dt \times x'(t - dt)$. In the earliest simulation language in the field (DYNAMO) this equation was written with time scripts *K* (the current moment), *J* (the previous moment), and *JK* (the interval between time *J* and *K*): *X.K = X.J + DT * XRATE.JK* (see, e.g., Richardson and Pugh 1981). The computation interval *dt* is selected small enough to have no discernible effect on the patterns of dynamic behavior exhibited by the model. In more recent simulation environments, more sophisticated integration schemes are available (although the equation written by the user may look like this simple Euler integration scheme), and time scripts may not be in evidence.

- □ Feedback Thinking: Conceptually, the feedback concept is at the heart of the system dynamics approach. Diagrams of loops of information feedback and circular causality are tools for conceptualizing the structure of a complex system and for communicating model-based insights.
- □ Loop Dominance and Nonlinearity: The loop concept underlying feedback and circular causality by itself is not enough, however. The explanatory power and insightfulness of feedback understandings also rest on the notions of active structure and loop dominance.
- □ The Endogenous Point of View: The concept of endogenous change is fundamental to the system dynamics approach. It dictates aspects of model formulation: exogenous disturbances are seen at most as triggers of system behavior; the causes are contained within the structure of the system itself.
- □ System Structure: These ideas are captured in Forrester’s (1969) organizing framework for system structure:
  - ⇨ Closed boundary
    - Feedback loops
      - ▪ Levels
      - ▪ Rates
        - ▫ Goal
        - ▫ Observed condition
        - ▫ Discrepancy
        - ▫ Desired action
- □ Levels and Rates: Stocks (levels) and the flows (rates) that affect them are essential components of system structure. Stocks (accumulations, state variables) are the memory of a dynamic system and are the sources of its disequilibrium and dynamic behavior.
- □ Behavior as a Consequence of Structure: The system dynamics approach emphasizes a continuous view. The continuous view strives to look beyond events to see the dynamic patterns underlying them. Moreover, the continuous view focuses not on discrete decisions but on the policy structure underlying decisions. Events and decisions are seen as surface phenomena that ride on an underlying tide of system structure and behavior.
- □ Generic Examples: (1) DO Sag Curve; (2) Populations of Foxes and Rabbits; (3) Modeling Sustainable Development: The T21 Model => A Brief Description of T21

- SYSTEM THINKING
  - □ Senge, Peter M., 1994. *The Fifth Discipline -- The Art and Practice of the Learning Organization*（彼得‧聖吉，1994，《第五項修練》，天下文化）=> rev. 2006
    - ⇨ http://en.wikipedia.org/wiki/Peter_Senge
    - ⇨ 五項修練：自我超越（Personal Mastery）；改善心智模式（Improving Mental Models）；建立共同願景（Building Shared Vision）；團隊學習（Team Learning）；**<u>系統思考（System Thinking）</u>**
    - ⇨ 系統基模（Systems Thinking Archetypes）(http://en.wikipedia.org/wiki/System_Archetypes)

- HOMEWORK #5 (2015/04/28 Due)：請建構氧垂曲線（Oxygen Sag Curve）系統動力學模型（系統動態模型），並設定模式參數值以求解、圖示該曲線之特性。