國立臺北大學自然資源與環境管理研究所
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課程講義(08)：系統思維與系統動力學
System Thinking and System Dynamics

- INTRODUCTION TO SYSTEM DYNAMICS (http://www.systemdynamics.org/what-is-sd/)
  - □ 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**: This approach can be summarized as:
    - ⇨ Beginning with a problem to focus systems thinking and modeling, involving the stakeholders whose understanding and action is required to implement change.
    - ⇨ Defining problems dynamically, in terms of behavior over time graphs (time series), employing actual data wherever possible.
    - ⇨ Striving for an endogenous, behavioral view of the significant dynamics of a system, a focus inward on the structures and decision rules in a system that themselves generate or exacerbate the perceived problem.
    - ⇨ Thinking of all concepts in the real system as quantities interconnected in loops of information feedback and circular causality, a consequence of the endogenous point of view.
    - ⇨ Identifying the key variables essential to address the problem and deciding on an appropriate level of aggregation for them. System Dynamics models range from highly disaggregate representations, such as individual items or agents, to highly aggregated representations, and can be deterministic or stochastic, as needed to address the purpose of the study.
    - ⇨ Formulating a richly explanatory behavioral model capable of reproducing, by itself, the dynamic problem of concern, drawing on all relevant evidence, including qualitative and quantitative data. The model is usually a computer simulation model, but is occasionally left unquantified as a map capturing the important accumulations (stocks) in the system, the flows that alter them, and the causal feedback structure determining the flows.
    - ⇨ Testing the structure and behavior of the model against all relevant evidence to deepen understanding and to build confidence in it, including the model’s ability to replicate historical data, ensuring the model is robust under extreme conditions, exploring the sensitivity of results to uncertainty in assumptions, and diagnosing the sources of unexpected model behavior.
    - ⇨ Designing and testing policies to address the problem of concern, testing these against data and comparing to real-world policies that have been tried in the system or similar settings.

- ⇨ Documenting the model and its supporting sources so that it is as transparent as possible and enabling others to critique, use, and extend the work.
- ⇨ Working with stakeholders and others to help translate model-based insights into implementable policies, assist in implementation, assess the results, and improve both the model and policies.

□ **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.

□ **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
- ⇨ The closed boundary signals the endogenous point of view. The word "closed" here does not refer to open and closed systems in the general system sense, but rather refers to the effort to view a system as causally closed. The modeler's goal is to assemble a formal structure that can, by itself, without exogenous explanations, reproduce the essential characteristics of a dynamic problem.
- ⇨ The causally closed system boundary at the head of this organizing framework identifies the endogenous point of view as the feedback view pressed to an extreme. Feedback thinking can be seen as a consequence of the effort to capture dynamics within a closed causal boundary. Without causal loops, all variables must trace the sources of their variation ultimately outside a system. Assuming instead that the causes of all significant behavior in the system are contained within some closed causal boundary forces causal influences to feedback upon themselves, forming causal loops. Feedback loops enable the endogenous point of view and give it structure.

□ **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.

- □ **Structure Drives Behavior**: The importance of levels and rates appears most clearly when one takes a continuous view of structure and dynamics. Although a discrete view, focusing on separate events and decisions, is entirely compatible with an endogenous feedback perspective, 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. It is that underlying tide of policy structure and continuous behavior that is the system dynamicist's focus.

  There is thus a distancing inherent in the System Dynamics approach — not so close as to be confused by discrete decisions and myriad operational details, but not so far away as to miss the critical elements of policy structure and behavior. Events are deliberately blurred into dynamic behavior. Decisions are deliberately blurred into perceived policy structures. Insights into the connections between system structure and dynamic behavior, which are the goals of the System Dynamics approach, come from this particular distance of perspective.

- SYSTEM THINKING
  - □ Systems Thinking (A system dynamics glossary - Ford - 2019 - System Dynamics Review) the use of conceptual system models and other tools to improve the understanding of how the feedback, delays, and management policies in a system's structure generate the system's behavior over time. Systems thinking does not use computer simulation. Systems thinking involves
    - (1) seeing interrelationships (feedback loops) instead of linear cause-effect chains, and
    - (2) seeking processes of change over time rather than snapshots. Systems thinking helps people see things on three levels: events, patterns of behavior, and system structure.
  - □ Senge, Peter, 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
    - ➩ 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)；**系統思考 (System Thinking**）
    - ➩ 系統基模（Systems Thinking Archetypes）：
      http://en.wikipedia.org/wiki/System_Archetypes) System Archetypes (albany.edu)
      Systems Archetypes I (thesystemsthinker.com) http://140.118.9.79/pkm/系統基模.pptx
    1. 反應遲緩的調節環路(Balancing Loop with Time Delay)(反應遲緩)
    2. 成長上限(Limits to Growth)
    3. 捨本逐末(Shifting the Burden)
    4. 目標侵蝕(Eroding Goals)
    5. 惡性競爭(Escalation)
    6. 富者愈富(Success to the Successful)
    7. 共同悲劇(Tragedy of the Commons)
    8. 飲鴆止渴(Fixes and Fail)
    9. 成長與投資不足(Growth and Underinvestment)
  - □ Mind Mapping => Concept Map vs. Mind Map (Concept Map vs. Mind Map｜MindMaster)