

System Dynamics

Feedback Process, SD Components & Notations

401.661 Advanced Construction Technology

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Lecture Outline

- Introduction of System Dynamics
- Component Variables
- Causal Loop Diagramming
- Application Examples
- Where to Get More

System Dynamics

- Developed to apply **control theory** to the analysis of industrial systems in the late 1950's by Jay. Forrester, MIT Professor
- Used to analyze **industrial, economic, social and environmental systems** of all kinds
- Providing **an analytic solution for complex and non-linear systems**
- **Well suited to dealing with the dynamic complexity in construction projects**, which are inherently complex and dynamic, involving multiple feedback processes and non-linear relationships [Sterman, 1992].

Types of Application

- System Thinking
- Policy Models
- Flight Simulators
- Project Models

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Stocks & Flows

As the final element of system structure, there are two kinds of variables ...

- Stocks (also called 'levels'): define the state of a system and represent stored quantities
- Flows (also called 'rates'): define the rate of change in system states and control quantities flowing into and out of stocks

Representations

Hydraulic Metaphor:



Stock & Flow Diagram:



"Clouds" represent stocks outside the system boundary

Integral Equation:

$$\text{Stock}(t) = \int_{t_0}^t [\text{Inflow}(s) - \text{Outflow}(s)] ds + \text{Stock}(t_0)$$

Terminologies in Different Disciplines

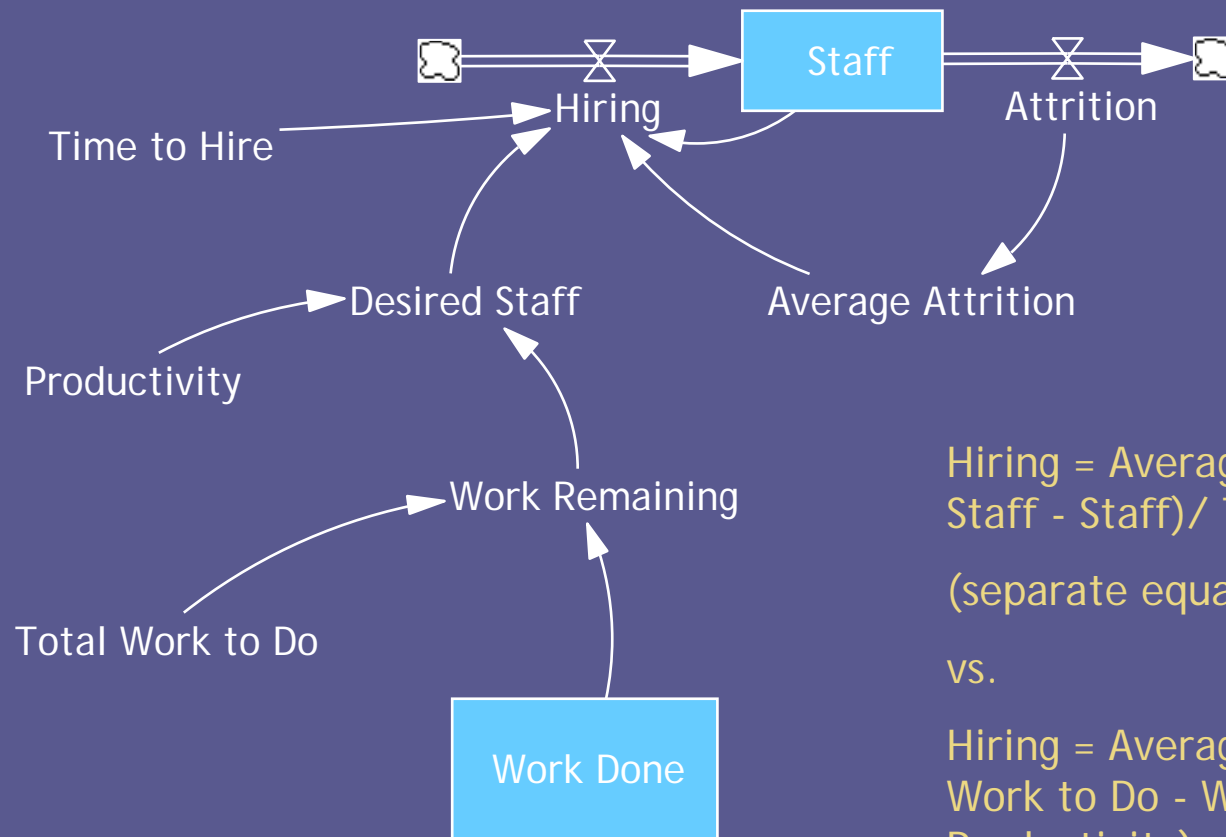
Discipline	Stocks	Flows
Mathematics, Physics, Engineering	Integrals, states, state variables, stocks	Derivatives, rates of change, flows
Chemistry	Reactants, reaction products	Reaction rate
Manufacturing	Buffers, inventories	Throughput
Economics	Levels	Rates
Accounting	Stocks, balance sheet items	Flow, cash flow or income statement items
Biology, Physiology	Compartments	Diffusion rate, flows
Medicine, Epidemiology	Prevalence, reservoirs	Incidence, infection, morbidity, mortality rates

Business Dynamics, J, Sterman, 2000

Auxiliaries & Constants

- **Auxiliaries:** intermediate variables to be used for easy of communication and clarity
 - Break up rates into **meaningful components**
 - Provide **alternative measures** for stocks or flows
 - Reduce diagram “clutter”
- **Constants:** factors which may be stocks or flows, but which **do not change over the time span of the simulation**

Break Rates Into Components



$$\text{Hiring} = \text{Average Attrition} + (\text{Desired Staff} - \text{Staff}) / \text{Time to Adjust Staff}$$

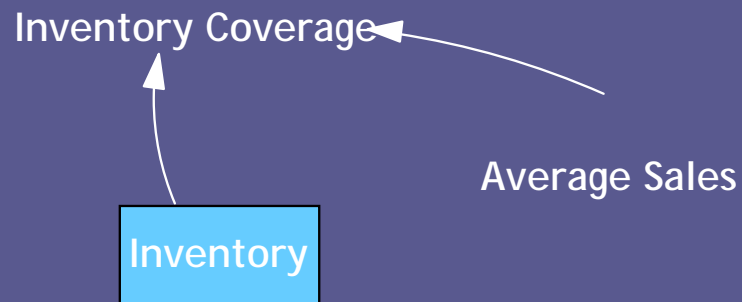
(separate equations for components)

vs.

$$\text{Hiring} = \text{Average Attrition} + ((\text{Total Work to Do} - \text{Work Done}) / \text{Productivity}) - \text{Staff}) / \text{Time to Adjust Staff}$$

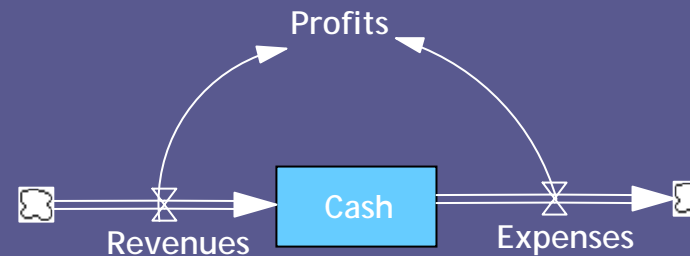
Provide Alternative Measures

For stocks...



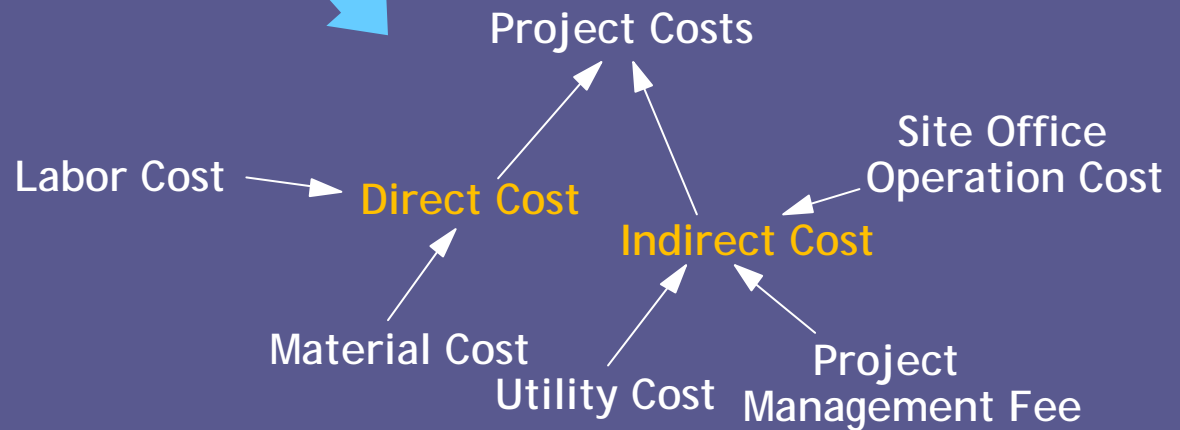
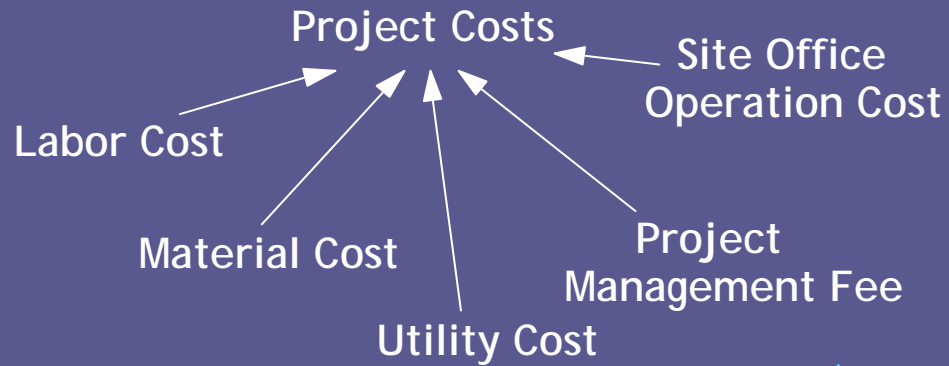
$$\text{Inventory Coverage} = \text{Inventory} / \text{Average Sales}$$

For flows...



$$\text{Profits} = \text{Revenues} - \text{Expenses}$$

Reduce Diagram Clutter



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Causal Links (Not Casual ...)

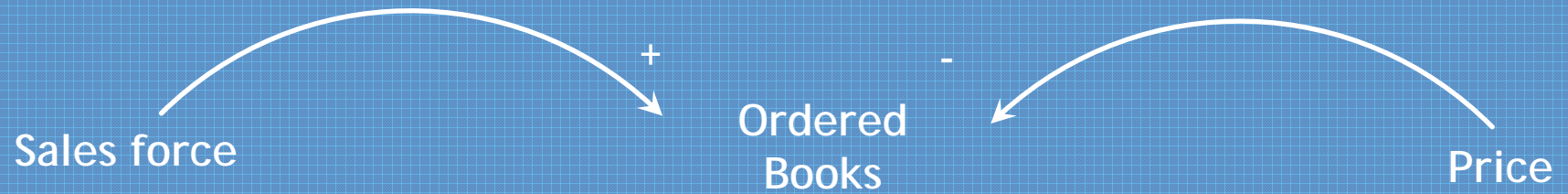
- An arrow with a positive sign (+): all else remaining equal, an increase (decrease) in the first variable increases (decreases) the second variable *above (below) what it would otherwise have been.*



- An arrow with a negative sign (-): all else remaining equal, an increase (decrease) in the first variable decreases (increases) the second variable *below (above) what it otherwise would have been.*



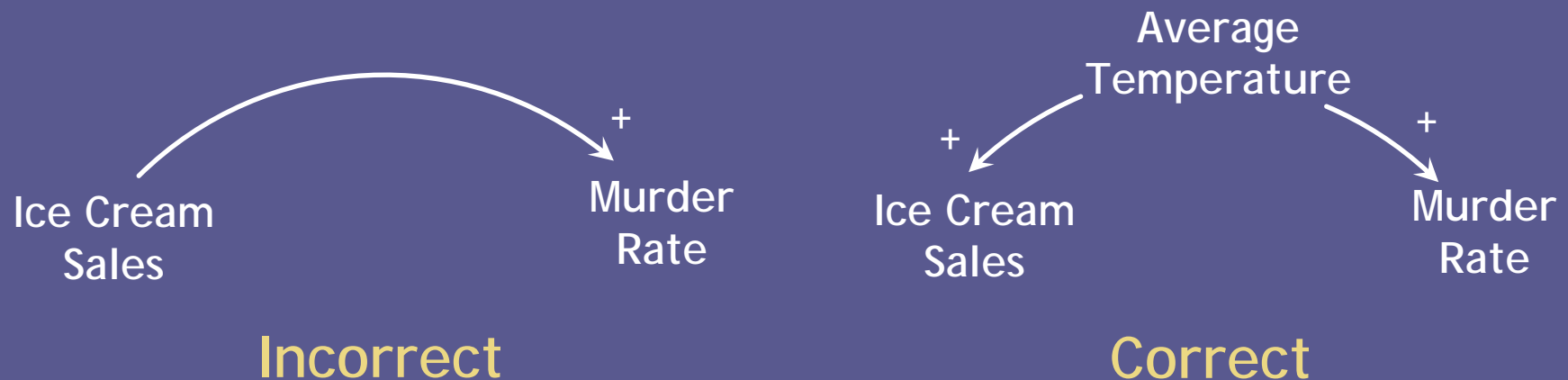
Labeling Link Polarity



Causation vs. Correlation

Causal diagrams must include only those relationships that capture the underlying causal structure of the system.

Observed behavior: "...Ice cream sales and murder rise in summer and fall in winter..."



Having Unambiguous Polarities

All causal links must have unambiguous polarities.

* Apparently ambiguous polarities usually imply the presence of multiple causal pathways that can be represented separately.

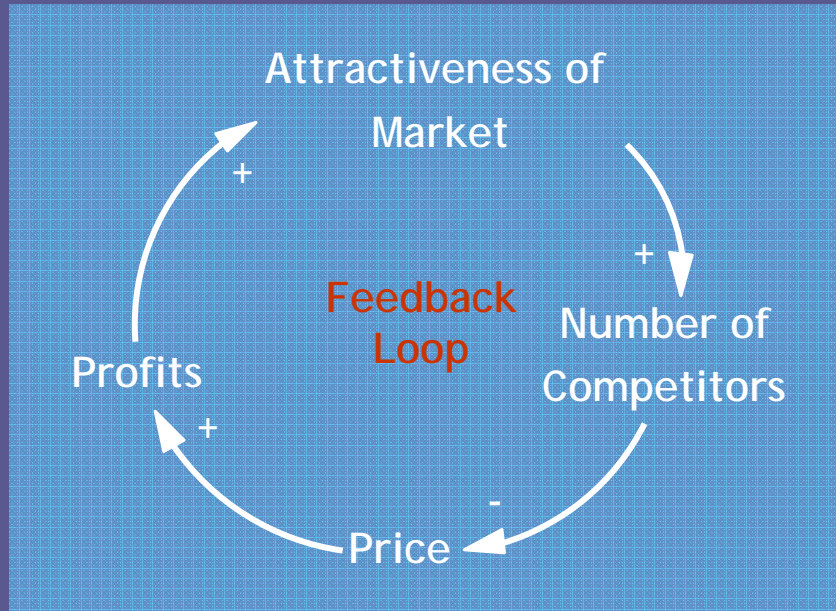
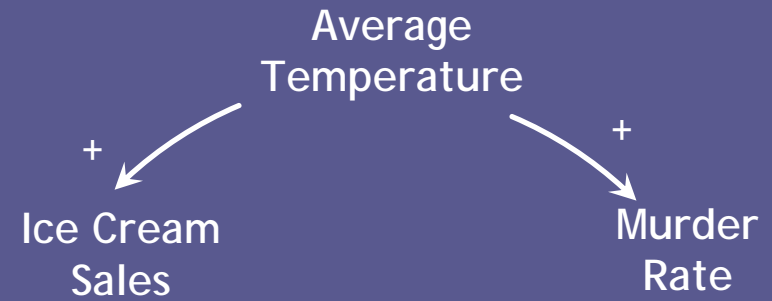


Incorrect

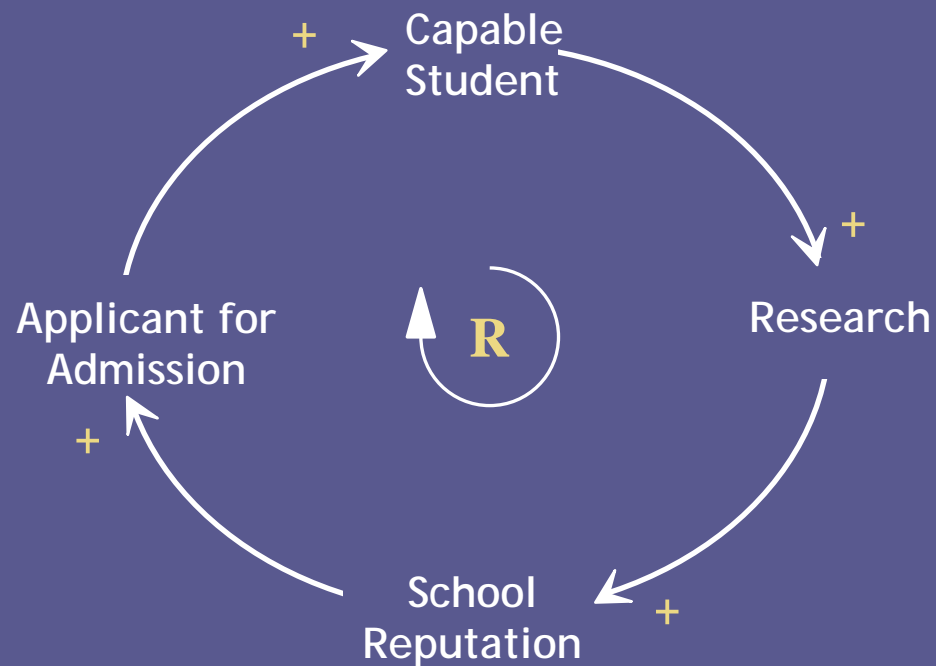


Correct

Identifying the Feedback Loop

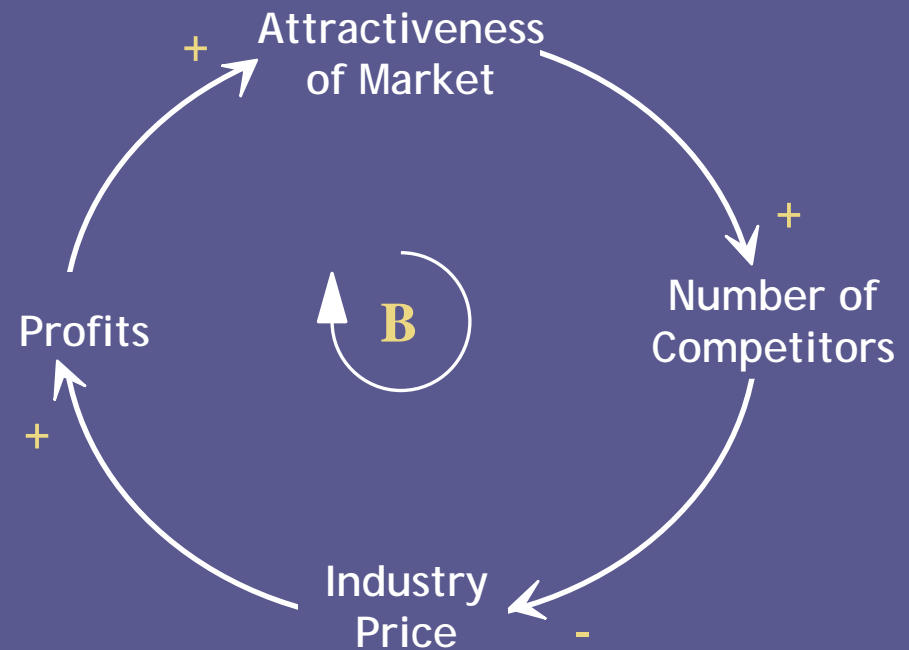


Loop Polarities: Reinforcing or Balancing?



Reinforcing Loops: loops with all positive or an **even number** of negative causal links

Balancing Loops: loops with an **odd number** of negative causal links



Naming Variables

*Names should be **nouns or noun phrases**.*

- The actions (verbs) are captured by the causal links
- A causal diagram captures **the structure of the system**, not its behaviors



Incorrect



Correct

Naming Variables

Names should have a clear sense of direction.

- Choose names for which the meaning of an increase or decrease is clear



Incorrect



Correct

Naming Variables

Choose variables whose normal sense of direction is positive.

- Avoid the use of variable names containing prefixes indicating negation (non, un, etc.)



Incorrect



Correct

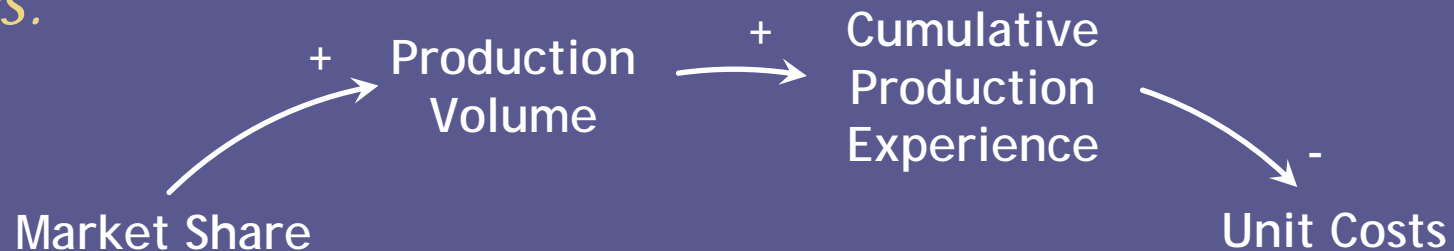
Choosing Right Level of Aggregation

Use *intermediate variables*, if they can make communication easier and clearer

If audience is confused by



You might make the *intermediate concepts explicit* as follows.



Making Goals Explicit

*Make the goals of negative loops **explicit**.*

- All negative feedback loops have goals (the desired state of the system)
- They function by comparing the actual state to the goal, then initiating a corrective action in response to the discrepancy.
- Making goals explicit encourages people to ask how the goals are formed.

Making Goals Explicit

The goal of the loop is determined by **management decision (human behaviors)**.

Incorrect

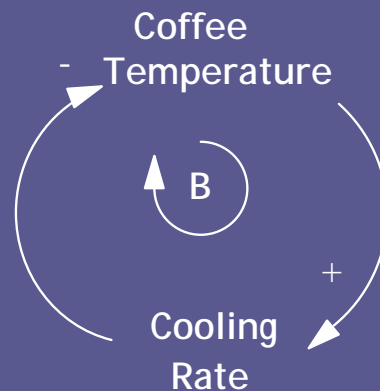


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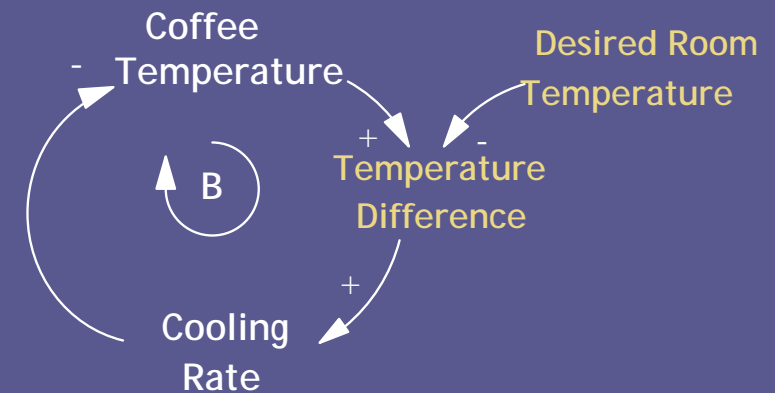


The goal of the loop is determined by **the laws of thermodynamics (natural processes)**.

Incorrect



Correct



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DPM

DPM - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Back Forward Stop Home Search Favorites Media Print Copy Paste Refresh Stop Links

Address http://star.mit.edu/dpm2/newdpm_1.html Go

Google Search Web Search Site New! PageRank Category Page Info Up Highlight

File View Tools Help

CONTROLS

Total Activity

28

DSM

SIMULATION INPUT

SIMULATION ANALYSIS

GAME

ACTIVITY TABLE

CO...	WBS	ACTIVITY NAME	D...	ST	FT
a1	TC-01-01	Sketch Plans	36	0	36
a2	TC-01-02	Final Plans	69	23	92
a3	TC-02-01	ROW Acquisition	116	29	145
a4	TC-03-01	Shop Drawing Submittals	39	96	135
a5	TC-03-02	Shop Drawing Review&B...	33	134	167
a6	TC-03-03	Shop Drawing Review&St...	34	134	168
a7	TC-03-04	Shop Drawing Review&R...	36	134	170
a8	TC-03-05	Shop Drawing Review&S...	34	134	168
a9	TC-04-01	Steel Fabrication & Rebar	54	136	190
a10	TC-04-02	Steel Fabrication BPads	101	136	237
a11	TC-04-03	Steel Fabricaton & Structu...	100	136	236
a12	TC-04-04	Steel Fabrication & Sheet ...	42	136	178
a13	TC-05-01	Prepare Site for Abutment...	35	168	203
a14	TC-05-02	Prepare Site for Center Pier	22	177	199
a15	TC-06-01	Construct Abutment E&W	33	205	238
a16	TC-06-02	Construct Center Pier	22	235	257
a17	TC-06-03	Set BPads & Girders	16	235	251
a18	TC-06-04	Construct Superstructure	25	251	276
a19	TC-07-01	Bell Telephone Cable	70	236	306
a20	TC-07-02	Relocate Gas Line	27	278	305
a21	TC-07-03	Relocate Water Line	27	305	332
a22	TC-07-04	Install Telephone DB	24	332	356
a23	TC-08-01	Realign Trable Cove Rd	19	355	374
a24	TC-08-02	Realign Rte 3 NB Ramps	24	374	398
a25	TC-08-03	Realign Rte 3 SB Ramps	26	400	426

ACTIVITY CHART

Treble Cove Bridge Project

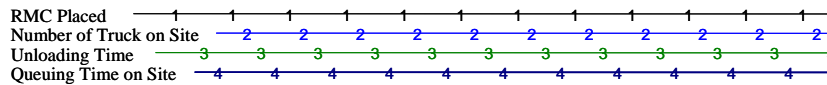
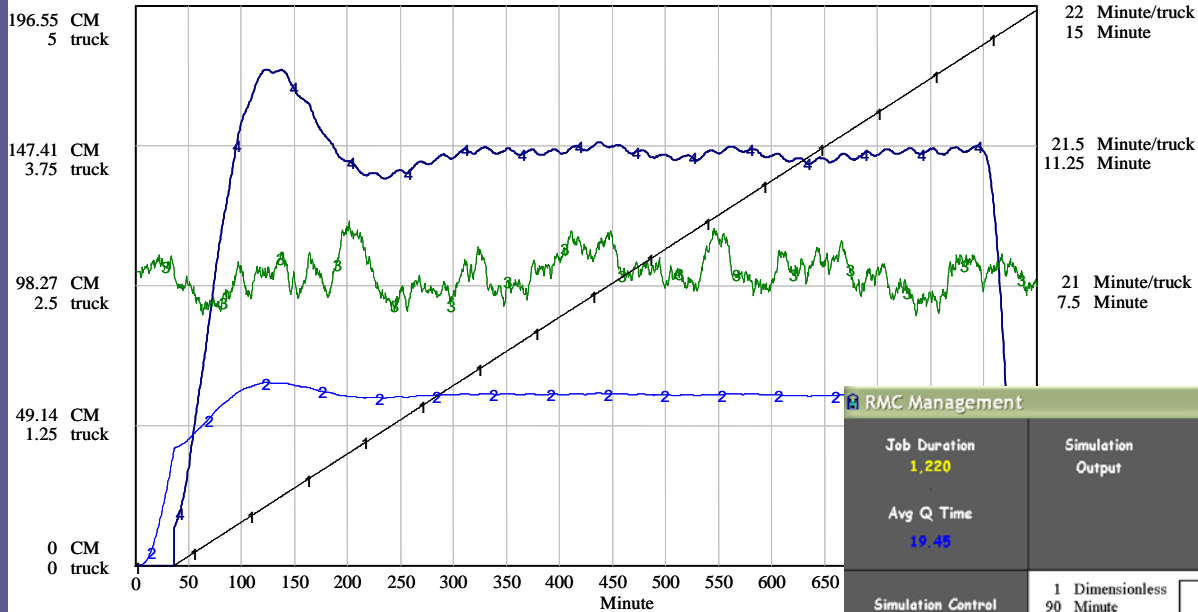
Code WBS Name Duration ST Time Unit

a7 TC-03-04 Review&Rebar 30 0 day

Add Delete Update

RMC Production & Delivery Automation

Dynamic RMC Supply Planning



RMC Management

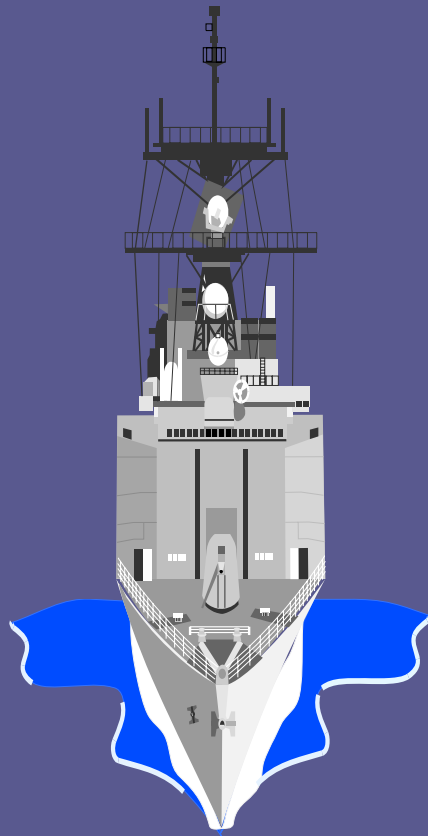
Job Duration 1,220	Simulation Output	Truck at Site 0.1909 trucks	Avg Time to Deliver 120.71	Rem Job Order 0.0051 trucks	Est Remaining T 0 min
Avg Q Time 19.45		Truck on Standby 4.403 trucks	Queuing Time 0	Est Unloading 0.0164 trucks/min	Job Progress 1 %

Simulation Control	1 Dimensionless 90 Minute 3 truck		Policy Change
Restart Game	0.5 Dimensionless 45 Minute 1.5 truck		Truck Dispatching Interval 60
1 hour Progress	0 Dimensionless 0 Minute 0 truck		Input Variation
3 hours Progress			Noise Standard Deviation 0.1
Whole Period			Noise Correlation Time 60 min
Graph Change		Progress : mygame	
Copy		Queuing Time : mygame	
Print		Truck at Site : mygame	

Time 1,304	Construction Settings	Time to Unload 66.66	Time to Position 1.653	Time to Load 1.312	Time for Slump T 2.982
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Application example:

the US Navy and Ingalls case

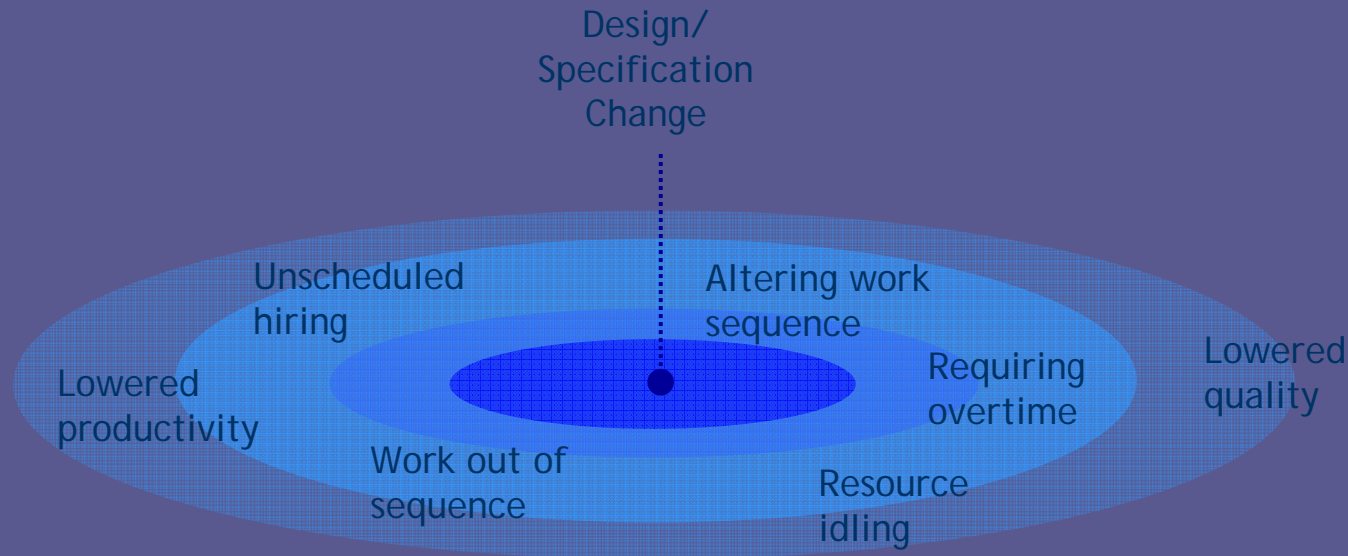


A system dynamics model developed by Pugh-Roberts Associates in the US was used to settle the claim against the US Navy in the late 1970's.

With help of this modeling approach, the ship builder, Ingalls managed to receive \$447 million as compensation for their financial losses caused by the owner's design and specification changes.

Quantifying the ripple effects

Traditional project management tools such as CPM, PDM, and PERT do not provide a mean to quantify the ripple effects that multiply the direct impact many times, leading to significant overall delay and disruption.



Providing evidencing data for arbitration

Traditional Dispute Resolution

A bunch of finger-pointing. Each party would say "Here's what the owner/the contractor did wrong" and blame all their problems on that.

There is no way to separate the impact of each party's problems or examine the synergy between them.

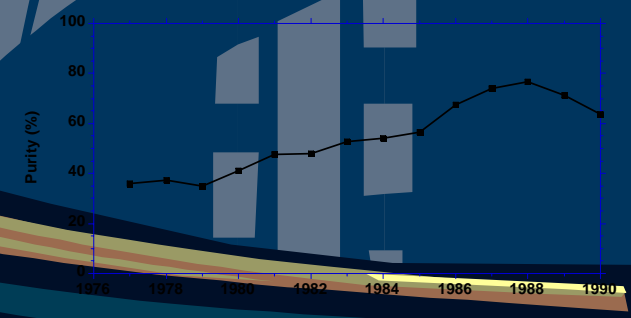
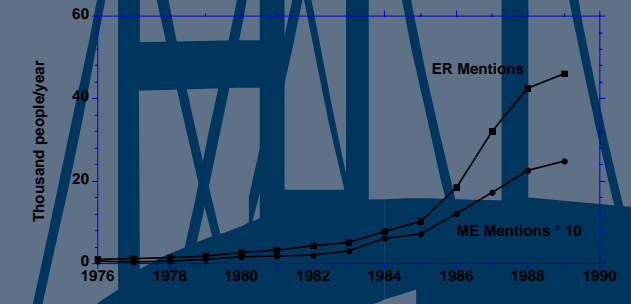
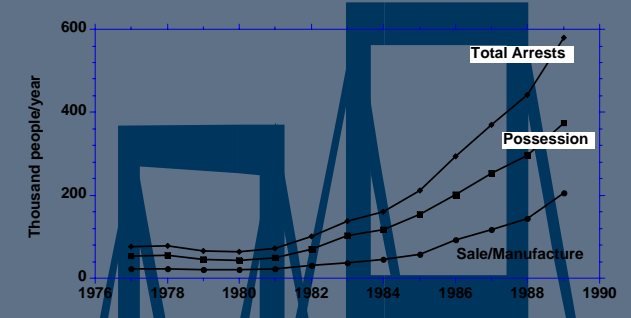


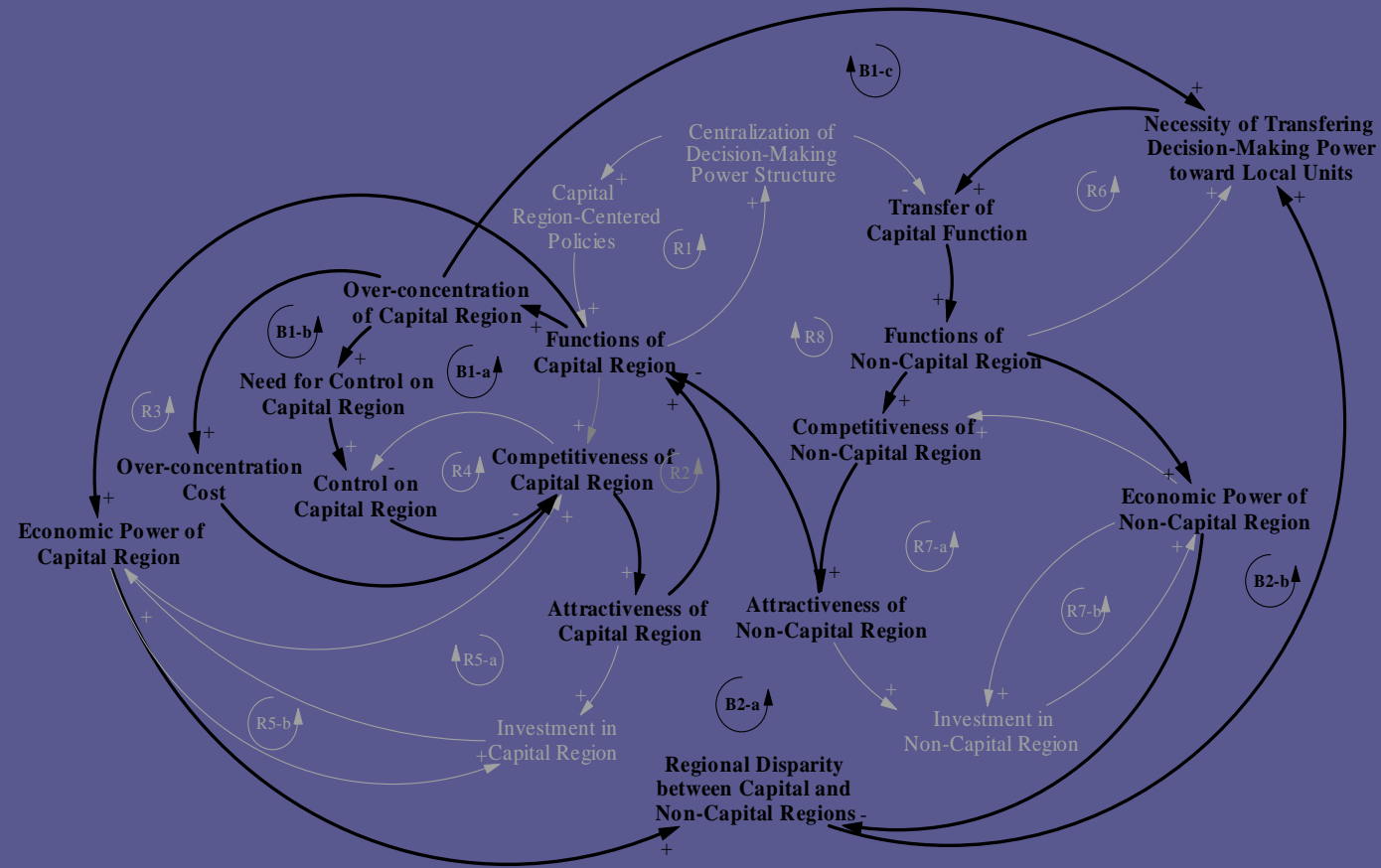
System Dynamics Approach

By simulating the model with different policy scenarios, it is possible to identify:

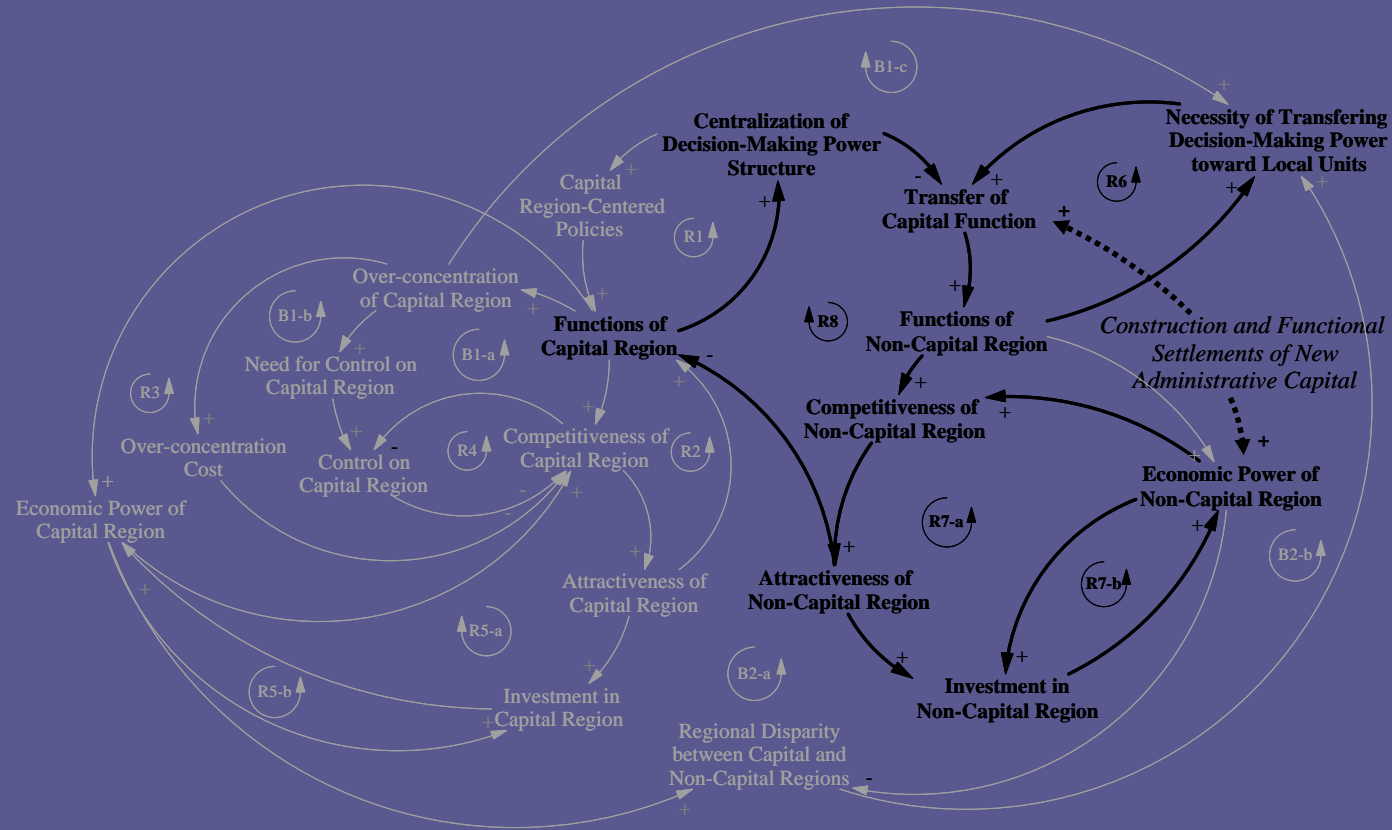
- 1) what are the things the owner/ the contractor didn't do well, and
- 2) how much each party contributed to time and cost overruns.

The War on Drugs





Decentralization Mechanisms



Loops of New Administrative Capital Construction

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Where to Get More

- System Dynamics Group at MIT

<http://sysdyn.mit.edu/sd-group/>

- System Dynamics Society

<http://www.albany.edu/cpr/sds/>

- System Dynamic Review

SNU Library

- Ventana Systems: download Vensim PLE version

<http://www.vensim.com/>

References

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