Integration of Knowledge on Feedback and Regulation for a System of Systems Processes (SSP-GST) Model and Application to Transportation: The GENSYSML Tool

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PURPOSE

- Develop a deeper comprehension of Feedback and Regulation and how they work within natural and man made systems at different scalar levels in non-linear dimensions
- Enable understanding of Feedback and Regulation of systems and their similarities across different disciplines to lead to a better knowledge of developing human systems
- Better define Feedback and Regulation and describe their context within the knowledge of System of System Processes
- Use information about Feedback and Regulation to move forward in the completion of the GENSYSML Tool

WORKING DEFINITIONS

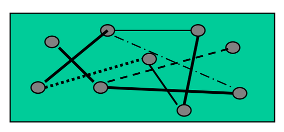
Feedback is fundamental to the design and function of complex systems. Feedback is information on the results of a process, activity, or mechanism that is returned to the system to be used to modify its behavior. The return of information in a cyclical manner is often called a feedback loop. Feedback, in terms of control mechanisms or processes, can either be positive and negative in order to regulate complex systems.

Regulation- "if an environmental variable (such as temperature) or an input or output variable (such as the flow demand on a system) changes and the system can nearly compensate for those changes in some other variable (such as outlet pressure) then the system is said to be regulated or regulated for that variable." (Principia Cybernetica)

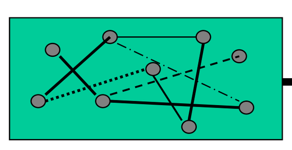
IDENTIFYING FEATURES AND FUNCTIONS

Our System of Systems Processes (SSP) analyzes each systems process for its major or key features. These are defined as the conceptual basis for the systems process that would allow a novice to find or identify that systems process for the first time in a newly encountered real system. We create logo's that capture the essence of the feature for easy recall. It is the entire group of ID features that defines any single systems process. For feedback we use the following ID Features….

Mechanism



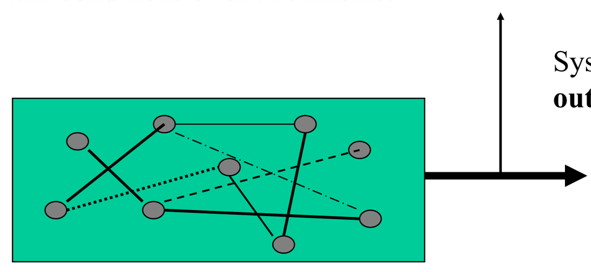
These are the so-called "black box" interactions among subsystems within the subject system. They are all the mechanisms that enable the system to function and last through time.



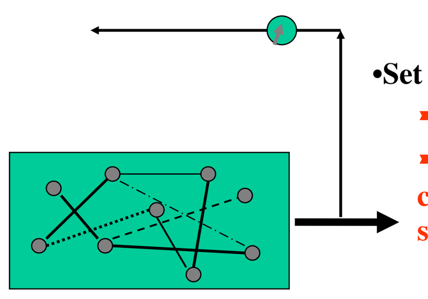
Output

The output is the product of the system over a certain time or given certain conditions or environments.

The system that senses is usually only a small quantity relative to the output of the system. It measures some relevant variables of the output to provide information about the output

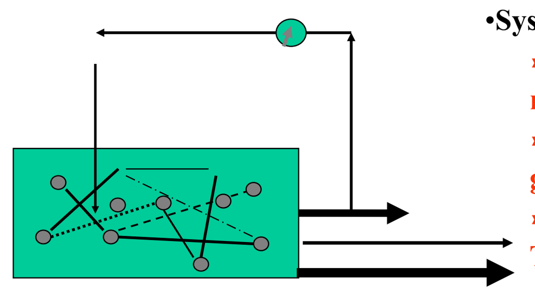


System that **senses output**



•Set Point

- **➸Compares output information to a standard**
- **➸Humans set standards but in nature they come from evolution; that is experience of past states and consequences**



•System that <u>Changes Mechanism</u>

- **➸Down regulation (negative feedback) leads to regulation, or equilibrium or homeostasis**
- **➸Up regulation (positive feedback) leads to rapid growth or decline or divergence**
- **➸Watch out for discinyms in this context. See Troncale paper for discussion of Discinyms.**

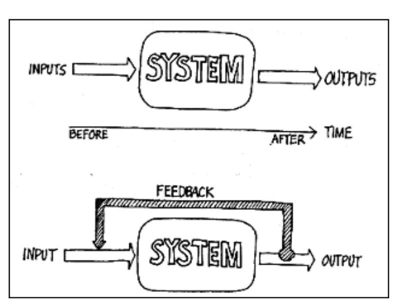


Image by de Rosnay 1997.
http://pespmc1.vub.ac.be/FEEDBACK.html

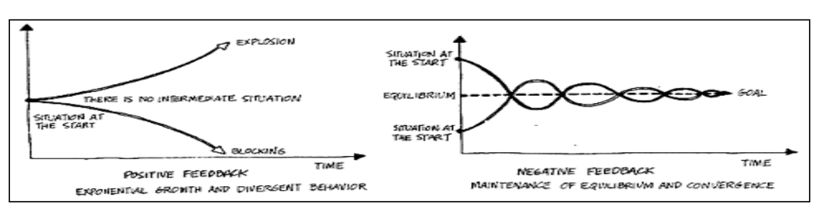


Image by de Rosnay 1997.
http://pespmc1.vub.ac.be/FEEDBACK.html

TYPES AND TAXONOMIES

Scalar Levels

Feedback as a thought process in humans vs. feedback in a computer system controlling a specific function vs. feedback forming climate processes such as the origins of hurricanes.

Regulations can be addressed in political systems where federal laws are passed to permit a certain rule about the methods that allow commercial goods to be transported across state boundaries. In the dynamics of cell growth and division a regulation of gene expression occur in metabolic transitions.

Transdisciplinary Levels

In electrical engineering, the concept of control theory feedback is determined by the output signal of a system which is returned to the input of the same system. Mathematics and theorems are well developed in systems engineering. Have they been modified and used for social systems design?

In economics feedback can be associated with the *hunting* of the stock market. When stocks begin to rise investors tend to buy before stocks peak in order to maximize profits, which reinforces positive feedback. If the investors foresee a peak in the same stock it would be wise to refrain from investing which acts a negative feedback mechanism.

SAMPLE INFORMATION BITS

"Feedback arrangements are widely used in modern technology for the stabilization of a certain action, as in thermostats or in radio receivers; or for the direction of actions towards a goal where the aberration from that goal is fed back, as information, till the goal or target is reached. This is the case in self- propelled missiles which seek their target, anti- aircraft fire control systems, ship steering systems, and other so- called servomechanisms." (Bertalanffy p. 43).

Bertalanffy, Ludwig von. <u>General Systems Theory,</u> 1968.

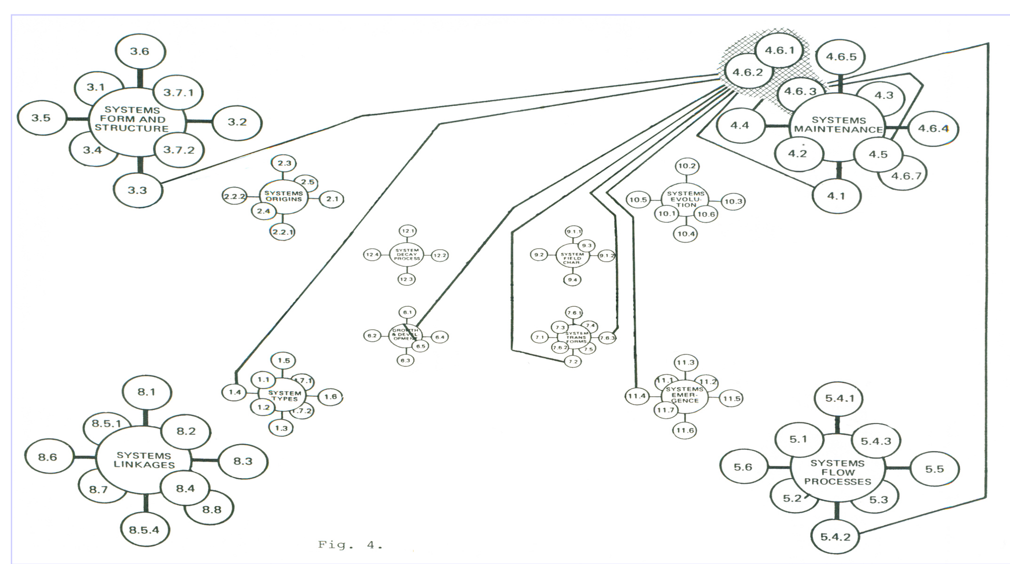
"Information theory may also come to play a central role in the theory of control and regulation. This is the hard core of system theory, for here occur the problems that demand real skill, not mere verbal plausibility. In regard to regulation, Conant [R.C. Conant, Information Transfer in Complex Systems with Applications to Regulation, IEEE Vol. SSC-5 No.4, pp. 334-338, Oct 1969] has proved the fundamental theorem (superseding the "law of requisite variety") that the capacity of any device or systems as a regulator cannot exceed its capacity as a transmitter of information. The relation between regulation and transmission was proved by him, in fact, to be not just possible but fundamental (Ross p. 88-89)."

Ashby, Ross W. *Systems and Their Informational Measures.* Ed by George J. Klir. <u>Trends in General Systems Theory,</u> 1972.

LINKAGE PROPOSITIONS

Some sample LP's (See definitions of LP's in Troncale Poster)

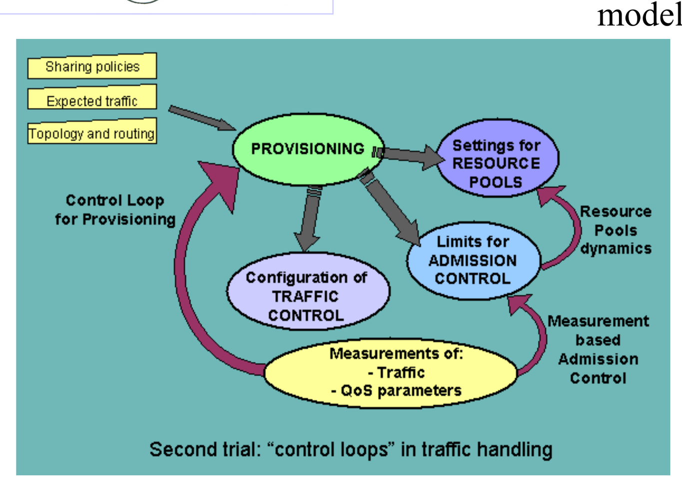
- <u>Positive and negative feedback</u> mechanisms are often found coupled together as a partial cause of <u>dynamic equilibrium</u> and stability.
- <u>Positive feedback</u> contributes, in part to <u>growth</u> mechanisms. <u>Negative feedback</u>, in part, to <u>equilibrium</u> or homeostasis.
- <u>Closed feedback loops</u> are in part the cause of constant <u>energy flows</u>.
- <u>Positive feedback</u> is a partial cause of amplification of rates of <u>growth</u> and <u>development</u> or decline and <u>decay</u> mechanisms.
- <u>Coupled</u> positive and negative <u>feedback</u> mechanisms are in part the cause of <u>oscillations</u>.
- <u>Goal seeking feedback</u> is in part the cause of <u>oscillations</u> and <u>cycling</u>



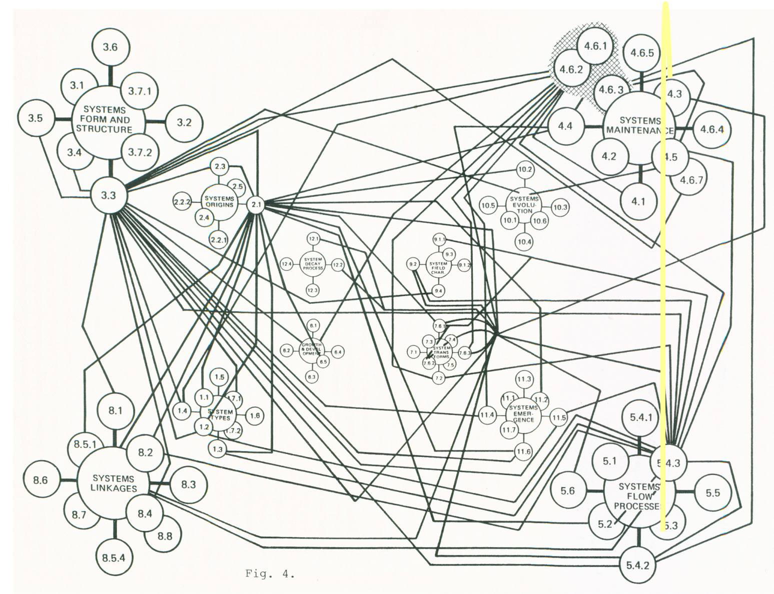
The SSP model shown in the cartoon above describes the interconnectedness of feedback and the association with other system concepts

4.1 Static States, 4.2 Stability, 4.3 Metastability, 4.4 Steady State/ Dynamic Equilibrium, 4.5 Transtemporal Stability, 4.6 Control/ Regulatory

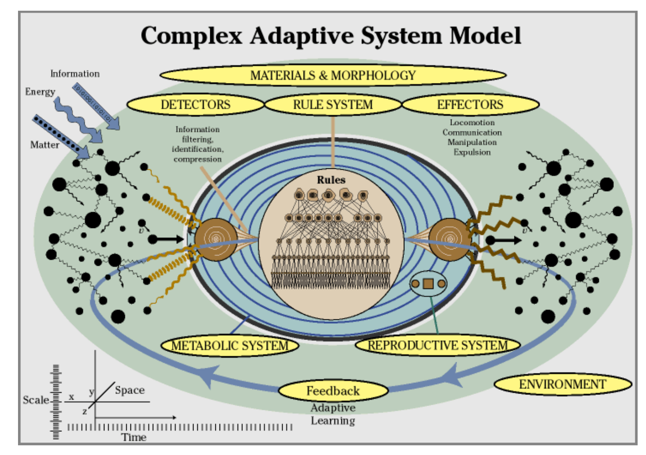
- 4.6.1 Negative Feedback
- 4.6.2 Positive Feedback
- 4.6.3 Coupled Feedback
- 4.6.4 Feedforward
- 4.6.5 2nd, 3rd Order Cybernetics
- 4.6.6 Single Loop/ Multiple Loop Feedback

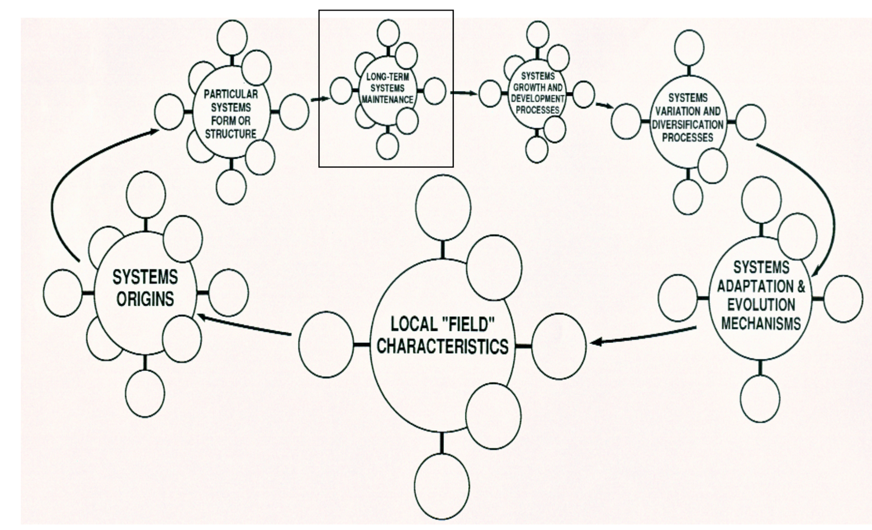


POSITION IN THE SYSTEM OF SYSTEM PROCESSES



The position of feedback and regulation are shown in the "system of systems processes" (SSP) at left, and the proposed General Systems Life Cycle (below). They are found within the "System Maintenance" functional cluster. The lines represent the interrelations and mutual influences between feedback mechanisms and other systems processes (isomorphies). For example "coupled feedback" a taxonomy in the system maintenance cluster is connected to a negentropic energy based "Systems Flow Processes" displayed by the highlighted curved line. Positive feedback is linked to hierarchical form in "Systems Form and Structure." The recognition of the many influences of feedback and the other processes that influence feedback could enrich our understanding of its role in systems dynamics.





WORKERS AND INSTITUTIONS

(Sample of contributors to knowledge on feedbacks intended for entry into the GENSYSML)

- **Norbert Wiener**- a child prodigy received his PhD from Oxford in Math at the age of 18 in 1913 and can be considered the founder of Cybernetics. He was able to thoroughly understand the concepts of control and regulating mechanisms and transferred the knowledge to living and non-living systems that served as the framework for Feedback.
- **Alberto Isidori**- received his doctorate in Electrical Engineering from the University of Rome where he also served at the same institution as Professor of Automatic Control Theory. He also served as a part-time Professor in the System Science and Math Dept in at the University of Washington in St. Louis. He co-edited <u>Systems, Models and Feedback</u> (co-editor, with T.J. Tarn), Birkhauser (1992), pp. 1-402.
- **Jay W. Forrester**- Professor at MIT created System Dynamics and contributed to feedback in control mechanisms for the military. Applied system dynamics to urban cities, global affairs and elementary educations.
- **Robert Rosen**- prominent theoretical biologist who received his PhD in Mathematical Biology from the University of Chicago in 1959. Some of his ideas have formed around biological control and regulation which is attributed to the concepts of feedback a main function of cybernetics. A Past President of the ISSS.
- **Raymond T. Stefani**- co-authored <u>Design of Feedback Control Systems.</u> Oxford, 2001.
- **Howard Odum-** Past President of ISSS, three texts on use of feedbacks in STELLA models of ecosystems. Craford Prize Winner.

APPLICATIONS IN TRANSPORTATION

(Please see diagram of network effects in real transportation systems at the left)

As developing countries become more developed, population increases, people move toward urban cities, and traffic on streets and freeway systems become ever more congested, what are the methods that decision makers will address these problems with? By overlaying the many LP's of the SSP and the many influences of feedback and regulation on dynamic transportation systems solutions may emerge. Regulations that allow a certain amount of vehicles to be used within a city may need to be enforced. In Bogata, Colombia on certain times of the year cars are restricted from entering the main capital allowing more flow for pedestrian, bicycle and transit modes which has significantly eased traffic and improved air quality. In addition, more dynamic network technology in remote sensing traffic devices that produce feedback signals that limit the time intervals for traffic lights would also improve the flow of traffic by allowing the optimum proportion of vehicles to pass and adjust itself to the number of users. Below is a sample of articles that have used system design and the concepts of feedback on transportation systems that we want to re-examine using the SSP and its feedback Linkage Propositions.

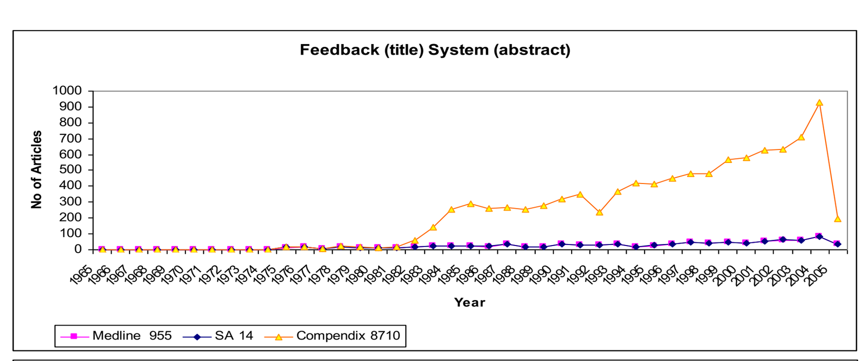
Controlling traffic jams by a feedback signal
<u>Zhao, X.</u> (School of Traffic and Transportation, Beijing Jiaotong University); <u>Gao, Z.</u> **Source:** *European Physical Journal B*, v 43, n 4, February, 2005, p 565-572

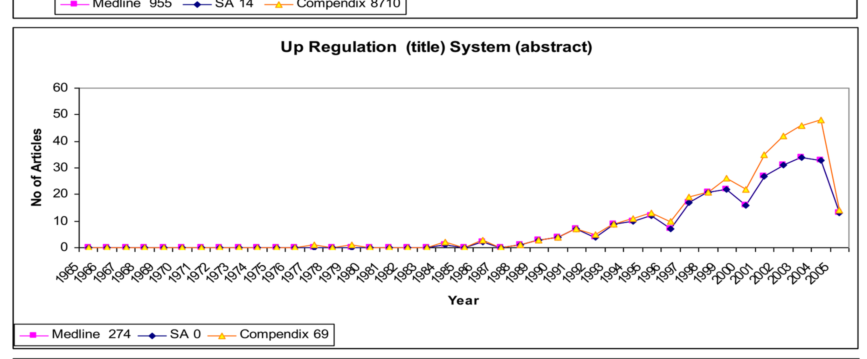
Predictive time-based feedback control approach for managing freeway incidents
<u>Sawaya, D.B.</u> (Department of Civil Engineering, Northwestern University); <u>Doan, D.L.; Ziliaskopoulos, A.K</u>. **Source:** *Transportation Research Record*, n 1710, 2000, p 79-84

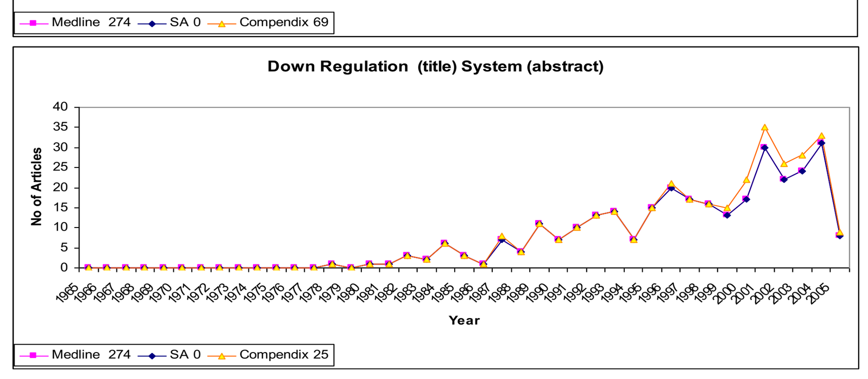
Cascading Control Strategies for Linear Systems with Application to Freeway Traffic Regulation.
<u>Goldstein, Nahum B</u>. (Univ of Minn, Minneapolis, USA); <u>Kumar, K. S. P.</u> **Source:** *Conference Record - Asilomar Conference on Circuits, Systems & Computers*, 1981, p 158-162

Suboptimal Control of Linear Systems by Augmentation with Application to Freeway Traffic Regulation.
Isaksen, Leif; <u>Payne, Harold J.</u> **Source:** *IEEE Transactions on Automatic Control*, v AC-18, n 3, Jun, 1973, p 210-219

SOURCES: SCOPE OF & TRENDS IN LITERATURE







The graphs represent searches from library journal databases; Medline, Sociological Abstract and Compendix. Altogether, nearly 10,000 articles were identified showing how rich the lit for these systems processes is for harvesting into GENSYSML. The searches were done through a specific criteria from 1965 to the present. On each of the graphs in the legend states the number of total hits found for each journal database.

In the top graph "Feedback" was searched in the title and "System" was searched in the abstract through the advanced search method in each database. Most of the articles containing Feedback were found in the engineering database Compendix. Very few articles were found in Sociological Abstract which is the online database for the behavioral sciences.

For the middle and bottom graph, no articles were found in Sociological Abstract for both "Up Regulation" and "Down Regulation" probably because these are terms used for feedback in the biological sciences. They are "discinyms" for feedback, showing the confusion that can arise from not knowing the different uses of terms in different fields. The results for both searches had more hits in Medline the online medical journal database and fewer in Compendix.

The significance of these searches should demonstrate where further research should be focused. The need for work in the behavioral science regarding feedback would facilitate the much needed knowledge for decision makers that deal with social systems.