Systems are Dynamic

All systems display dynamic behaviour (some systems react either so fast or so slowly that they can be treated as static, but in reality there is no such thing as a static system). The behaviour of a system manifests itself in several ways as events and patterns:

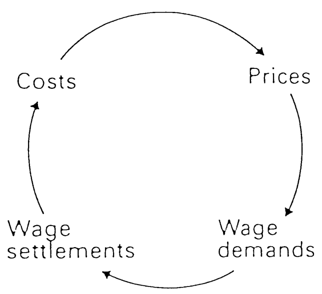
- Events are things that happen at a certain point in time. For example, a commercial aircraft retracting its undercarriage can be treated as an event, so can a mid-air collision, or the launch of a rocket.
- Patterns are an accumulation of events that display a recurring trend over time. For example a commercial aircraft taxis, accelerates down the runway, rotates, becomes airborne, retracts its undercarriage, etc is a series of events that defines a pattern repeated by most commercial aircraft.

To fully understand a system it is necessary to examine its behaviour over time. Although systems can display complex dynamic behaviour this is a consequence of just two forms of feedback:

- Reinforcing feedback
- Balancing feedback.

Reinforcing Feedback

Reinforcing or positive feedback is where successive changes add to the previous change in the same direction. A classic example of “pure” positive feedback is the inflationary spiral, a version of which is shown below:

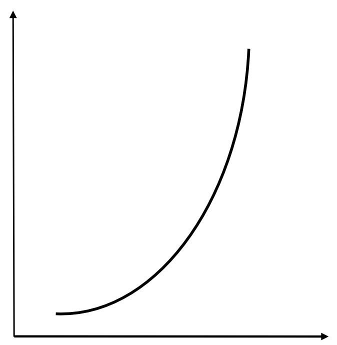


In this simple model an increase in prices will lead to an increase in wage demands which will lead to an increase in wage settlements which will lead to an increase in costs that will lead to an increase in prices and so on. This type of system dynamics if left unchecked will lead to hyper-inflation such as that experienced in Germany in the early part of the last century as shown in the table below.

Reinforcing or positive feedback is often considered to be a “bad” thing. Indeed, pure positive feedback will lead to exponential behaviour as shown. It can, however, be useful. In fact in some systems it is essential. For example in electronics, positive feedback is employed in certain types of oscillator.

Date	Whole Price Index
July 1914	1.0
January 1919	2.6
July 1919	3.4
January 1920	12.6
January 1921	14.4
July 1921	14.3
January 1922	36.7
July 1922	100.6
January 1923	2,785
July 1923	194,000
November 1923	726,000,000,000

German wholesale price index

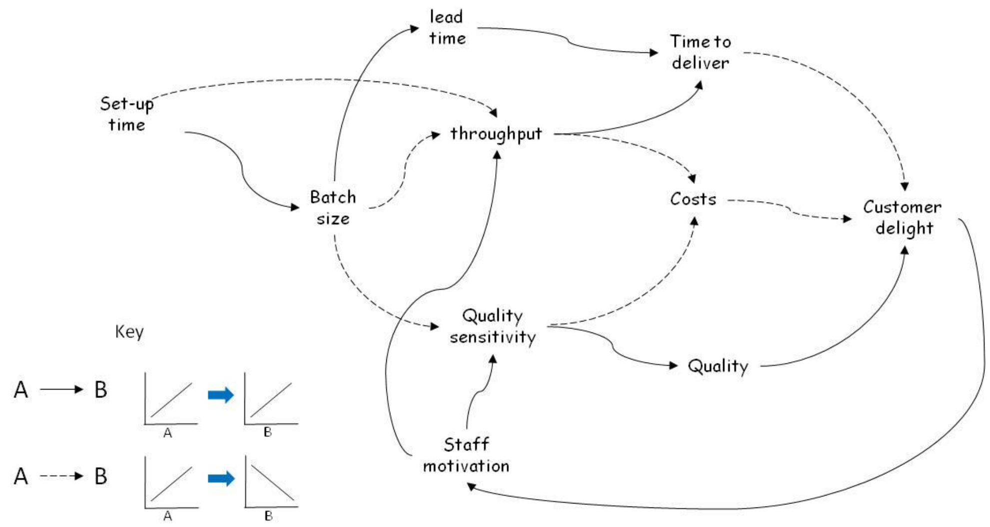


The exponential growth of positive feedback

Balancing Feedback

Balancing or negative feedback is where change in one direction is opposed by producing change in the opposite direction.

Most systems are a complex combination of both reinforcing and balancing feedback loops. For example, the diagram below presents a model of the principles of lean manufacturing. In this model, reinforcing behaviour is shown with the full arrows and balancing behaviour with the dotted arrows. This particular model is not complete but has sufficient detail to explain how reducing set-up times will result in customer delight.



A Causal Model Displaying Some of the Principles of Lean Manufacturing

It is interesting to note that irrespective of the level at which we conduct our investigation, higher level feedback chains can be found. In the case of the above diagram, an increase in customer delight will result in increased sales and therefore profit. That profit can be spent on further set-up reductions and so on.

The combination of reinforcing and balancing loops within a system will naturally determine how that system behaves. Of critical importance here is the concept of system stability.

System Stability

The stability of a system concerns its time-related behaviour following some disturbance. There are three possible behaviours:

1. The system returns to its starting condition. This is a stable system
2. The system comes to rest at a new condition. This is a marginally stable system
3. The system continues to move away from its starting condition in an increasing manner. This behaviour is unstable and can be so large as to destroy the system.

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When engineering a new system having the right degree of stability is critical. Stable systems can be "sluggish" and unresponsive but ultimately safe. Unstable systems can be very responsive but potentially unsafe. The behaviour of the Millennium Bridge was verging on instability, but not so bad as to destroy the bridge. This can happen! The infamous Tacoma Narrows Bridge in the USA was destroyed due to wind induced torsional oscillations. It was certainly not designed to behave in this manner and is yet another example of unexpected (and undesirable) emergent behaviour.

System Stability is determined by the interconnectedness of the system elements and can be changed by increasing or decreasing (removing or adding) "connections"

- A stable system can be made less stable by reducing/removing balancing feedback or by increasing/adding positive feedback
- An unstable system can be made more stable by reducing/removing positive feedback or increasing/adding balancing feedback.

How a system is put together and how the elements interact is critically important. The observed behaviour of a system is a consequence of how all elements in that system interact. Change those elements or interactions and the system will change the behaviour. The behaviour of a human-made system is purely the consequence of the choice of elements (the technologies) and the way in which they are organized (the architecture). It is interesting to note that people believe that changing the technology will have the biggest impact upon a system's behaviour. In practice changing the elements or technology of a system usually has the least effect. Donella Meadows provides an excellent example of this by considering a football team as a system (Meadows, 2008). The elements of this system are the players, the interconnections are the rules of football. If you change the players in a football team it will be still be recognisable as a football team (it might perform better). If the rules change then the system may be greatly altered!

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