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Introduction to Systems and Causal Loop Diagrams

adapted by
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1.0 Introduction

System thinking has been developing for the last 50 years and is increasingly having more influence on science. In brief terms system thinking is a science that deals with formulation of logic and integration of disciplines for understanding patterns and relations of complex problems. System thinking is also known as principles of organization, theory of self-organization. Holistic perspective is also known as "systemic" and the way of thinking it involves "system thinking".

By shifting the attention towards interdisciplinary approach, system thinking becomes inevitable part of analysing problems. It enables one to understand causes and effects of problem and how different aspects of society and the natural environment interrelate through feedback loops.

2.0 How the system theories evolved

In the 1920 the Russian multi-discipline researcher Alexander Bogdanov formed the first comprehensive theoretical framework, describing organisation of living and non-living systems. Bogdanov clarified principles of organisation in his theory Tektology, by defining them as the totality of connections among system elements. He identifies three elements that characterises complex systems (Capra, 1996).

- Organised complexities, where the whole is greater than the sum of its parts.
- Disorganised complexities, where the whole is less than the sum of its parts.
- Neutral complexes, where the organising and disorganising activities cancel each other.

Ludvick von Bertalanaffy, independently followed up the work of Bogdanov and initiated the general system theories in the 1940´s from which the modern cybernetic movement emerged. Bertalanaffy made clear that system theory was a science of wholeness, which could guard against superficial analogies in science. Bertalanaffy further elaborated that duplicating the same knowledge between isolated disciplines was unnecessary since system thinking transferred the principles among fields.

The cybernetic movement, formed after the World War II was a group of mathematicians, neuroscientist, social scientist and engineers, led by Norbert Wiener and John von Neumann. They developed important concepts of feedback and self-regulation within engineering and expanded the concept of studying patterns, which eventually led to theories of self-organisation (Lagerroth, 1994; Capra, 1996). The Neumann group discovered an important feature with system thinking, the ability to shift the attention back and forth between details and wholeness through different levels (system levels) and observe how different kinds of laws act within each system level. It enabled a contextual analysis of seeing different system levels interacting in a larger whole, i.e. the interaction of species in an ecosystem or the urban society and people.

One of the most significant discoveries by system thinkers is the implication that all sciences are in principal non-linear. This was clearly expressed by the Nobel Laureate Ilya Prigonine where, in his research on complex systems, he concluded that only non- linear equations are capable of describing systems far from equilibrium. Prigonine's studies led him to the development of new thermodynamics that could describe the phenomena of self-organisation, which he called *dissipative structures*.

Apart from conventional thermodynamics, which describes the world as a place with ever decreasing energy and procedure towards equilibrium, dissipative structures maintain their energy flow far from equilibrium and can evolve towards increased complexity (Capra, 1996; Lagerroth, 1994). Maturana and Varela further elaborated this in their theory of *autopoiesis* (self-making), that described self-organisation of living systems.

What is interesting and very important from studies of self-organisation is the understanding that developed in the sixties and early seventies when several hypotheses from the natural and social sciences evolved, based on system theories. Meadow, Forrester and Lovelock, all met strong opposition in their work when they tried to make holistic perception by synthesising different disciplines and draw conclusions from it. According to Lovelock (1995), the critique from the scientific community was largely based on misunderstanding since system theories where basically unknown to the scientific community at the time.

Misunderstanding of this type is understandable since communication between disciplines has been limited throughout the century. What is developing in biology is of little interest for geologists, seems to be general notion, even if these two subjects are closely interwoven. This has been clearly unfolding in recent years through the study of earth's history where both disciplines debate about evolutionary processes.

In recent years, scientists are realising the importance of creating educational basis that incorporates holistic perception, which is interdisciplinary in character.For the last 10 years system thinking has been finding its way into popular universities and many corporations.

2.0 Seeing structure and logic in problems

To some people, many of the environmental problems seem to have their origin in the recent 30-40 years. Increasing concerns about them has motivated us to ask ourselves many different questions on how and why they are there to begin with. Our immediate response, understandably, to difficulties would be to resolve the most visible problems by applying some sort of quick fix method that shows swift results and restores the issue to its original condition. Problems often appear to be solved for some reason but can usually resurface in another form elsewhere in the society in a new shape not expected.

What is characteristic for solving problems are the socalled "end of pipe" solution. It is a tactic based on "curing" symptoms rather than the source of a problem. Curing symptoms can be described as putting a filter on a smoke stack, building longer sewage pipes out to the sea etc. In the seventies, it was considered economically viable in the short term for the state and companies to apply the "end of pipe" approach instead of upgrading the machinery or changing production methods. This was the general view since environmental problems were not seen as a direct threat to society. This approach revealed its weaknesses in the long run when the debate on climate change started. Many of the "economically viable" solutions in uncovered manifold increases in expenditure, as the solutions did not take into account the long-term consequences of environmental problems. One good example are the coal driven power plants. The carbon dioxide debate has shown that in order to obtain a sustainable energy structure many of today's power plants are obsolete as their primary source of energy, coal, is considered unsustainable (see figure 1).

Figure 1: The "end of pipe" solution approach is a typical example of fixes that fail.

End of pipe solutions are not unique for the heavy industry, they can also be related to our socio-economic and ecological strategies. Northern Europe for example has experienced for several decades high sulphur deposition. This problem is often referred to as the problem of "acid rain". It is a typical problem that is transboundary which no "one" country in Europe can be blamed for. In the eighties lake ecosystems started to "die off" due to increased acidity. The immediate response to this problem was to initiate lake liming programs, which was basically pouring Calcium Carbonate into lakes in order to reduce the acidity effects. The purpose of lake liming was to restore the original pH level in the lake to recover the initial ecosystem.

Figure 2: Lake liming as a measure to reduce acidity in aquatic ecosystems.

After several years of research and lake liming it was discovered that runoff from land was primarily responsible for acidity in lakes. Sulphur deposition on soil affected groundwater and runoff water, which then affected pH in lakes. As a result many decision makers initiated “soil liming” programs as a mean to deal with the worst affected areas. One might ask if it would be more reasonable to attack the problem from its source, thus to deal with the industry that is primarily responsible for the sulphur emissions, instead of treating the symptoms. As long as the externalities of environmental degradation were not included in economic activities it was reasoned in the eighties (and still is) that environmental degradation of this sort was economically acceptable.

Figure 3: soil liming as a measure to reduce acidity in groundwater.

The story of acid rain is just one of many similar ones, politicians found themselves dealing with much greater problems than before. Liming soils was a much larger task and more costly than liming lakes. This was no longer a problem that focused only on soils or lakes but an *interdisciplinary* problem that touched also on agricultural productivity, forest productivity and socio-economic aspects. For decision makers this was suddenly an immense problem that needed joint focus involving all actors.

Transboundary pollution is a problem that is impossible to deal with on a country level. It would seem reasonable for the country with the source emission to bear part of the costs for ecological degradation. This sort of problem is impossible to deal with in the absence of all the actors involved and without increasing the so-called "system boundaries" of the problem. When we view the problem on a local level we only see the symptoms and often dismiss the feedback to the "doer" (see figure 4). This is not intentionally done but rather stems from our problem solving strategy. Our problem solving strategy is often based on linear thinking, which neglects the feedback and the behaviour in our problem. We become focused on treating the symptoms rather than dealing with the underlying cause.

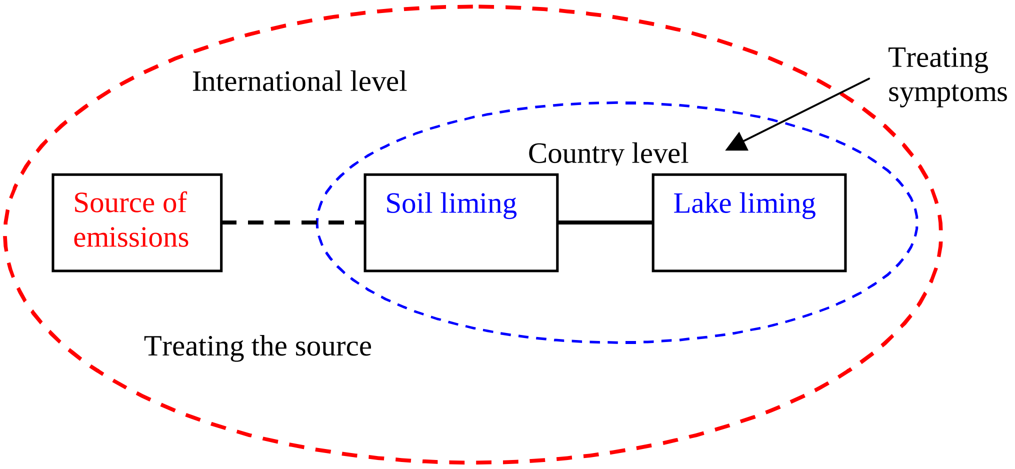


Figure 4: In order to deal effectively with the dilemma of acid rain all the actors need to be included.

Such misunderstanding can be explained by the structure of logic we use. We all have a mental model, which is a simplification of how the world works around us (Dörner, 1996). This mental model of reality we use continuously to learn and analyse situations and making decisions. Normally there is not a problem with our mental models because they appear to work in most cases, e.g. filtering coal emissions works as long we ignore the long-term consequences of CO_2 production and climate change. As a consequence we tend to develop routines and skills that are based on our mental models e.g. driving early to work to avoid traffic or putting on a jacket before going outside and etc. These routines seem very simple and obvious and not necessary connected to mental modelling, but we have grown unconscious of our routines since the models we have developed about them are working just fine. We base all our decisions on our mental models and since we often become so dependent on our routines and skills we have difficulties to detour from our route in order to take in new understanding (see figure 5).

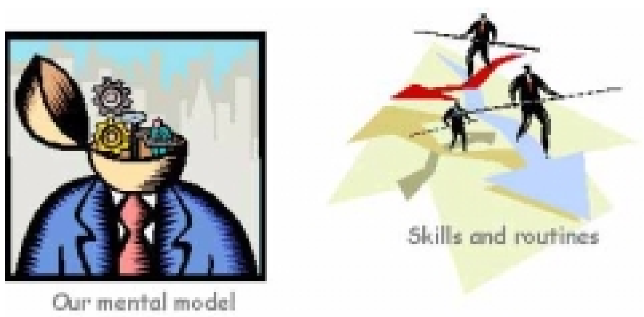
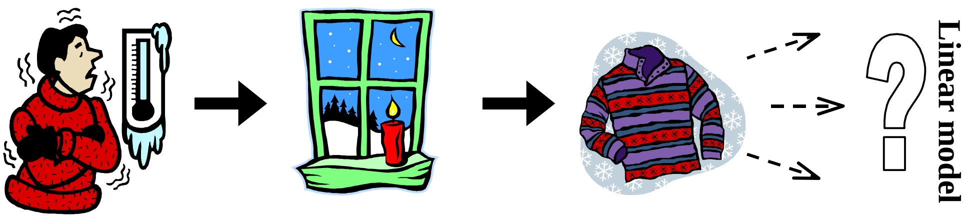
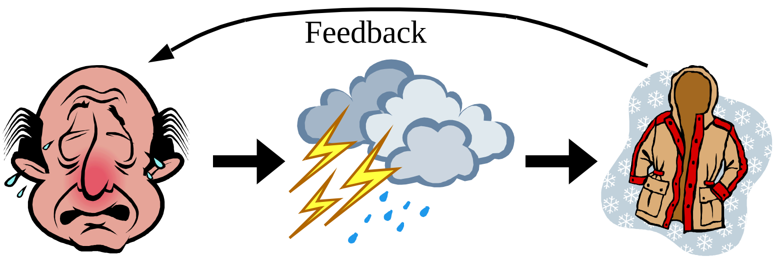


Figure 5: From our mental model we develop our skills and routines.

The models that the human mind develops are so called static models, which describe a set of linear relationships that *do not change* over time. If for instance we are situated downtown during rush hours we observe that almost everything is moving, but when we take a picture of the situation, we "freeze" the moment (Grant, 1997). That is, everything is fixed according to the particular moment of time when we took our picture. Static models are "frozen" models or so-called linear models were time is not an independent variable. All "movement" in static models is extracted like in regression examples, e.g. correlation between number of cars and number of bus passengers or quality of lake and reproduction of fish. We know that when it is cold outside we need to put an extra sweater on (see picture below). Here time is not relevant to us since we use the temperature to determine the amount of clothes needed to maintain a comfortable temperature. This is how our mind works in most cases, our simplification works well in most situations. We only encounter problems when our static representation of reality (routines and skills) is inefficient to simplify the complexity of the real world.



Most problems are dynamic that means that variables and relations vary with time. The most essential factors concerning dynamic behaviour are the feedbacks. In a dynamic behaviour the feedback is determined by time or the so-called time lag. We can estimate the amount of clothes needed for certain temperature, but our initial assumption does not take into account fluctuation in temperature during the day because it is not linked with time. If we know that it will start to rain later in the day (assuming weather forecast) we start to link time to our mental model and just to be on the safe side we take a rain jacked with us. Just in this simple example we have created dynamic mental model with a feedback (see picture below). Another example of dynamic model could be a model, which describes a fluctuation in household water consumption or urban traffic during the day.



Although the human mind can understand behaviour through time it performs poorly when confronted with complex dynamic behaviour that incorporate many variables. Usually we have no problem to grasp behaviour of two to three dynamic variables. The problem starts to arise when variables exceed three or four components that move dynamically. The mathematics are just too complex for us to comprehend, especially the longer the time aspect is (similar to the dynamics of the economy or interaction in an ecosystem). At this stage it is very important to structure our logic such that we can identify what, how and when to act in complex situations (Dörner, 1997). This is how and why system thinking was developed.

2.1 What is system thinking?

System thinking was developed in the fifties as a method to deal with problems in complex systems. It is a science based on understanding connections and relations between seemingly isolated things. In technical terms system thinking is; understanding relationships and patterns between components in a network of relationships. The essential properties of a complex system are derived from its internal relationship (Capra, 1997). In general terms system thinking is mental modelling and science of structuring logic but it has also a practical application called system dynamics which was developed in the sixties by Jay Forester at MIT. System dynamics deals with mathematical representation of our mental models and is a secondary step after we have developed our mental model (see figure 6).

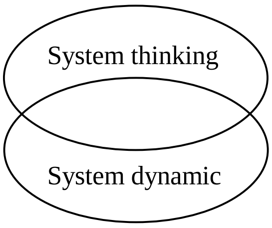


Figure 6: A Venn diagram describing the relation ship between system thinking and system dynamics (from Cover, 1996)

The traditional education has taught us that reality is made of linear relationships. Actually reality is made out of circles or circular arranged events but we tend to see everything in straight lines. A linear view always suggests a simple locus of responsibility. When things go wrong, this is seen as blame- "he, she, it did it" –or guilt- "I did it." At a deeper level, there is no difference between blame or guilt, for both spring from linear perceptions. From linear view, we are always looking for something that must be responsible (Senge, 1990). In mastering system thinking, we give up the assumption that there must be an individual or an individual agent, responsible for the problem encountered in a system.

The practice of systems thinking starts with understanding the simple concept "feedback" which shows how actions can reinforce or counteract (balance) each other. The meaning of feedback in our daily life is often used to gather some kind of opinions about some thing we have undertaken; "give me some feedback on the assignment", or "what did you think about my idea?". Feedback has in this context got the meaning of encouraging remarks or simply bad news. In system thinking the "feedback" concept has much broader meaning. *It means any reciprocal flow of influence.* In systems thinking it is an axiom that every influence is both *cause* and *effect. Nothing is ever influenced in one direction.* The most important issue about the feedback perspective in system thinking is the suggestion that *everyone shares responsibility for problems generated by a system.* Thus no "one" factor is solely responsible for changes in a system (Senge, 1990, 1994).

In the practice of system thinking we use the concept *causal loop diagram (CLD),* which is a tool that assists us to structure and conceptualise our problem. With the CLD's we have the possibility to construct our circular connections and the feedbacks in our problem. By drawing our mental model in such a way we can predict the behaviour of our problem.

In the following text we will focus on the following things:

- ✓ Systems and behaviour

- ✓ Feedback
- ✓ Causal loop diagram
- ✓ Reference behaviour

3.0 Systems and behaviour

In nature and in the human environment everything is connected to everything else in a complex web of interactions. For us to grasp only fraction of these connections we need to isolate the issues we want to observe and confine systems. What is a system? A system is a network of multi variables that are connected to each other through causal relationship and has certain behaviours, which we only can characterise through observation as a whole. The principal attribute of a system is that we can only understand its behaviour by viewing it as a whole (Grant et al, 1997).

3.1 Different systems

What kind of system exists there? Basically everything can be categorised and defined as a system. One way to describe a system is to review a technical one, which we can easily sort out, e.g. a bicycle. A bicycle can be considered as a *system* or a whole where its functions are dependent on interactions of its parts, the frame, chain, wheel, breaks etc (see figure 5). In isolation, the parts can never be identified as a *bicycle* because the function of the bicycle is not embedded into individual parts but into the interaction between all of its parts. A person that has never seen a bicycle and sees one lying on the ground will never consider it other than a pile of metal welded together. Only if one sees someone riding a bicycle he/she will gain understanding of the functionality of the "pile of metal welded together" and connect its use in a broader terms to transport or leisure etc. As a result we can only understand the behaviour of the bicycle if we see someone ride it (see figure 6).

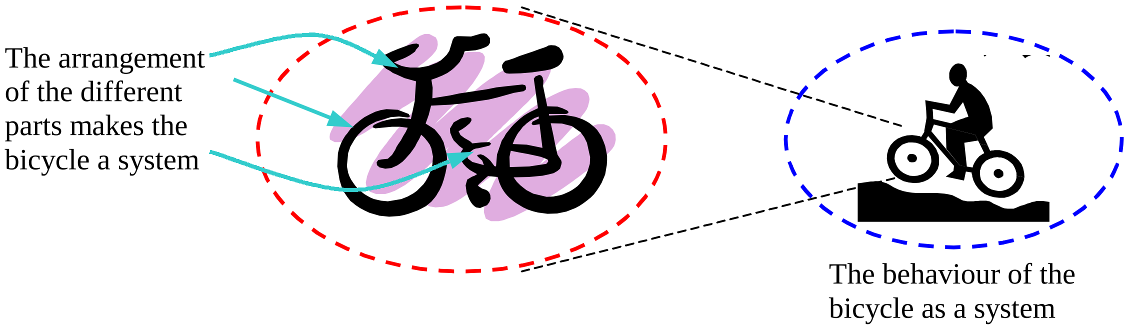


Figure 6: A bicycle is a system, which is characterized by its behaviour, the interaction with the bicyclists.

What is essential in this aspect is the bicycle rider. Without him the behaviour of the "bicycle system" does not exist. We have now made distinction between the *parts* and the *whole*. The *parts*, which we analyse in a system, are the physical bicycle components by themselves and the whole is the interaction of the parts and the behaviour of the bicycle as a functional unit.

Let us now look at a natural system. Properties of a forest cannot be analysed just by looking at one tree. Factors such as the climate, grazing animals, soil and topography, are components, which characterise a forest and can thus not be excluded if we want to understand a forest as a whole (figure 7).

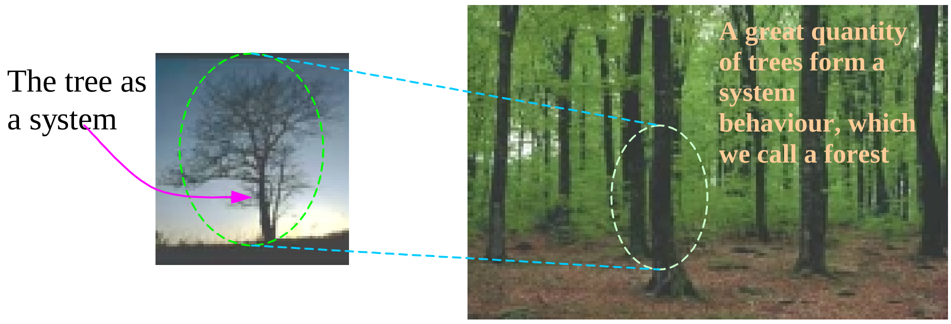


Figure 7: The forest is much more than can be observed in individual trees.

The tree by itself is a system that takes in nutrients and water and exchanges gases. Alone the tree stands fragile against winds and rains but collectively in a forest the trees change the evolution of the topography, the soil and the microclimate. This is the behaviour of the forest system. A forest itself also hosts many specialised species that thrive on the conditions created by the forest and these conditions are mutually the *whole* created by the parts (the trees).

People and society are also a system. Similar to the forest the individual person collectively creates the society and all the specialisation. We as individuals stand fragile alone, because our capacity for survival is limited. In a group we can specialise and have certain functions, which collectively benefit the group as a whole, and the individual. A team of sailors are an example of individuals that have specialised functions on board a boat. Together they accomplish more than if all of them were merely individualists and uncoordinated. They work together towards a benefit that is accomplished by their cooperation. Another example of a large system is a city, which can be viewed as a system whose purpose is to provide employment, housing and other social benefits for its inhabitants. People have specialised jobs and functions in the society but collectively we all increase the quality of life of all the individuals (see figure 8).

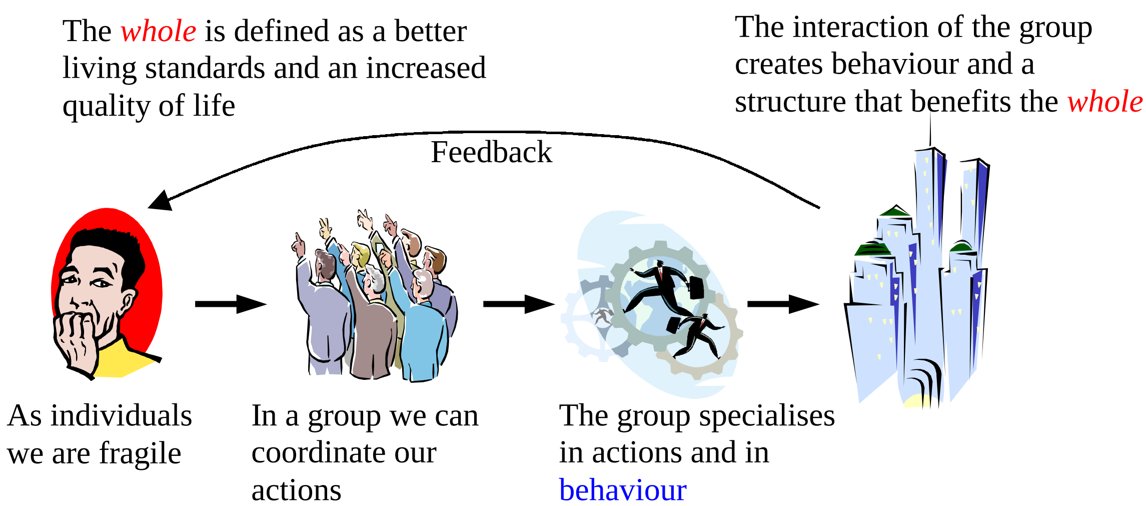


Figure 8: By participating in a large dynamic group, the individual acquires certain benefits that are only generated by the *whole*.

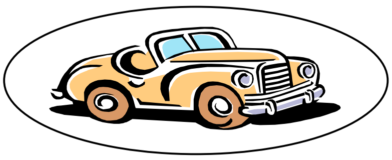
As a conclusions we can state that when we use system thinking we are observing the *dynamic relationship* between all the parts within a system. The system is steered by its feedback and in order to understand the behaviour of the system we need to understand the feedback.

3.2 System boundaries

All systems are defined by its boundaries. In order for us to understand a system properly we need to understand how systems behave and what their properties are. Systems are usually confined by certain inflow and outflow of energy. What makes it difficult sometimes is to see the pattern confines the system, e.g. determining where do the boundaries between forest and prairie lie.

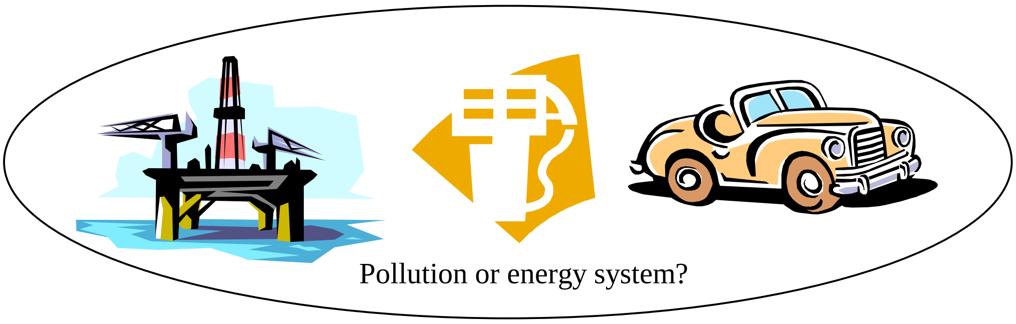
The ideology of system dynamics is that all behaviour of a system is a consequence of its structure. The structure of a system determines its success and failure. Everything you need to solve within a system is right there and going outside it to look for a cause of the problem is erroneous and indicates that we need to expand our system boundaries. Of course we cannot solve all problems within confined observation vicinity. This is because a system is always embedded within a larger system and, has subsystems itself. For example a corporation may be experiencing difficulties that originate not internally from its own policies but from governmental regulations or the macro economy (Cover, 1996).

A car for example can be considered a system that has special functions. The variables (components) in the "car system" are the engine, gearbox, steering system, tires, electrical stuff and etc. What we consider a "car" is the sum of *functions and interactions* between all of these components in the car. The car maintains its functions through *feedback processes* of all its rightly placed components. We know for example that the tires must be placed under the car not on top of it and they need to be circular not square for them to operate with satisfaction. We also know that the car will not operate properly if we take away some of the components such as the headlights, windows etc. This we know because we have fairly good understanding of how the car behaves as a system when we drive. Not because we understand all the details how the car is build, but how *its system behaviour* is, e.g. the driving itself, re-fuelling, small maintenances, etc. The system boundaries for the "system" car would be the physical structure itself incorporating all its components (engine, fuel lodge, battery etc) or simply "the car".



How can we be sure that this would be our definition of the system "car"? One way to look at it is to observe what goes in and out of the system. For the car example we know that the car is in simple terms dependent on fuel, oil and air. It transforms these materials through its system to exhausts fumes and kinetic energy. What is important to notice here is that the "car system" is not dependent on fuel or oil from explicitly one geographic region or is restricted to exhausts its fumes at a certain time or location. These aspects are non important, the car runs excellently as long as its criteria for functionality (the feedback processes), fuel, air and oil are met. The system is considered to be in balance.

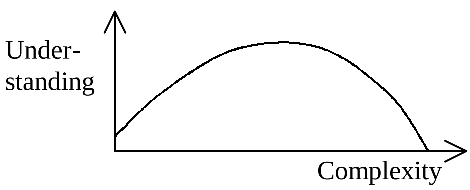
We could *extend* our system boundaries to incorporate the fuel and air pollution but then we would be increasing our system level and the "car system" would become one variable (sub-system) of many in a larger system. Such a system (if considered) could be called "fossil fuel system" or "air pollution system", but these are all definitions we set for us when observing certain aspects of reality.



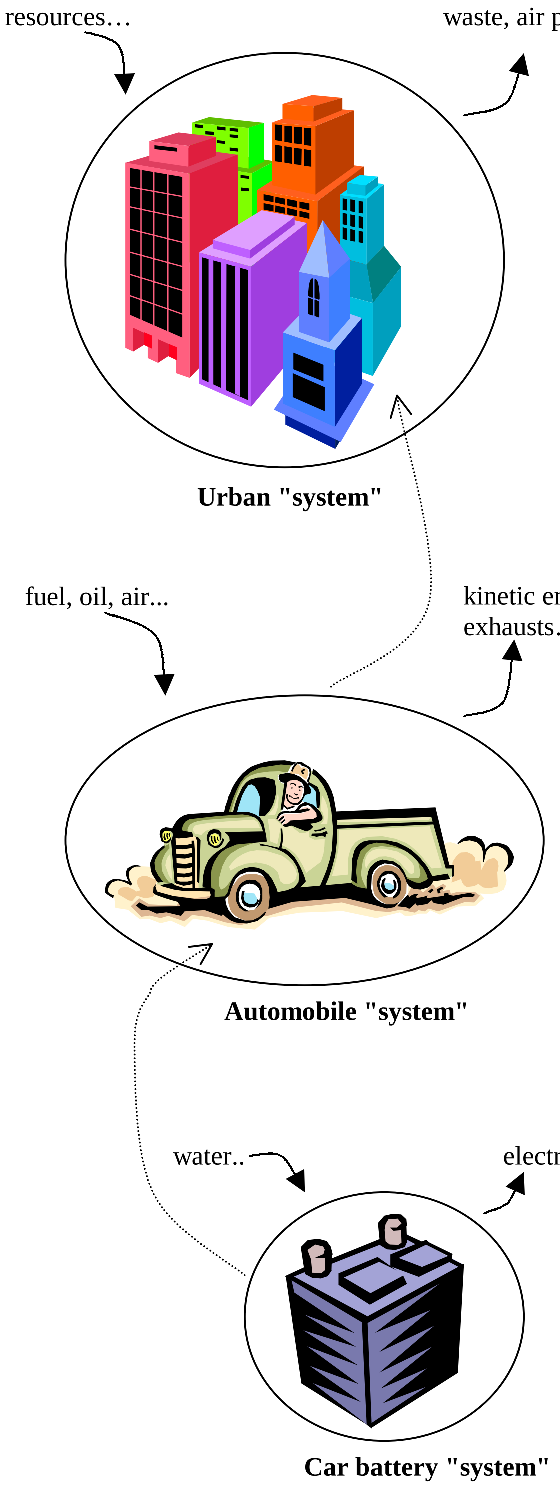
Similarly we could downsize our system boundaries and decide to analyse e.g. the battery in the car. The battery is a sub-system in the "car system" and can also be defined and confined by boundaries. The variables would be water, acid, lead, copper, structural organization of the container etc. The "battery system" is characterised by its production of electricity and like the car it functions perfectly if certain basic criteria are met (adding occasionally water etc). We consider the system to be in balance.

When we define and confine a system we need understand its basic behaviour, understand what is flowing in and out of the system. Then we need to define the system level we are observing, is it on a molecular scale or a global scale? “Does the system which I observe move between different system levels?” E.g. dealing with local climate change in global perspective.

It is important to understand *dynamic complexity* not *detailed complexity*. When we construct our mental model and define our system we need to be aware of the level of details. Generalisation is often the key to understanding complex systems. The following figure illustrates how our understanding of the system increases to certain extent until we have added so many factors in our mental model that our understanding decreases due to its complexity (Roberts, 1983). This happens because our ability to grasp the total dynamic of the problem becomes weaker and weaker the more variables we add (see picture below).



When we create mental models we do not intend to capture the whole reality in one model. Such models are as complex as reality itself. What we want to do is to map part of the reality in such a way that it gives us a basic understanding of a complex issue. In the figure we can see that at one point we have generated the highest understanding from the system in proportion to its complexity. That’s where our level of details should not be more. For example if we are trying to understand car pollution in a city system, going into engine details would only add unnecessary details and complexity and weaken our understanding of the system’s behaviour (see figure 9).



A city is a large-scale system, which converts resources and energy into waste and products through complex interaction of the variables in the city. The economy, social organization, infrastructure, **automobiles** and people are all examples of components which interact within the urban system. The system boundaries are less clear for the urban system than for the car battery or the automobile since the city contains many sub-systems that are based on sub-systems and so on. More generalization is needed in larger systems such as for a city. Rudimentary, from a perspective of a physicist the urban system can be confined and defined as a geographical point where resources are converted to energy and waste.

An automobile is a system made up by components such as engine, gearbox, **car battery**, tires etc. The automobile system boundary is defined by its physical size and the interaction of its components. The production of kinetic energy is the automobile's system behaviour and it is in balance if necessary materials maintain it (in this case gasoline, air, oil etc.)

A **car battery** is a system confined by its casing and the components water, lead, copper, acid, iron etc. which create electricity through interaction. The delivery of electricity is the system behaviour of the battery. The system is in balance if necessary materials and service maintain it (in this case water and recharge of electricity from a generator).

Figure 9: system, system levels and system boundaries.

The above examples show different systems and system levels. Every system incorporates some sub-systems like the above example. The car battery is theoretically a sub-system on a very detailed level within the urban system and similar can be said about the automobile. But what can be seen here is hierarchal tracing of the urban system. We define the automobile as an interacting component within the urban system, influencing its development and the car battery, we define as an interacting component within the automobile system.

In figure 9 we can see how systems are incorporated within other systems. A typical system can be based on components, which are in fact sub-systems themselves and their components also sub-systems and so it can go on forever. It is important when defining and confining a system to identify the system level that we operate on. Do we have variables that are transparent through different system levels? We can justify one thing, the greater the number of variables we have the greater the complexity and interaction between the variables will be. Generally we can state that a large-scale systems containing endless number of variables and integrates through multi system levels such as the global climate, needs simplifications in analysis. There is a need to generalise, thus move the level of detailness up to appropriate level for the study (see figure 10). It becomes very important when defining the system to observe **supersignals** (Dörner, 1996).

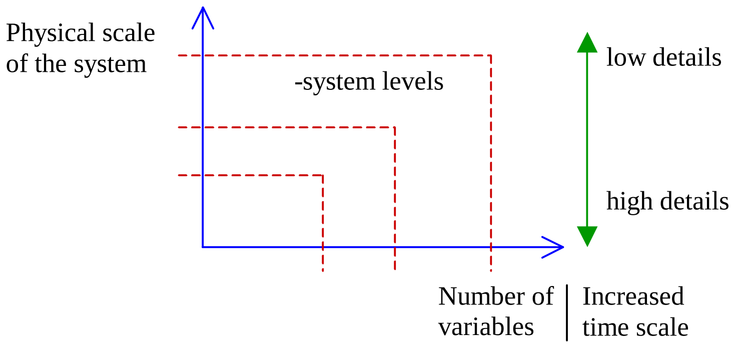


Figure 10: Large systems incorporate many variables which requires more generalisation of the system without necessarily loosing accuracy in the study. Notice that with increased physical scale of the system the time dimension changes.

Supersignals are the patterns or the feedbacks we observe from the interaction of the variables. For example when we learn to drive a car or to ride a bicycle, we learn, by detecting the feedbacks we get from steering in different directions, accelerating or braking. Supersignals are our key to understanding the system behaviour and the classification of the system. When we are defining the level of detailness in our system we should select the level needed to understand the interrelationship among our "goal" variables, the one we want to influence. When we have defined that level, then detailed knowledge of the underlying components is not needed. In the case of the driving, detailed knowledge is not needed on the construction of the engine; we can operate the vehicle without such knowledge. Our supersignal in the driving process comes from the overall behaviour of the underlying variables in the vehicle. A number of features collapse into one supersignal (see figure 11)

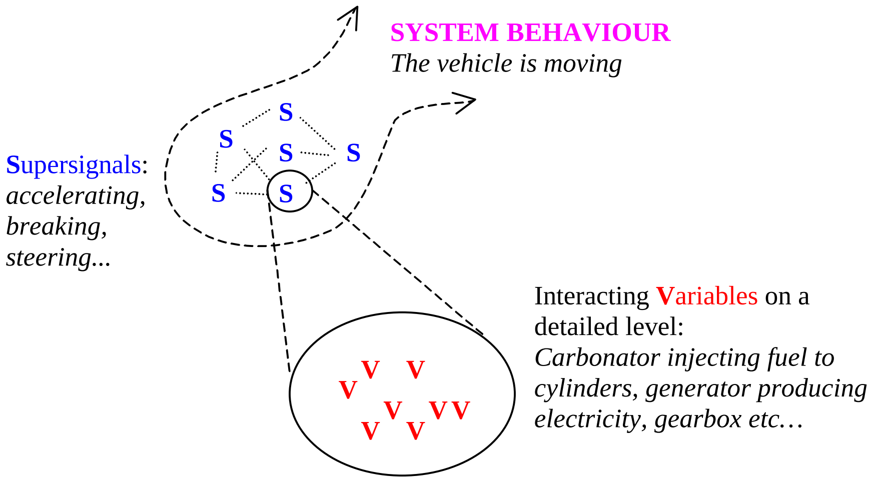


Figure 11: Supersignals helps us to identify the level of detailness we want to study.

To deal in an effective manner with a complex system lets summarise the following:

- We need to know on what other variables the goal variables that we want to influence depend. We need to understand, in other words, how the causal relationships among the variables in a system work together in that system.
- We need to know how the individual components of a system fit into a hierarchy of broad and narrow concepts. This can help us fill in by analogy those parts of a structure unfamiliar to us.
- We need to know the component parts into which the elements of a system can be broken and the larger complexes in which those elements are embedded. We need to know this so that we can propose hypothesis about previously unrecognised interactions between variables (Dörner, 1996).

3.3 Identifying main actors

After you have specified your system boundaries of the study you should start listing all key variables that are relevant for the study. There are two types of variables in a system, *endogenous* and *exogenous*. Endogenous variables are the elements that are interactive within the system, influencing all the other variables (in the modelling they are stocks and flows). Exogenous variables are factors that are not enclosed by the system boundary but influence the system (in the modelling they are constants). Exogenous variables are on the other hand not influenced by variables enclosed within the system. For example if we are investigating grass growth in relation to herbivores, climate would be considered as an exogenous influencing factor but herbivores an endogenous factors (figure 12).

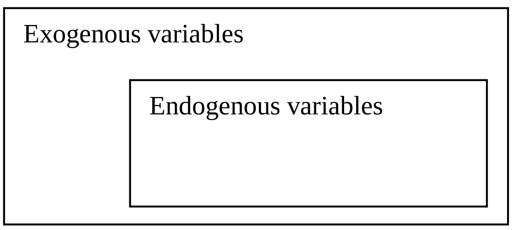


Figure 12: Endo- and exogenous factors.

You should use variables names that can be quantified or related to numbers later on in the modelling phase, such as "oil stock" or "forest stock". Often we need to define "soft" variables that are linked to non-quantifiable data such as "mental capacity" or "gained learning". These variables need to be well defined. Scaling is important when defining soft variables; use words like happiness and learning but not words like attitude or lifestyle.

Generally we can divide influencing variables into two categories; *critical variables* and *indicator variables*.

Critical variables are the key variables in the system that interact mutually with a large part of other variables in the system. If we change them we alter the status of the whole system. For example if we consider a river ecosystem, minimising dramatically the flow rate of the river would exert major influence on the wild life in the river.

Indicator variables are those variables that depend on many other variables in the system but have themselves negligible or limiting effect on the entire system. In the example of the river system, fluctuation in the amount of sediment carried by the river is likely to have less effect on the biological system rather than severe drought.

How do we identify the main actors in a system? We should start by gathering information and listing all the variables we feel are appropriate for the system. Then we try to categorise critical and indicator variables. It gives us much more clarity when we then start constructing our causal loop diagram. One way to arrange this is to list the variables in hierarchical order according to importance. Lets look at one problem concerning the solid waste problem. It is a complex issue incorporating many different components, not to say viewpoints and interests. In the following example several factors are listed and sorted according to importance. Endogenous variables are "within the system" and tagged as important. Exogenous variables are "outside the system" and are tagged as unimportant (see figure 13).

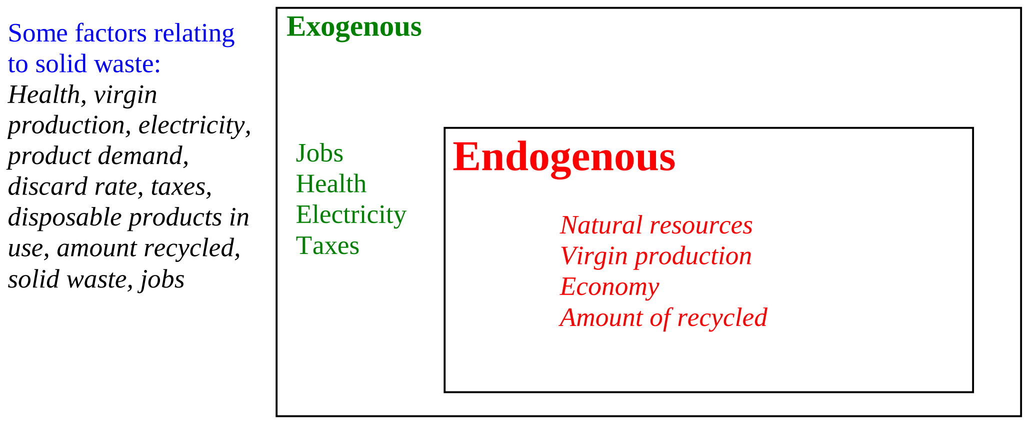
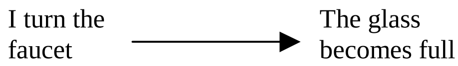


Figure 13: We need to categorize the influencing parameters to determine if they are endogenous (important component) or exogenous (less significant components).

4.0 A closer look on feedbacks and causal loop diagrams

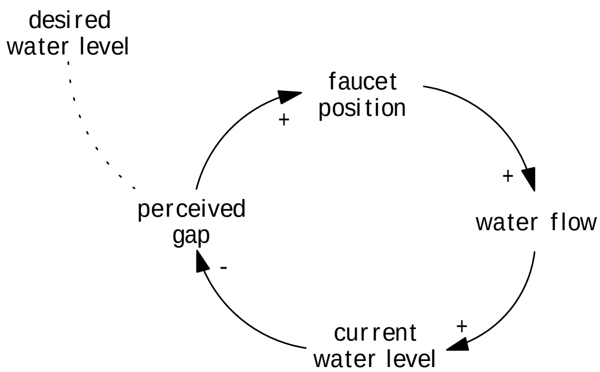
As you probably have noticed there has been quite a lot mentioned about feedback in the examples above. The purpose is to familiarise the reader with feedback in the daily life. In this chapter we will look closer at how exactly feedback is formed in a system and link it to causal loop diagrams.

The key to seeing reality systemically is seeing circles of influence rather than straight lines. Let's look at one example that is very familiar to all of us- filling a glass of water. In the linear viewpoint we would typically say; *"I am filling a glass of water"* which of course sounds very logical but only tells us half the story. We may control the rate of water flowing into the glass (as the statement implies) but the level of water in the glass also signals us when to close the faucet. The traditional logic would be something like the following:



If we use the system-thinking language, we see things in circles rather than straight lines. Instead of looking at the action from an individualistic point of view, where the *"I am"* is the doer and at the centre of attention, we shift our perception to the *structure* of the action. The *"I am"* simply becomes a part of the feedback process, not standing apart from it. Suddenly we have shifted our attention to the structure of the behaviour and we can observe that *the structure causes the behaviour* (see below). Following the "feedback" in the causal loop diagram we can read through it like a story. Since we desire a certain water level in the glass, let's start by turning the faucet;

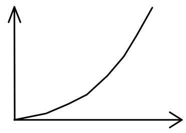
> *I set the faucet position, which adjusts the water flow, which changes the water level. As the water level changes, the perceived gap (between the current and desired water levels) changes. As the gap changes, my hand's position on the faucet changes again. And etc…*



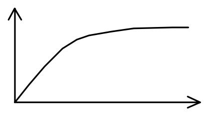
We have now transformed traditional linear thinking in to a circular arrangement. Lets at last observe the difference in perception between the original statement: *I am filling a glass of water* and the new one we have just formed with the system thinking; *My intent to fill the glass of water creates a system that causes water to flow in when the level is low, then shuts the flow off when the glass is full.* Both the statements express the same intention but describe the process in different way.

4.1 Causal loop diagrams

Now we understand that system thinking can be described as process thinking, understanding cause and effect between different components within a defined system. Systems always behave in a circular organization forming feedback loops. As observed in the causal loop example above, *the effects of the last element influence the input of the first element*, which results in a self-regulation of the whole system. Regulation of a system can either result as a *self-reinforcing* system or a *self-balancing* system. A reinforcing system (or amplifying) is a system in growth; a good example can be a bank account, economic growth or bacterial growth. We usually observe this graphically as follows:



A reinforcing system is an escalating effect due to equivalent influences between the components, which can be either a downward spiral or an upward. In a *balancing* (or stabilising) system there is an agent which controls the exponential growth or is a limiting factor to the growth. The example of filling the glass of water is an illustration of balancing system since the glass can only hold certain amount of water. The balancing system can be illustrated as the following figure, after a certain level is achieved, things level out:



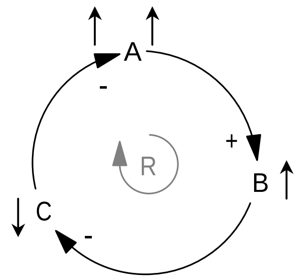
To put system thinking in practise, several rules have to be followed so that "cause" and "effect" can be monitored in a right way.

Summarised explanation of the causal loop concept (adopted from Roberts *et al.* 1983, p56)

Symbol	**Meaning**
Arrow → Tail Head	The arrow is used to show causation. The item at the tail of the arrow causes a change it the item at the head of the arrow.
→ +	The + sign near the arrowhead indicates that the item at the tail of the arrow and the item at the head of the arrow change in the *same* direction. If the tail *increases*, the head *increases*; if the tail *decreases*, the head *decreases*.
→ —	The – sign near the arrowhead indicates that the item at the tail of the arrow changes in the *opposite* direction. If the tail increases, the head decreases; if the tail decreases, the head increases.
(–) or (–)	This symbol (also B), found in the middle of a closed loop, indicates that the loop continues going in the same direction, often causing either systematic *growth* or *decline*, behaviour that unstable moves away from equilibrium point. This is called a *positive feedback loop*.
(+) or (+)	This symbol (also R), found in the middle of a closed loop, indicates that the loop changes direction, causing the system to *fluctuate* or to *move toward equilibrium*. This is called *a negative feedback loop*.

4.2 Drawing causal loop diagrams

To further illustrate Roberts explanation of the causal loop concept let's look more closely at the variables at work in the loop. We can start by analysing hypothetical variables A, B and C, and give the following assumptions: *variable A has an increasing effect on B and B has a* *decreasing effect on C but C has increasing effect on A.* Constructing such diagram would look like the following:



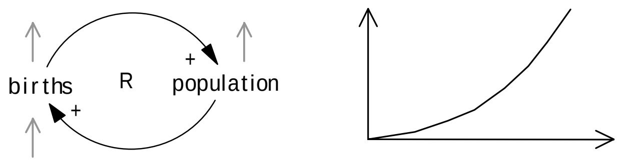
<u>When looking at signs on arrows:</u>

↑↑	+	Same direction	R
↓↓	+	Positive relation	
↑↓	-	Opposite direction	B
↓↑	-	Negative relation	

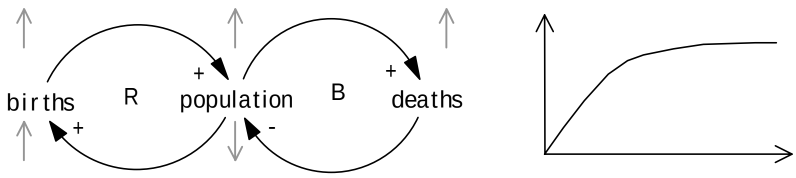
We use small arrows to help us understand the changes in the variables (see diagram above). Let’s read through the diagram by starting with variable *A*, *if A increases, B will increase (↑↑).* Since there is a relationship in the same direction (notice arrows), we assign plus (+) and say that there exists a positive relationship (variables can also be decreasing in the same direction ↓↓ which is also a positive relation). *If B increases, C decreases (↑↓),* here we have an opposite or negative (-) relationship between the variables (notice arrows). The variable *C* is the feedback on *A and* has a negative impact on variable *A*, thus we assign a minus sign to the relation between C and A *(C decreases, which causes A to increase ↓↑).*

After we have assigned the pluses and minuses we go through the whole loop and compare the starting and the ending arrows for the initial variable A. The whole loop is a reinforcing system (indicated with R), since the last variable is influencing A *(↑↑)* in the same direction. If we would have a system that had starting and ending arrows in the opposite directions *(↑↓)* we would have a balancing system (indicated with B). When we are done with the whole loop we should erase the small arrows.

Basically there are two systems that are at work in nature, a *balancing* system and a *reinforcing system.* Let’s now look at an example that is escalating. In this case net population increases since number of births are increasing. This system is typical for populations that have higher birth rate than death rate. By going through it step by step following reasoning can be made: *Increased births increases population, in which population increases (note the use of arrows).* This is a reinforcing system indicated with little “R” loop in the middle (plus sign can also be used). The graph on the right indicates exponential growth:

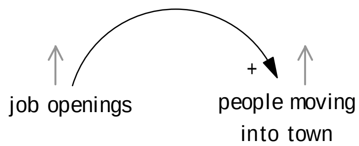


An example of balancing system would be the following. If birth would be replaced by death, the system would also be reinforcing but escalating exponential downwards. In actual situation death rate would balance increase in population since population is not immortal, the factor “death” can be added to the system to balance it. Note that when *population increases, the number of deaths increases, which decreases the population (↑↓= B).*

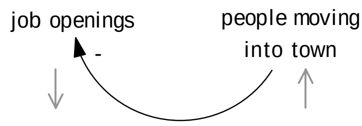


The system is now balanced toward some initial point that is determined by the number of births or the number of deaths. Despite complexity, *all systems attempt to balance themselves in one way or another.* This is important since it indicates that a reinforcing system is only a temporal state and the important factor is to identify how long the situation will endure (it can last from minutes to millions of years).

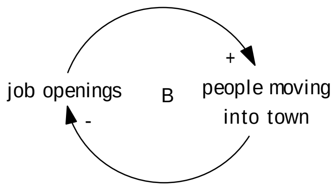
Let's look at another example in making causal loop diagrams. Before we actually start drawing the loops we need to identify the driving forces in the system we are analysing. A common concept that everybody recognises in an urban community is job and job-opportunities. Lets look at the effects that migration has on job openings in a city. We start by identifing the driving forces in the system which in this case is simple or just two variables; *Number of job openings* and *number of people moving into towns.* We start by reasoning that *number of job openings* increases *number of people moving into towns*. We assign "plus" sign at the arrowhead to indicate the increase in *number of people moving into towns.*



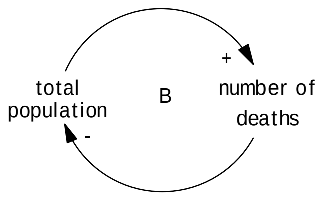
Since increased migration causes a decrease in jobs available we put "minus" at the arrowhead by the variable *number of job openings* (see below).



Finally we have a causal loop diagram, which describes a balancing system between the number of jobs and the number of people moving into towns (see causal loop diagram below).



Sometimes when reversing a causal loop, e.g. going from an increase in a system to a decrease, we are faced with a situation when interpreting a minus or a plus sign can lead to confusion. Lets look at the following example of population dynamics (see below).



This causal loop suggests that the *more* people there are, the *more* deaths there will be. The connection to total population is that the *more* deaths there are the *fewer* people there will be. This sounds very reasonable but we can also look at this in another way, for example; when there is a *decrease* in the total population. We can express it as such; *the fewer people there are, the fewer deaths there will be*; *the fewer deaths there are, the more people there will be.* But is that necessary true? If death goes down, does population actually rise? Not unless the number of births exceeds the number of deaths. Alternatively if number of deaths decreases, the population still decreases but at a slower rate. More accurate would be to say; *the fewer deaths there are, the more people are left remaining in the total population.* In the situation as such, “increase” reads correctly in the loop diagram, but reading “decrease” needs slight rewording for accurate reading. One important aspect should be kept in mind when drawing causal loops:

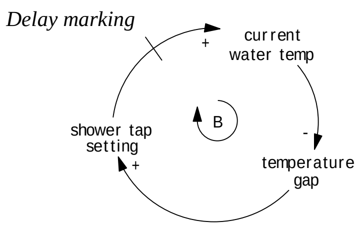
> *“Once the appropriate sign has been placed at each arrowhead and in the centre of a closed loop, the signs should not need to be changed. The signs should be correct wherever reading around the loop may be started and whether increases or decreases in loop elements are considered. Proper regard should be given to the slight wording issues identified…” (Roberts, et al., 1983, p39)*

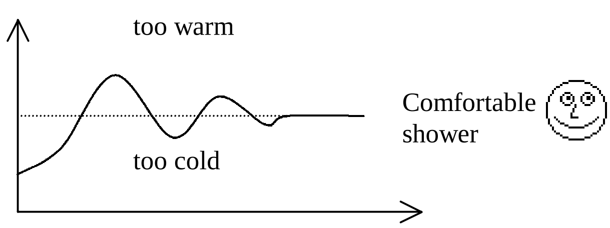
Identifying driving forces within a system and drawing causal loop diagrams is the basis for making system analysis studies. It should be well organised and thought through before proceeding into computer modelling. Roberts, *et al.* (1983) give good interpretation on the system thinking works in practise:

> *“...Causal thinking is the key to organising ideas in a system dynamics study. Typically an analyst isolates key causal factors and diagrams the system of causal relationships, before proceeding to build a computer simulation model. However, the notion of causation can be subtle, and using the concept requires careful attention.” (Roberts, et al. 1983, p11)*

4.3 Delays in the system

Everybody is familiar with waiting time, standing in the line at the bank, keeping patience while the car is getting warm in the winter time, etc. All systems have some kind of *delay*, which can range from seconds to days, centuries or millions of years. When the initial action is taken there is a response time until it starts to have effects on other components in the system. A good example is when we take a shower. Everybody knows that it takes some seconds for the hot water to become warm and because we are freezing in the shower we turn the faucet wide open. When the actual hot water arrives it is so hot that we are forced to turn it off and etc, until we have optimised the temperature in the shower. A graphical expression of this situation would look something like the following:





Delays are hard to predict within a system. Most of the time we do not know how long the delay period is so we tend to use trial and error approach to assess the delay time (similarly when we take a shower). One important rule of thump can be assigned to delays, *the harder we push the system, the harder it pushes back.* In that sense drastic decisions often create instability and oscillations in the system but are not necessarily felt instantly. That is why the systemic viewpoint is generally oriented towards long-term conditions, which enables us to identify delays and feedback loops that determine the behaviour of the system.

5.0 Creating reference behaviour pattern RBP

What is a reference behaviour pattern? It is a graphical representation of the behaviour over time of one or more variables in the system we are analysing. We use RBP to chart our understanding of the system. When we are drawing causal loop diagrams we should sketch a diagram from each loop to graphically visualise the behaviour of the loop. For example if we are analysing population growth that is escalating under a certain time period such as bacterial growth, we can express it in CLD´s and RBP (see figure 14).

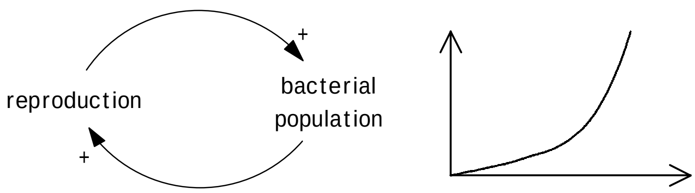


Figure 14: exponential bacterial growth represented as CLD and RBP

The bacterial reproduction illustrates reinforcing growth or, as we observe in the figure, exponential growth. When we are analysing a system we generate RBP fundamentally according to the behaviour of basic eight graph structures. All systems fall within the structure of linear or non-linear relations (figure 15).

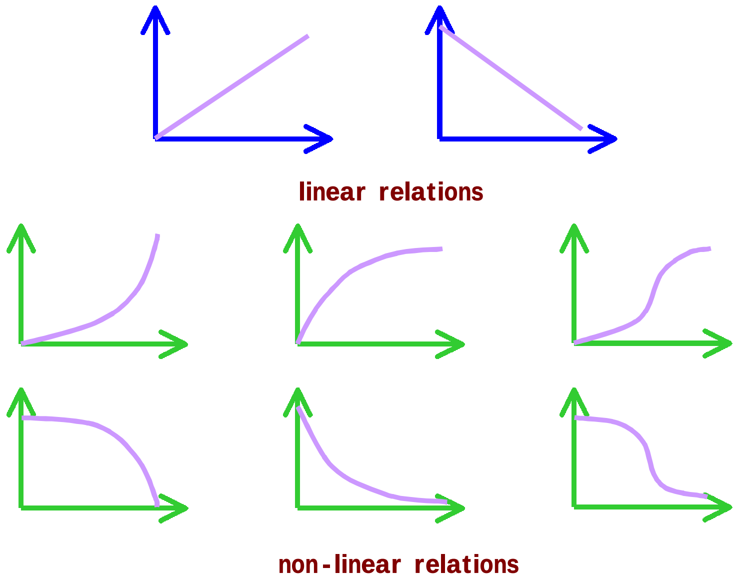


Figure 16: All systems can in basic terms be categorized according to the above principles.

It can be stated that in general, all systems have their principal behaviour according the above figure (figure 16). On a more detailed level in simulations we may observe fluctuations that seem to behave chaotically, but when such observations are aggregated on a higher level the overall system will behave as listed above. But it must be kept in mind that the overall behaviour of the system is a result of the individual patterns of subsystems, which are called supersignals. The patterns or the supersignals are determined by the interconnections of a large number of variables.

It is important when initially analysing systems to observe isolated loops and draw appropriate RBP and then compare the results from each loop to predict the RBP from the whole system. Lets look at another example that involves analysis of soft variables, regarding sibling interactions. In a family situation the following actions are observed (Roberts, 1983):

> *"Mark and Ellen are youngsters which are respectively and frequently engaged in skirmishes, which their parents terminate as quickly as they can. A common pattern in their relationship is Ellen becoming bored and picking on Mark to get some kind of excitement. Mark usually hits her back and so ends up being punished for what was originally Ellen's acts of aggression"*

We can start the analysis of the actions here by constructing string of events (see figure 17) and then create a CLD of the situation (see figure 18).

Figure 17: string of events in the sibling situation.

A CLD graph from this string of events looks somewhat different although it represents the same situation. A CLD illustrates more action or events in the arrows and gives us the possibility to distinguish between the basic RBP graphs, and further more to identify the feedback. In the figure below (figure 18) we draw RBP for each causal loop. This is possible since we know how each loop behaves, thus if they are reinforcing or balancing. When we go through the diagram we start with the variable *Ellen's boredom* indicated with T1 (time step one), then we continue to the loop which we think is next in the sequence and continue until we have gone around (see the stepwise sequence in the graph, T1,T2,T3 and T4).

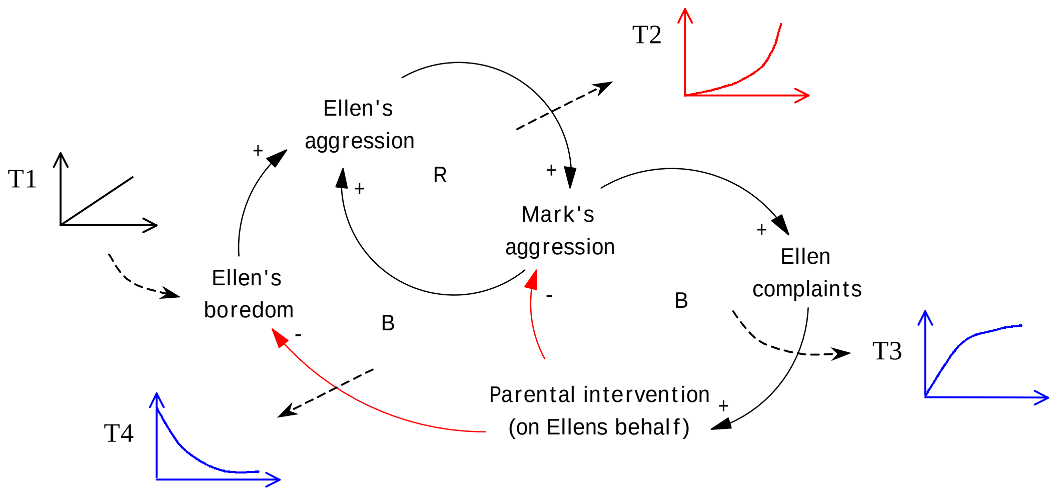


Figure 18: A small RBP behaviour is extracted from each loop and time sequenced.

It is not important to know exactly what the time steps are in reality and such knowledge is only possible to gain through modelling but what is important to extract from the small RBP's is the overall behaviour of the system (see figure 19).

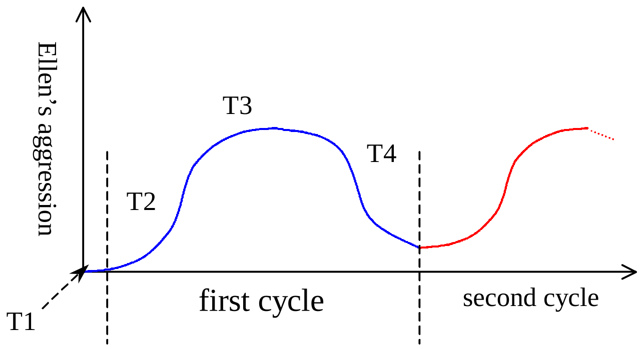


Figure 19: When the small RBP's and the time sequence has been determined we create an overall behaviour of the CLD by putting together the time sequences and the graphs.

When we create causal loop diagrams and the reference behaviour patterns, we can predict the overall behaviour of the system and in what sequence different causal links will behave. The only thing we cannot determine is the time delay itself, if it is 1 hour, 1 day or year. In order to determine the time delay we need to perform computer simulations.

5.1 Riding a bicycle

Let us look at a situation involving a young boy riding a bicycle.

> *John is riding his mountain bike in the country site one beautiful morning. After several stunt tricks and jumping he discovers that he has damaged the rear tire of his bike. He can hear hissing sound of air passing through the tire and he recognises that soon the tire will be completely deflated. In order for him to be able to bicycle home he realizes that he needs to pump air into the tire several times on the way. But this action will also damage the tire further by increasing the size of the hole and therefore deflate the tire more quickly each time its inflated.*

We can start the analysis of the actions here by constructing strings of events and compare it to the construction of the CLD. String of events or the so-called linear representation gives us only half the story since it lacks the feedback mechanism (from pumping air into the tire to riding the bicycle, see figure 20). Without the feedback mechanism it is hard to estimate the effects of inflating the tire again since there are more than one factor influencing the deflation rate from the tire (e.g. the tire hole becomes larger with every inflation and riding the bicycle damages the tire further).

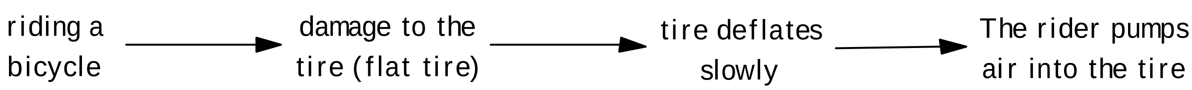


Figure 20: Strings of events of riding a bicycle.

A CLD graph from this string of events looks somewhat different although it represents the same situation. A CLD illustrates more action or events in the arrows and gives us the possibility to distinguish between the basic RBP graphs, and further more to identify the feedback. In the figure below (figure 21) we draw RBP for each causal loop. This is possible since we know how each loop behaves, thus if they are reinforcing or balancing. When we go through the diagram we start with the variable *air in the tire* indicated with T1 (time step one), then we continue to the loop which we think is next in the sequence and continue until we have gone around (see the stepwise sequence in the graph, T1,T2,T3 and T4).

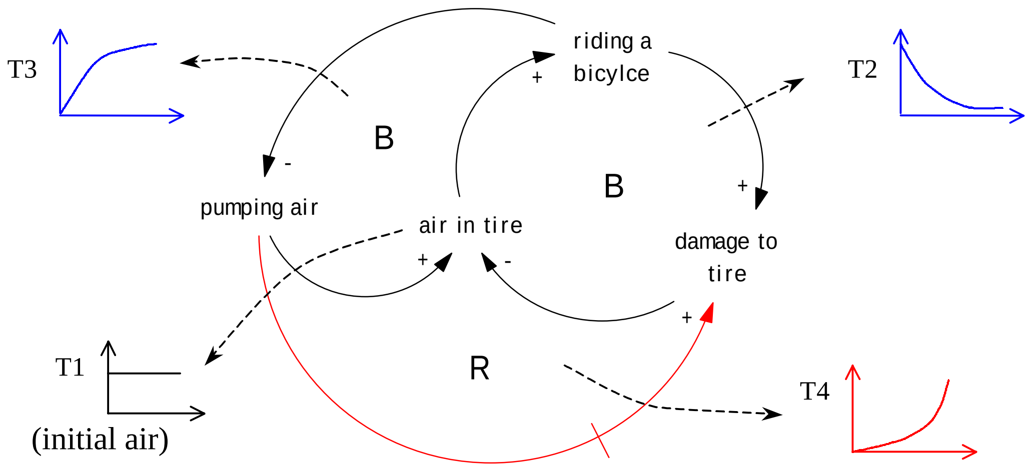


Figure 21: A small RBP behaviour is extracted from each loop and time sequence.

It is not important to know exactly what the time steps are in reality and such knowledge is only possible to gain through modelling but what is important to extract from the small RBP's is the overall behaviour of the system (see figure 22).

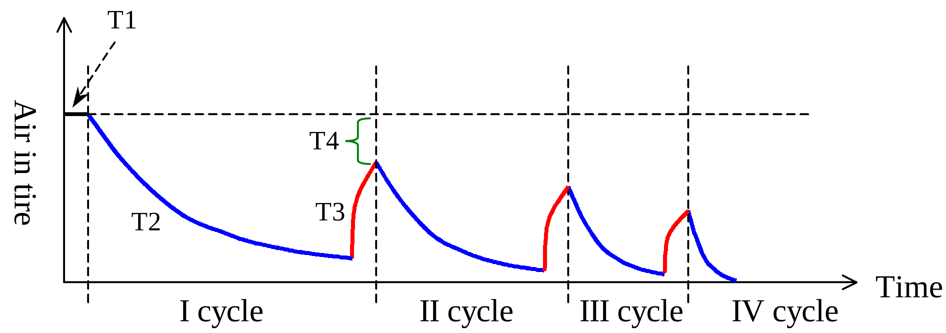


Figure 22: When the small RBP's and the time sequence has been determined we create an overall behaviour of the CLD by putting together the time sequences and the graphs.

When we create causal loop diagrams and the reference behaviour patterns, we can predict the overall behaviour of the system and in what sequence different causal links will behave. The only thing we cannot determine is the time delay itself, if it is 1 hour, 1 day or year. In order to determine the time delay we need to perform computer simulations.

6.0 Purpose and goals in our research

Without concrete goals, there are no criteria that can be used to judge whether progress is in fact being made (Dörner, 1996). One of the most important things when working with dynamic systems is to formulate goals and strategies. We need to know what is our purpose of the study and how we are going to achieve our objectives. Defining goals and hypothesis should be one of the first steps taken in the analysis because it is not directly obvious in every situation what it is we really want to achieve. It not only aids us to clarify our task but minimises the time unwisely spent when we gather information.

A separation should be done between a general goal in our study and a specific one. A general goal is often only defined by single criterion, as a specific goal is defined by multiple criteria. Defining our goal as specific has its advances over general terms. It will enable us to arrange the information in an overall picture and sort out what is important and unimportant for the study. It also gives us an idea about what elements in the system are directly linked and which ones are not and how we should use our information.

The first step is to specify one main goal we want to accomplish by the study and then define several strategies or partial goals to reach our final destination. It is also possible to define several goals at the same time, which is often the case in complex systems, but one principle should be considered, contradictory goals are the rule, not exception. For example, trying to lower unemployment and at the same time reduce inflation is often thought of as a contradictory goal. Or when businesses want to minimise investments cost at the same time increase profits is also a contradictory goal. This usually harmless as long as we are aware of the situation, but in a situation where we are not aware of it, which is in most cases, we face difficulties in reaching our original goal. When deciding the complexity of your model you need clear goals. It will direct your decision regarding certainty of data and accuracy of numbers.

There are two types of goals, a positive goal and a negative goal. A positive goal is working toward a desirable condition. "We want fish harvesting to reach 1143 tons this year", is a definitive and a positive goal. A negative goal is desiring certain condition not to exist or intentions to avoid something. "Things have to change", "I need something to drink" or "the present situation is intolerable", these are examples that imply rather unspecific or vague goals. Negative goals are thus more general terms. To use the logic "not" is often difficult to grasp in our reasoning, e.g. we do not talk of "noncar" or "nonhouse" since these terms are much more difficult to define than just a "car" or "house".

It is advisable to follow these steps when formulating objectives for the study:

- State specific main goal for the study and develop a hypothesis
- Formulate partial goals and objectives to reach the main goal
- Use goals that have a positive approach to the problem
- Write your statements on paper and keep them at close range

7.1 Developing a hypothesis and drawing causal loop diagrams

After we have specified our goals and gathered the necessary information for our goals and defined our system boundaries, we should develop a hypothesis and draw causal loop diagrams. Drawing causal loop diagram (CLD) can be regarded as creating art in the sense that it takes skills and a lot of practice to gain understanding and insight into the problem one is analysing. Every problem is unique and requires special considerations. The CLD approach is a powerful problem-solving tool, but can only be effective if it is handled in the right way. The following suggestions can help us from creating common mistakes that can arise from the systemic approach (adapted from Richardson & Puch, 1981)

1. Think of variables in causal-loop diagrams as quantities that can rise or fall, grow or decline, or be up or down. But do not worry if you can not readily think of existing measures form them. Corollaries:
    a. Use nouns our noun phrases in causal-loop diagrams, not verbs. The actions are in the arrows (see figure 23).
    b. Be sure it is clear what it means to say a variable increase or decreases. For example; *"tolerance for crime"* not *"attitude toward crime"*.
    c. Do not use causal-links to mean *"and then…"*
2. Identify the units of the variables in causal-loop diagrams, if possible. If necessary, invent some: for example, some psychological variables might have to be thought of in *"stress units"* or *"pressure units"*. Units help to focus the meaning of a phrase in a diagram.
3. Phrase most variables positively, e.g. *"emotional state"* rather than *"depression"*. It is hard to understand what it means to say *"depression increases"* when testing link and loop polarities.

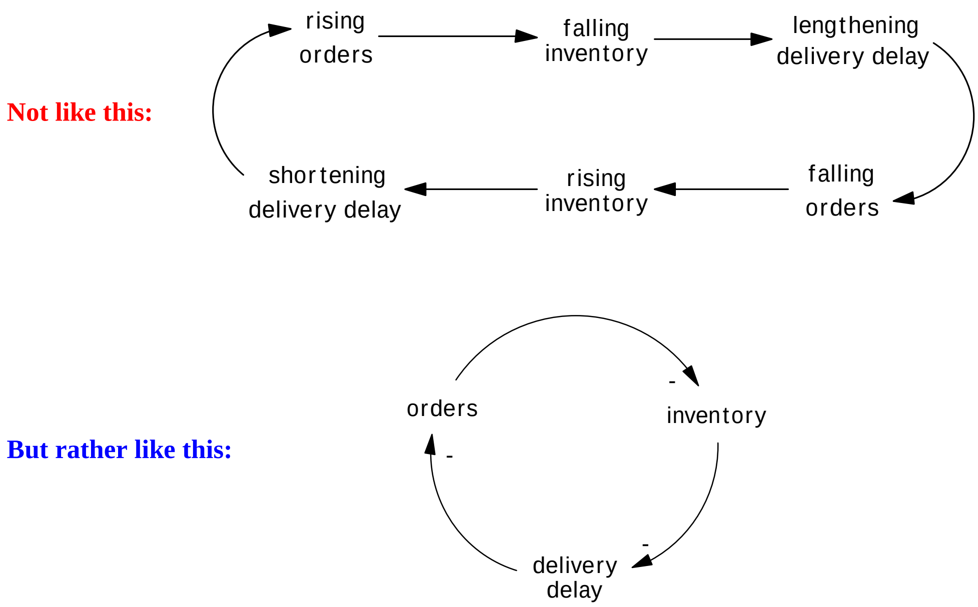


Figure 23: Loops illustrating that the action in CLD´s is best left to the arrows.

4. If a link needs explanation, disaggregate it- make it a sequence of links. For example, a study of heroin-related crime claimed a positive link from heroin price to heroin-related crime. The link is clearer if disaggregated as in figure 24 into the sequence of positive links from heroin price to money required per addict, frequency of crimes per addict, and finally heroin-related crime.

Some might feel a high price deters addicts and so lowers the number of addicts as it well might, but that is another link (see figure 24).

5. Beware of interpreting open loops as feedback loops. Figure 24, for example, does not show a feedback loop.

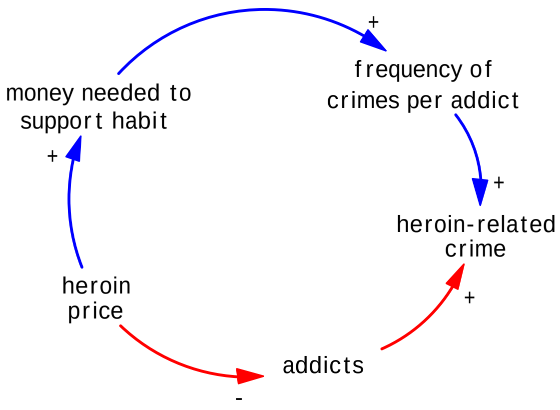


Figure 24: Links relating to heroin price and crime; this is *a pseudo-loop*.

7.2 Testing different policies in your modelling

In all planning or modelling procedures there is a need to predict and assess the possible effects a project has on development issues. This is not only restricted to environmental aspects but also to socio-economic issues since these are closely integrated. In a world were resources are becoming scarce, the marginal for errors is diminishing. There exists less and less space for manoeuvring in long-term planning. Two approaches exist in modelling and planning, the so-called *"forecasting"* and *"backcasting"*.

7.2.1 Forecasting

Forecasting is used to describe or estimate possible future conditions and trends. Predictions are useful to help us identify possible resource shortage or how to design policies to avoid shortfall. Availability supplies of resources such as oil, minerals or natural capital are calculated and forecasted by estimation and extrapolation of current use. Similar to weather forecasting there are uncertainty factors, which are hard to estimate and calculate the further ahead we look. This is due to complexity factors that are interacting in our predictions. In many forecasts conducted there are given assumptions, which are built on arrays of other assumptions. These arrays can be a blend of technological, social and economical issues that are difficult to perceive and forecasts often turn to be wrong because of the mix of different presumptions. If assumptions are not initially met the prediction cannot be correct.

In forecasting it is important to *focus* on relevant questions. Three questions are essential when creating a forecast. These are:

- What *can* happen? (feasibility)
- What *ought* to happen? (desirability)
- What is *likely* to happen? (probability)

In traditional forecasting there is often too much attention focused on *probability* and not on *feasibility* or *desirability*. In making a forecast an equal amount of time should be allocated on all the three concepts. One good way is to work on two parallel tracks. Identify the desirable future we would like and simultaneously work on current trends to analyse if they are likely to lead us to the desired future. We can ask us the following; where would we like to be? And is the current path the right one to get us there? It is important to consider what actions we are going to take when we reach our destined end point. We make "reality check" to emphasise what we should consider a *feasibility*, *desirability* and *probability*.

7.2.2 Backcasting

Backcasting differs form forecasting in such a way it focuses upon identifying desirable and attainable futures. When conducting a backcasting one works backwards from a desired future point and checks the feasibility of achieving that point. Backcasting determines what actions are required to achieve our desired future. Bruce Mitchell (1997) elaborates further:

> *Backcasting is designed to determine the consequences of different choices regarding the future, and those choices are not selected because of their likelihood of occurring through a continuation of present policies, but rather from creation of new policies (p100).*

By conducting backcasting we are identifying the consequences of different choices. This is similar to computer modelling where we are given the chance to test our ideas. In short, when we use backcasting we define our future goals and objectives and create our future scenario. Then we evaluate our scenario in terms of its policy, physical, technological and socio-economic perspective. When we conduct backcasting we should aim for long-term perspectives. It is recommended that implementation should cover at least 25-50 years to allow changes in lifestyles and turnover of natural capital.

8.0 Summarization on mental modelling and simulation

When constructing a mental model the following guidelines should be practised. The first step is the development of the mental model. The second step is the dynamic simulation of the mental model by using computer programs build mathematical models.

I. Developing a mental model.
   a. State explicitly the purpose and goals of the analysis- Gather information, define and confine system boundaries
   b. Identify the main actors in the problem and list them according to hierarchal order.
   c. Develop a hypothesis and draw Causal Loop Diagram (CLD)
   d. Create a reference behaviour pattern (RBP)

II. Dynamic simulation of the mental model
   a. Try to identify what will be stocks and flow in your model- draw the outline of the model and possible sub-models on paper.
   b. Start very simple using the core variables in your system. Be sure you understand what you are doing.
   c. Keep track of the units in the model do not mix different parameters.
   d. Test you model with conceptual figures against extremes in the model "Norwegian laughing test". Does the model reflect the CLD?
   e. Design and test different policies, " what if" method.

Although system thinking looks promising in theory, it is easy to misinterpret the concept if the methodology is incorrectly used. Several researchers (Roberts, *et al.*, 1983) have expressed the importance for people that develop logic to identify the possible failure in reasoning when constructing scientific arguments. There are three main indicators, which could describe how failures could occur in the scientific methodology of system analysis.

First, solving complex problem necessitates deep knowledge of the problem and cannot be solved only by analytical techniques. Secondly, the researcher must have the skills to structure and organise the problem. The researcher must be able to know what factors are important to include in the analysis and which can be excluded. Thirdly, one has to keep track of important relationships once they have been clarified. The results of using system methodology are very much based on initial knowledge and skills of the researchers. Inevitable this requires co-operation between scientist from different disciplines to acquire the necessary understanding to explain complex problems.

One important factor that arises from co-operation between disciplines is the line of reasoning, in which scientist often get new insights into their field. There is however a language barrier between disciplines that puts pressure on effective communication. This problem is clearly reflected through the conventional education system where current educational method is inclined towards separation of different disciplines and not of synthesis.

What makes it possible to use a system approach in science is the discovery that our knowledge is only approximate, which is crucial insight to all modern science. It recognises all scientific concepts and knowledge as approximate and limited. In the systemic view, complete and definitive understanding can never be accomplished, only approximate. This insight is important for us to recognise when we undertake studies in any field. The approximate knowledge enables us to make sufficient generalisations in research to accomplish the goals and objectives in our science.

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