

2 Basic Concepts of Systems Theories

When defining what systems are, the first thing that comes to mind is how often people use the word: system. All kind of professions and knowledge domains denote different meanings to this concept used in daily language. Engineers frequently talk about systems when they review designs or analyse technical equipment, e.g. the propulsion system of a ship. Computer experts point to information and communication systems. Biologists see the oceans as ecological systems. In addition, many consider organisations as systems. Thus, the word systems refers to objects (discrete systems) as well as purposeful constructs of the mind that are abstract in exchange between people, such as the conceptualisation of an organisation as a system. Distinguishing systems within reality helps to describe, to analyse and to create. To support the analysis of problems and to generate solutions, this chapter will define systems, discuss their properties and expand on their application in the domain of technical design, biology and organisations, while keeping in mind that the principles are applicable to many (scientific) disciplines.

The use of systems theories as a methodology of description and analysis originates from the drive to simplify reality and to comprehend natural events. The interpretation of reality has fascinated mankind since long and many have tried to explain phenomena that we experience daily, to understand patterns and to predict what will happen. The complexity surrounding us has forced investigators to look at interrelationships between objects and events. How does a propulsion system of a ship react to changes in forces? How does an information and communication system react to a cyber attack? How does an ocean as a system react to pollution? And how does an ecological system react to human interventions? Putting it all together, we are looking for approaches and methodologies to understand what is going on and how to solve a wide range of problems presented to us. As mentioned in Section 1.2, in the spirit of generating knowledge and solving problems, systems theories attempt to bridge different disciplines by their range of applications and at the same time act as a platform for multi-disciplinary perspectives. Applied Systems Theory, as one of the systems theories (later, Chapter 11 will introduce briefly a few other theories), provides such an opportunity to describe and analyse problems, mainly due to its holistic approach.

This chapter starts by looking what the concept of systems means and by defining them in Section 2.1; some of the key concepts for the definition will be elaborated on. The section thereafter discusses the properties of systems, needed for further analysis of a system. The chapter continues by looking at subsystems and aspectsystems appear in Section 2.3 and 2.4, as specific ways of examining systems, in more detail. The state of systems, related to their properties, is the topic of Section 2.5, and pertains to events and activities

that happen in the environment of a system. Since systems may respond to changes in their environment, Section 2.6 introduces the various concepts of systems' behaviour. Finally, Section 2.7 addresses the system boundary.

2.1 Systems

Although incorporated in daily language, when we talk about systems, each of us might attribute total different meanings to this comprehensive word, the key to any systems theory (see examples of definitions in Box 2.1). What we intend telling is that we separate elements from a total reality to study the nature of the system driven by the purpose of a particular study. This will enable the investigator to analyse and to predict the behaviour of such

BOX 2.1: DEFINITION OF SYSTEMS

This box provides definitions of systems to show similarities and differences in what a system is according to different authors.

APPLIED SYSTEMS THEORY

A system consists of elements discernible within the total reality (universe), defined by the aims of the investigator. All these elements have at least one relationship with another element within the system and may have relationships with other elements within total reality.

ALTERNATIVE DEFINITIONS

... any entity, conceptual or physical, which consists of interdependent parts. [*Ackoff, 1969, p. 332*]

... sets of elements standing in interrelation ... [*von Bertalanffy, 1973, p. 38*]

... the word "system" has been defined in many ways, all definers will agree that a system is a set of parts coordinated to accomplish a set of goals. [*West Churchman, 1979, p. 29*]

... system is defined as a set of concepts and/or elements used to satisfy a need or requirement. [*Miles Jr., 1973, p. 2*]

System ... is a set of entities, real or abstract, comprising a whole where each component interacts with or is related to at least one other component and they all serve a common objective. [*Wikipedia, 2007*]

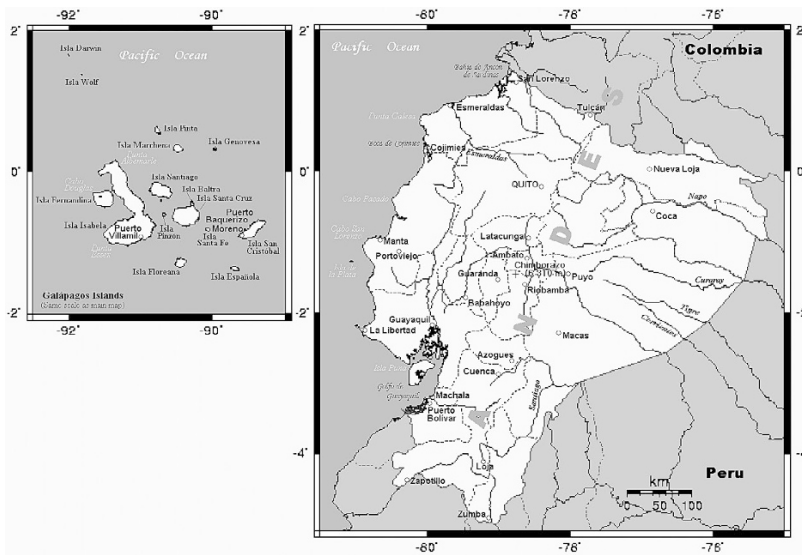
a system, for example an organisation. Anybody wanting to describe or analyse an organisation does not start by enumerating everything outside the organisation or by defining all small objects within a company, for example individual employees and forms in use. The simplification starts by defining objects and entities of interest given the problem statement. That means that the elements of study may quite differ when we perform a analysis of a quality system or a logistics system even when it concerns the same company. Once the entities have been defined, the investigator will examine the relationships enabling the understanding of the behaviour of a system.

Defining Systems

That means that a system is more than just listing its elements. Think about a watch; all separate elements (parts) of a watch do not make it work and indicate the time; however, when the parts are put together and an energy source activated (manual winding, automatic winding, battery, etc.), then the watch starts showing the time. For the purpose of analysis and design, the separation of a system from its surroundings helps understanding the relationship between the system and its environment, the relationships between its elements and elements in that environment and the interaction between elements within the system (see definition in Box 2.1). Cutting the relationships of the system, better those of its elements, from the environment will result in limiting any study to the optimisation of the system itself; it will not lead to embedding in its environment or to adapting the system to its environment from which it makes part. Which interaction to review, within the system and with the environment, depends entirely on the nature of the study and the analysis. As Checkland [1993, p. 101] notes: ‘the observer will, *for his own purposes*, use systems thinking as a means for arriving at his description’.

Some examples will illustrate this definition of systems. Box 2.A shows a map of the Galápagos Islands and demonstrates that the view on the system will differ when considering it from a geographical perspective, from a socio-economic view or from an evolutionary perspective (the Galápagos Islands appear in the work of Charles Darwin [1859]). Another example is the service and overhaul of airplanes by an airline that may serve as an element of the airline when exploring the adherence to flight schedules. When looking at the way that interaction takes place between workers within the Technical Service Department to optimise co-operation, people will serve as the elements of the study. However, if we want to observe the maintenance and overhaul of the airplanes themselves, only the steps necessary for this process constitute the elements of study. The interaction with the environment will differ as well. We might consider the propulsion of a car as a system. The propulsion system then includes all elements related to moving a car, e.g. engine, transmission and tyres, but other elements of the car, such as the dashboard, will not be part of the system. The two examples merely demonstrate the notion that the nature of a study entirely determines how to look at any system or even how

BOX 2.A: INTRODUCING THE GALÁPAGOS ISLANDS



Source: Wikipedia [2009]

The Galápagos Islands have become famous through the work of Charles Darwin (1809–1882); they are an archipelago of volcanic islands distributed around the equator in the Pacific Ocean, 972 km west of continental Ecuador (South America), see figure above. The Galápagos islands and its surrounding waters form an Ecuadorian province, a national park and a biological marine reserve. The islands' population (ca. 23,000) lives mostly of tourism, farming and fishing.

When examining the geographical position of these islands, the only interest is into the shape and the position of islands relative to continents, countries or islands (for example, the relative position to the rest of Ecuador). However, if an analysis would concentrate on the social-economic conditions, the elements and relationships to consider are social-economic entities, such as fisherman, fleets, food processing companies, traders, tourism agencies and their collaborations. Although the geographical location might be to the advantage of social-economic prosperity, it is not the prime concern. As a third case, Darwin's study focused on the fauna, particularly, the populations of finches that he studied and that allowed him to verify the theory of natural selection that was simultaneously proposed by Alfred Russel Wallace (1823–1913) [Darwin and Wallace, 1858]. Again, the geographical location might favour the study of natural selection but does not include it in the first instance. Hence, these three examples of investigations into a system show that the elements and relationships to consider might differ substantially from study to study.

to define a system (and therefore, it depends even on the perception of the observer).

Modelling systems by using Applied Systems Theory starts out with analysis of the elements and their relationships, and the interaction of a system with its environment. Figure 2.1 shows also that you can distinguish a system within total reality, but not separate it from that same total reality. This points to the need to consider organisations as open systems rather than closed systems. The definition, the one of Applied Systems Theory, mentions several key concepts (see Box 2.2) that need elaboration before moving on to discussing the properties of systems and closed versus open systems.

Elements

The elements constitute the smallest parts needed for the purposeful analysis of a system within a specific study. In Figure 2.1 all elements, except G, are part of the analysis undertaken; the systems itself consists of the elements A, B, C, I and J. To understand the purpose of any system, you need to look at the relationships between the external elements and the internal elements. For example, an element of the propulsion system of a car is the engine. The engine converts thermal energy (through the combustion of fuel) into mechanical energy and transfers that energy through the drive shaft to the gearbox, another element of the propulsion system, to the axles that are attached to the wheels; finally, it creates the driving force through the contact with the road surface (this contact constitutes the relationship with the environment). As another instance, within the logistics system of a factory, the department responsible for the supply of materials may be seen as an element of the system when analysing the flow of goods. Both the propulsion system and the logistics system have relations with the environment, which affect the performance of the system. For example, the propulsion system is linked to the driver as an element from the environment; actions generated by the driver influence the behaviour of the propulsion system. And conversely,

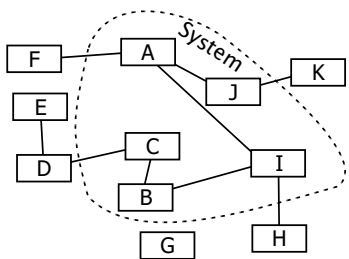


Figure 2.1 *System with its elements and relationships. Each of the internal elements has at least one internal relationship to other elements within the boundary (A, B, C, I and J). The environment consists of those external elements that have direct relationships with internal elements (D, F, H and K). Some elements outside the system boundary have no or no direct relationship with internal elements (E and G) and should not be considered part of the system's environment.*

the reaction of the propulsion system to external circumstances, think about slippery road conditions, determines how the driver has to adjust the speed of the car. In the case of the logistics system of a company, the department responsible for material supply within the logistics system connects to suppliers as external elements. Thus, the logistics performance of any company depends not only on the internal elements but on the performance of suppliers as well. Both examples show that the environment has a strong impact on the performance of systems. For that reason, the examination of the interaction of a system (through its elements) with the environment often constitutes the first step of analysis.

Elements may range from physical objects to constructs of the mind, depending on the study's objectives. When examining the material flow as such within a company, the flowing elements of the system consist of the materials and parts transformed into products. In the case of information systems, the elements also depend on the problem definition. The micro-processor within a computer or server handles bits or bytes, the elements that make up a system through batch-jobs or files that pass through that processor. However, in the case that the investigator wants to analyse the infrastructure of the information system, the servers, computers and cabling are the elements of the system. In another case when we are examining the interaction between the organisation and the information system, the information is considered the element (information is then the combination of bytes into data with an attributed meaning; information is a construct of the mind). As might become clear, the problem definition has a strong influence

Box 2.2: KEY CONCEPTS OF SYSTEMS

ELEMENTS

The elements constitute the smallest parts needed for the purposeful analysis of a system within a specific study.

RELATIONSHIPS

Relationships describe the dependencies amongst elements, whether it be a mono- or bi-directional influence.

UNIVERSE

The universe comprises of all elements and relationships, known and unknown.

ENVIRONMENT

The environment is that part of the universe that has any (known) direct relationships with the elements of the system.

on what to consider as elements and whether these have a discrete, physical nature or have abstract meanings within a particular study.

Relationships

The elements in the environment and the internal elements have relationships that describe the dependencies amongst elements, whether it be a mono- or bi-directional influence. This influence reflects the change(s) in values of properties of systems. Between elements, different relationships might exist. For example, in the propulsion system of a car the engine and the gearbox share both an energetic relationship as well as a geometric relationship. Note that within a system interrelationships exist between elements, which implies that all elements are connected by relationships and no isolated elements are present. When examining the logistic relationship between a supplier and the customer aimed at the physical goods flow, the human interaction is of no interest for the study at that point of time; therefore the directors of the company are not part of the system being studied, but part of total reality. Hence, the aims of a study determine the relationships, both internal and external, to be considered for analysis.

Universe

The total reality points to the universe comprising of all elements and their relationships, known and unknown. Depending on the nature of the study, we will consider only a partial set of elements and specific kinds of relationships within the total reality as identified by a problem definition. This implies that not all elements and relationships bear any weight for a specific study. Besides, no one can be aware of all elements and relationships; the regular discovery of stellar systems, planets, etc. demonstrate this notion. In most cases it is possible to distinguish the elements in the universe that have an impact on the system under investigation. For the propulsion system of a car, the universe consists of other systems from the car, e.g. the suspension system, as well as other systems, such as the weather system, which do not directly influence the behaviour of its propulsion system. Even so, this applies equally well to the human resource management when studying the optimisation of the logistics system of a personal computer manufacturer for deliveries to customers; at first sight human resource management is not directly related to this system, unless, for example, their skills are inadequate for tasks or training is needed. The concept of the universe as a total reality beyond full comprehension points to the limitation of any study: taking only a part of total reality into account.

Therefore, the view on a system might totally differ when considered from distinct disciplines and sciences each having their own objectives as well. Considering the definition of a system, each study requires emphasising specific elements and relationships within total reality. This notion indicates that each of the different disciplines working together in a context of solving

a problem within a specific study should generate an unique focus on the elements and relationships within the universe. Take for example, the customer service department of a bank. A computer specialist may look at it from the perspective of hardware, integration with communication technologies and software applications that control workflow. However, a marketer will approach the same department from the frame of reference for communication with customers, offering of products and resolution of complaints. In other words, no system will be the same for investigators from different backgrounds; it will even vary from study to study how a system is defined.

Environment

When analysing a system, in the first instance, we tend to restrict ourselves to that part of the universe that has any (known) direct relationships with the system. The environment consists of the elements that have any relationship with the system but are not part of the system and for that matter are part of total reality (universe). In Figure 2.1 element G is no part of the environment, whereas the environment itself is part of the universe; even element E should not be considered part of the environment, because it does not have a direct relationship with any internal element. West Churchman [1979, pp. 35–37] notes that those elements that are outside the system's control but relevant to its objectives constitute the environment. The examples as mentioned above identify the driver as part of the environment for the propulsion system of a car and the supplier as environment for the logistic system for deliveries to customers. Again, the objective of the study determines which elements outside the system make up the environment.

The environment exerts a strong influence on systems, even beyond what is visible by the eye. For example, the ancient Egyptians did cut trees and papyrus under the moonlight during the full moon, which was for a long time considered superstitious. As it later turned out, this timing for cutting papyrus would enhance its durability due more being saps present in the logs. Nowadays, we would not consider the timing of harvesting wood in relation to the lunar cycle. From the point of view of the increasing importance of durability in our age, this superstition turns into expansion of our view on sustainable production of wood. The example shows that we need to consider carefully what constitutes the environment for a specific problem and how it affects the behaviour of the system, because this possibly influences the effectiveness of an intervention or solution.

2.2 Properties of Systems

Once you have defined a system related to the scope of the specific study, the need to describe the system emerges for the purpose of further analysis and later for generating solutions. The description of a system allows further

Box 2.3: GENERIC PROPERTIES OF SYSTEMS**CONTENTS**

The contents of a system represents all elements that constitute the smallest parts needed for the purposeful analysis of a system.

STRUCTURE

The structure consists of all interrelationships that describe the dependencies amongst elements, whether it be a mono- or bi-directional influence. The structure is consisting of both an internal structure (relationships between elements of a system) and external structure (the relationships between external elements and relevant internal elements).

ATTRIBUTES

The attributes consist of the properties of the system or the properties of its constituent elements.

EMERGENCE

Emergence refers to properties of the whole that cannot be solely explained by the properties of the constituent elements.

analysis by pointing out which properties it possesses in relation to the problem definition. The generic properties of a system (see Box 2.3) allow doing so and are divided into the content, the structure and the attributes. In addition to content, structure and attributes, the emergent properties of systems demonstrate the principle of systems that they are more than their elements. And finally, the degree of interconnectedness between elements is expressed by the dimension of wholeness and independence. These five properties help to understand the behaviour of the system.

Content

The content refers to the listing of all internal elements of a system; for example, in Figure 2.1 the content of the system is: A, B, C, I and J. The concept of content compares to a list of parts on a technical drawing, the bill of materials used for logistics management and a directory of files on a computer. The content does not describe the relations between the elements and between the system and the environment. However, it does separate those elements that belong to the system from those that do not within the universe. It is simply a list of elements and the level of detail for the elements may vary depending on the problem definition. For example, if somebody wants to know if all meetings have been documented a list of minutes of

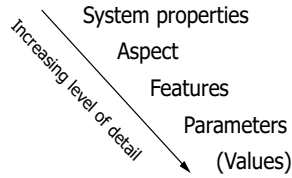


Figure 2.2 *Interrelation between properties, aspects, features and parameters. The system properties may be broken down into aspects, which reflect the types of relationships that are investigated. When decomposing aspects, the investigator of a system considers features and parameters; to parameter values can be attributed. That means that the figure shows that by going into more detail, sometimes the relationship with the original property of the system might become less clear.*

meetings (content of a file) will suffice. If somebody else wants to know whether a specific issue has been addressed, the contents of the minutes of the meeting will need to be examined (that means a lower level of detail). Henceforth, the distinction of the level of detail of elements depends on the aims of the investigator and the content merely enumerates the internal elements of a system.

Structure

To understand the properties of a system, the investigator needs to examine the structure of the system, i.e. the listing of all interrelationships between elements; please note that it always concerns the relationships of interest to the study undertaken. Relationships imply that elements do have a mutual influence on each other that stretches beyond the fact that each of these elements is present within the system. It approaches the concept of connectivity as described by Hitchins [1992, pp. 79–80]. He notes that only when elements have some influence on each other, an interrelationship exists, changing at least one of the properties under consideration. For example, when a user saves a document on the hard disk of a computer and the programme saves data and settings in separate files. For retrieving documents, the specific application will have to use the interrelationship between the data and settings to make an adequate representation of the document in the user interface (for example, the display of the computer or tablet). Thus, the examination of the structure clarifies the influence elements may have on each other.

To distinguish the relationships within the system from the relationships with the environment, a division exists between its internal structure and its external structure. The internal structure records all the relationships between the elements within the system (internal relationships). For example, Wilson [1990, p. 70] mentions that physical layout, power hierarchy, formal and informal communications reflect the structure of the organisation as a system; most of these descriptions are internally oriented. The relationships with the environment, so-called external relationships, are the domain of the

external structure, which means that exploring these requires crossing the system's boundary. For instance, the relationships with suppliers are part of an organisation's external structure. Generically speaking, the external structure has a strong affect on the internal structure.

Attributes

Elements do have attributes that we commonly describe by using features. The shape and performance represent attributes of a delivery van in general, the dimensions and transport capabilities features belonging to them (attributes carry similarity to aspects which Section 2.4 will introduce). A feature may be classified as either determinate or determinable. A determinable feature is one that can get more specific. For example, colour is a determinable property because it can be restricted to redness, blueness, etc. A determinate feature is one that cannot become more specific. These features may be described by parameters that in turn may have values. Features do not have necessarily a quantitative value, for example the colour is also a parameter that does not have directly a numerical value (although physicists use wavelengths of light as numerical value and the painting industry a standardised coding to describe colours). Instead you may describe features with meaningful adjectives, such as blue for the parameter colour. Figure 2.2 depicts the relations between the system properties, aspects, features and parameters.

Emergence

Especially, when describing complex systems, the whole may have properties that refer to the whole and are meaningless in terms of the parts that make up the whole [Checkland and Scholes, 1990, pp. 18–19]; these we call emergent properties of the whole system. This notion becomes increasingly important when systems consist of many elements and numerous types of relationships. This is apparent for a car: all individual parts cannot provide its transport function, however when put together it is capable of transporting passengers and goods. Conversely, when we strive for reducing systems by distinguishing elements, the emergent properties might be lost. Organisations often achieve performances that exceed the sum of the individual capabilities (often referred to as synergy). These performances elevate the organisation from being a collection of elements to a level of self-being. Thus, the performance of an organisation cannot be traced back to an individual even though that person might have had a strong influence. In that respect, emergence is a property of the whole system more than of individual elements.

For organisational, biological as well as technological systems this points to an integration step when discussing the properties of a system. When looking at the whole system we might attribute different properties than when reviewing the elements themselves. For the purpose of analysis, we may loose perspective moving from the system level to the level of elements. Conversely, when shifting attention from elements to the system as a

whole, we will discover properties that were not noticeable before. These phenomena might explain why ecosystems show resilience when a species (as an elements of it) becomes extinct because of self-regulating mechanisms at the level at the whole ecosystem; for example, the bird called dodo (*raphus cucullatus*) died out at the Indian Ocean island of Mauritius during the mid-to-late 17th century, however, Mauritius' ecosystem has continued to flourish (that is until recently). Whereas for some events biological systems show resilience, ecosystems can also collapse because of changes at the level of the elements. For example, that happened when the sea lamprey (*Petromyzon marinus*) – a marine invader from the Atlantic Ocean that entered the Great Lakes (between Canada and the U.S.A.) through the ship canals and locks built to bypass obstacles, such as the Niagara Falls – outcompeted smaller, native lampreys and devastated the fish communities of these lakes from the 1930s on. These examples show that systems theories are by definition not reductionist in the sense of Descartes' view but provide a balancing insight between properties that can be attributed to the system as a whole and properties that are an extension of the properties of the elements.

BOX 2.4: DEFINITION OF SUBSYSTEMS AND ASPECTSYSTEMS

SUBSYSTEMS

A subsystem is a subset of elements within the system, while retaining all original relationships between these elements.

ASPECTSYSTEMS

An aspect system is a subset of relationships within the system, while retaining the original elements on the condition that all remaining elements have mutual relationships within the system.

In contrast to denotation of subsystems, there are many definitions on how to call a system with a subset of relationships under consideration. For example, aspectsystems are also known as partial systems. Calling them partial systems might cause confusion because some authors [e.g. de Leeuw, 1979, p. 97] follow the definition of aspectsystem from Applied Systems Theory and some use the mathematical sense where it means a subset of equations. Further adding to the confusion, some denote a partial system as a subsystem. And a subset of relationships has been called a functional system as well ([Gershenson and Heylighen, 2003, p. 608]. Finally, aspects are equated to subsystems ([van der Zwaan, 1975, pp. 150, 153]. In the definitions of Applied Systems Theory, there is a strong distinction between looking at specific elements (subsystem) and at specific relationships (aspectsystem).

Wholeness and Independence

This especially holds true when elements have many interrelationships. Wholeness indicates that all elements have relationships with all other elements within the system whatever these might be. In such a case changes in any relationship will affect all its elements and in practice lead to instability within the system and towards the environment. Some extended operating systems for computers, such as versions of the Windows® operating systems, and large software applications tend to possess this characteristic and within the community of information technology have a name that adaptations have unpredictable outcomes. At the other side of this spectrum is independence when elements within the system have no interrelationships at all. In fact, we cannot call this a system since it does not comply with the definition in Box 2.1, which presumes the presence of relationships between elements. Hence, the degree of interconnectivity within the system also indicates how difficult it might be to intervene. For systems that are gravitating towards wholeness, there are possible ways to counter that; for example, modular design of products and services aims at achieving a higher degree of independence that way creating more flexibility and less dependence of production control to market demands. Practically, systems span a wide range of connectivity between elements ranging from wholeness to near independence; however, the higher the degree of interrelationships between elements, the more complex it is to understand, to describe and to analyse the system (note that Chapter 8 will expand on complex adaptive systems, partially addressing this type of complexity).

2.3 Subsystems

When conducting a study of a particular system, the need to examine specific parts of the system might emerge. In the case of evaluating the performance of an organisation we may need to analyse the purchasing system as part of the logistics system. While designing a windmill, we might need to look at the energy conversion. Both examples show an expansion of details, while ignoring other elements or relationships. Since a system consists of elements and relationships, we might as well distinguish two ways of breaking down a system into ‘partial’ systems (that follows from Figure 2.1 that depicts the key elements of a system: elements and relationships). First, we might look at specific set of elements contained within the total system, then we speak about a subsystem (the purchasing system) and, second, we might examine certain types of relationships by distinguishing an aspect system (the energy conversion).

Looking at clusters of elements, subsystems, helps defining main parts within a system without describing endless lists of elements (see the definition in Box 2.4), especially when the original system contains a large number of elements. Imagine a listing of all the parts of an airplane, the individual

organisms of an ecosystem (such as the rainforest) or all the personnel working for a company, such as Shell or Philips, through which the investigator has to find his way to find a certain type of parts, species or personnel, e.g. database specialists. Subsystems define sets of elements as purposeful entities within the system. Doing so, the relationships within the system, with the environment and, therefore, the relationships between the subsystem and the other elements remain the same. The original system becomes now part of the environment of the subsystem. When looking at a system, an investigator might view it as a set of interrelated subsystems.

The application of dividing systems into subsystems strongly relates to simplifying the structure of a system to purposeful entities without losing overview. During the study of these systems and their elements, subsystems serve as intermediates between the system as a whole and the elements. The airplane has different subsystems, e.g. the electrical system, the fuselage of the plane, the wings, etc. An organisation will have subsystems, too. When studying the logistic system, the purchasing system and the warehouse system are subsystems. Within the purchasing system, goods receipt is one of its subsystems. All these subsystems have interrelations. In a house, one might have a subsystem for water supply and a subsystem for supply of electricity; these are interconnected by the geometrical position in the building. Thus, subsystems may have various levels, depending on the depth of the study, but the different type of subsystems also have interrelationships to each other.

The definition in Box 2.4 also reflects that a subsystem itself is a system (see Figure 2.3). Defining subsystems results in studying the smaller parts of a total system without isolating them from the system and its properties. It implies as well that a specific study into a subsystem requires an adapted problem definition for the subsystem. The original objective of the study results in distinguishing that particular set of elements and relationships while the need for exploring a subsystem has narrowed down the focus caused by further analysis at system level. This further analysis informs limiting the scope to these particular elements, i.e. the subsystem. Thus, the need for investigating a subsystem has a strong link to the progress of the analysis and detailing as part of a study.

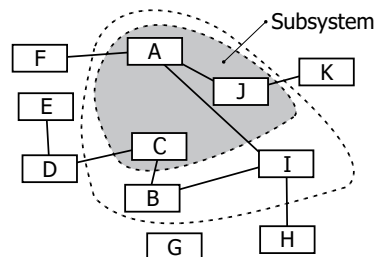


Figure 2.3 *A subsystem within a system. Some elements are not looked at as part of the particular subsystem (elements B and I in this example); they become part of the environment of the subsystem.*

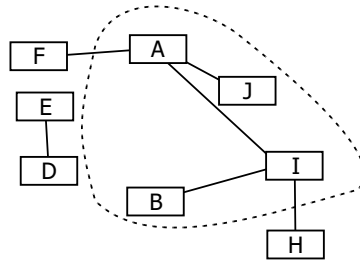


Figure 2.4 *Aspectssystem.* While principally retaining all elements, the specific relationships studied result in discarding some elements as being part of the system under review. A comparison with Figure 2.1 shows that element C is no longer part of the aspectssystem and that elements D, E and K are no longer part of the environment, because they have no specific relationships of this type with elements of the aspectssystem.

2.4 Aspectsystems

The second principle for having a more detailed look at a system focuses on which relationships in particular draw interest in the perspective of the problem definition. An example in economics illustrates this. When a cost-price analysis results in the quest to find data on prices of parts or on units of labour, the physical characteristics of the product are of no interest except for obtaining the proper data for the cost-price calculation. Other relationships than those related to the objectives of the study have no impact on the results, for example, the aesthetic aspect of the product. This way the number of relationships under examination is reduced to the necessary ones according to the nature of the study. The relationships subject to closer study are called the aspect or aspects and an aspect always concerns a subset of the relationships present in the system and its relationship with the environment.

An aspectssystem reflects the choice for particular relationships as the area of interest. Basically, we eliminate all the relations except the ones we choose to explore (see the definition in Box 2.4). If it occurs that some of the remaining elements do not have any more relationships with other elements in the system, these elements need to be removed, leaving the aspectssystem always with elements that have mutual relationships within the system or with elements outside the system; see Figure 2.4 in relation to Figure 2.1, where elements D and E have a relationship of the aspect but no relation to elements within the system for which these should be discarded as part of the study. An example might illustrate this; the fuel consumption of a jet engine has no direct relationship to the use of lubricants for rolling parts within the total system of the airplane. Hence, the focus on a specific type of relationships not only reduces the number of relationships to consider but may also affect the number of elements in a more detailed study.

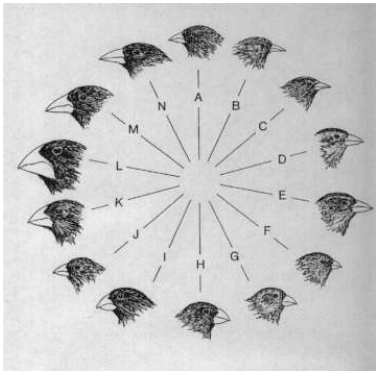
No predefined aspectsystems do exist since the aspect under review, a particular set of relationships, finds its origin in the specific problem definition. The example of the Galápagos Islands in Box 2.B demonstrates

how the concept of subsystems and aspectsystems can be applied to the study of evolutionary biology. When communicating people often point to general classes of aspects that might have a common meaning for all, e.g. the energy system. Within companies, the quality system and the logistics system are mostly seen as separate entities. Though when quality is a must, improvement of the business processes might require investigating both these general aspects and integrating them into one aspect for the study at hand (and may be even skipping relationships of quality and logistics that do not relate to the focus of the study). This example underlines the necessity to articulate in each situation the aspect for further evaluation.

For illustration of the concept of aspects, two examples in addition to Box 2.5 will follow with generic classifications of relationships. To describe an office building and an organisation an architect may distinguish several aspects (the first example):

Box 2.B: GALÁPAGOS ISLANDS: SUBSYSTEMS AND ASPECTSYSTEMS

The Galápagos Islands have become most famous through the work of Charles Darwin (1809–1882) when he studied populations of endemic species. From the perspective of systems theories, he has applied thinking in subsystems and aspectsystems. Consider all fauna in these islands as a system. By taking a specific species within the fauna, a subsystem is created. A specific population of one the species on one of the islands should then be called a subsystem of a subsystem. By comparing subsystems of subsystems, most notably the finches, Darwin did find the evidence for the theory of natural selection and adaptive radiation. However, by concentrating on the anatomical appearance of species, he has focused on only one aspect; for example, he did not consider predatory relationships. Nowadays, biologists would rely on a number of aspects before concluding on relationships between populations of species, DNA samples being one of them.



- the geometrical aspect. This includes the dimensions of the structure of the building, the size of the offices, the lay-out, the position of the building in the environment, etc.;
- the functional aspect. The functional aspect describes the use of the building, the flow of people through the building, the goods entering the building, the catering facilities and so on;
- the energetic aspect. In present times, the energy consumption plays an important role in the design and construction of buildings;
- the utilities aspect. This aspect consists of the power supply throughout the building, the information and communication infrastructure, the water supply and piping, the drainage system, the illumination and so forth;
- the aesthetic aspect. Office buildings should be a pleasant place to work in and might have to leave an impression in people's mind;
- the structural aspect. Buildings have to withstand external influences, weather and earth movements, and display internal strength during the time of occupancy;
- the maintenance aspect. The building has to be kept in a working state due to the deterioration (as wear and tear) appearing in the course of time.

Each of these aspects describes particular sets of relationships of the building, which may have little or limited interrelations. Eventually, the problem definition will define which particular sets of relationships are of interest and this way what the aspect compromises. Generic classifications of aspects have little meaning for specific problems except that they may be helpful for generating theories for generic aspects, such as in the case of an organisation, the second example:

- the logistic aspect. This aspect consists of the flow of materials and goods through the company and to the customers. It also includes planning of production, storage and movements;
- the quality aspect. This aspect entails meeting the customers' requirements and maintaining the standards for products and processes;
- the technology aspect. The deployment of skills and knowledge to expand the product range and to improve primary processes are the domain of technology;
- the human aspect. It addresses the way people within the company communicate and collaborate either with others in the company and with persons outside the organisation;
- the information aspect. This entails the flow of information through the company and the processing of data;
- the financial-economic aspect which compromises the cash-flow, the budgeting, the decision-making on investments, etc.

These aspects of an organisation follow more or less the division of (scientific) disciplines, neither one describing the system in its full extent. When choosing for a specific aspect, the study limits itself to a partial description of the object under review. However, such a description might go beyond a single aspect as a generic classification. For example, in the case of the firm,

if a study is undertaken into handling of complaints, only a part of the quality aspectsystem and part of the logistics aspectsystem will be of interest. Thus, for specific problems the aspects under consideration may be unique and not following canonical divides and that means that what is considered a system and aspectsystem is contingent on the problem definition.

Describing a system in fuller detail requires the comprehension of interrelationships between aspects that may exist, though at a specific point in time little might be known about these. These interrelationships come into the picture during evaluation, appraisal and decision-making. Managers and engineers take decisions regarding trade-offs between quality and cost-price but each person attributes different values to the two aspects. Even persons fulfilling similar jobs will have different opinions. Therefore, the trade-off between aspects is subjective and may differ from one occasion to an other, mainly because little is known about the interrelationships between aspects.

2.5 State of Systems

At a certain moment in time, a system might have defined properties, the content, the structure and the attributes, the so-called state of a system (see definition in Box 2.5). For example, a company has a set of elements, an organisational structure and has certain values for the financial and logistic

BOX 2.5: DEFINITIONS OF STATE AND BEHAVIOUR OF SYSTEMS

STATE

The state of a system describes its content, its structure and (the values of) its attributes at a given moment in time.

BEHAVIOUR

Behaviour is the capability of a system to respond to variations in external relationships and modifications of the external structure, either through changes in attributes, adjustments of the structure or adaptation of the external structure.

One could say that the state of a system is related to a specific point in time and behaviour is considered during a certain period of time.

Behaviour can be static or dynamic; behaviour is called dynamics when properties or relationships change. The properties can change deterministic or probabilistic. If the properties remain stable within a specific time-frame, the system is in a steady state; however, when the outcomes depends on the memory of the system, the behaviour is transient.

aspect, all representing the state of the system at a given moment. When the state of the system does not change in view of the problem definition, the entity is a static system, the properties remain the same within the given time-frame. The position of a bridge in a landscape on a map marks a static system. In the case that as a result of an event any of the system's properties changes, whether it concerns the content, the structure or attributes, then we call the system dynamic. A capital expansion of a firm represents such an event, some of the features concerning the financial aspect do change with the intent to strengthen the financial-economic position of the company. Activities, events leading to other events, take time in general, creating interdependencies between several states of a system. To summarise, when the state of a system remains unchanged, the system is called static; when activities cause any type of changes in the state, the system is regarded as dynamic.

Therefore, the state of a system is dependent on previous events and states; all these successive stages, the history of all previous states and events, correspond to the memory of the system. In the case of companies, the state of an organisation has roots in previous organisational structures, the intake from orders and the knowledge gained by people working in the organisation. If the elements and relationships remain unchanged over a period of time and only the attributes change, that means that the scope of a system is limited to its present capabilities for dealing with events and perturbations. The memory will tell us about the adaptations taking place in response to changes in the environment because they are embedded in the current state of a system.

When modifications occur in the interrelations, within the system or those with the environment, or elements, this implies directly also alterations in relationships; the system has an altering structure. Such an altering structure might display a repeating pattern; in general it is assumed that these variations are irreversible due to the memory. Managers and engineers exert a similar characteristic in this view when both look for interventions to enhance performance of either organisations or technical objects through structural changes. These structural changes always concern changes in elements and relationships; for example, changes in the organisational structure or redesign of equipment. The observation that the structure does not change may entirely depend on the interval between the monitoring moments, pointing out the caution to drawing early inferences on the dynamic capabilities of a system. To summarise, the behaviour of a system tells about the ability to undergo changes in state, whereas the changes in the structure also reflect only on the internal and external relationships among the elements (also called the dynamic capability).

Based on the previous typologies for changes in the state of systems, examples of the various possibilities are:

- bridge on map (position in the landscape): static system;
- car engine (delivering power for propulsion): dynamic system, permanent structure;

- company (delivering products to customers): dynamic system, altering structure.

Generally speaking, systems either have a permanent structure that we intend to change in a revised or new permanent structure or have a changing structure that we influence as participants in the system.

2.6 Behaviour of Systems

A dynamic system will display specific behaviour during the time of the study depending on the nature of the objectives either through variation in attributes or by modifications of the internal structure. The time frame may influence the outcomes of the study depending on its horizon: how did the system respond to changes in the external structure during different periods. Take a company as an example, on the short-term substitutes for products from competitors might lead to direct changes in price and delivery time by a company, whereas on the long run it should develop a new product range to divert the threat of this unexpected event. Therefore, the events in the external structure always lead to an internal response by the system. In addition to the internal response, in many cases the internal activities also result in changes towards the external relationships again causing a reaction by the environment, as seen from the example of the company (for instance, the new products may lead to different customers to trade with it). Behaviour denotes the capability of a system to respond to variations in external relationships and modifications of the external structure (see definition in Box 2.5).

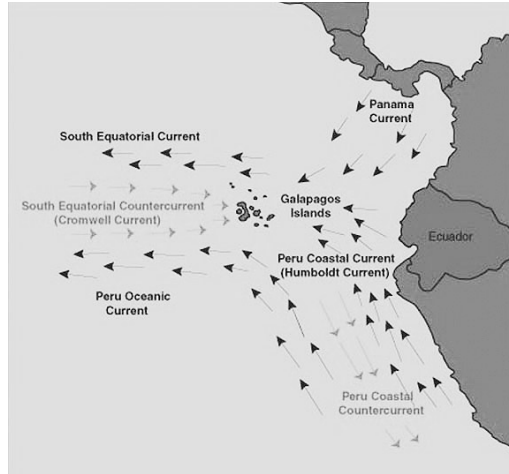
During the studies, the investigator might encounter one of the two typical cases of a system's behaviour:

- static system behaviour. The properties of external relationships depend only on the specific values of events acting on the system and the timing of these values;
- dynamic system behaviour. The properties of external relationships depend also on the history of events over time.

For example, a company processes orders for standardised products from a wide variety of customers. If the lead-time remains the same no matter how many orders it accepts, the company displays static behaviour in terms of the lead-time; to achieve this, it should be possible to tune the capacity to the order flow, which implies that the company should have an infinite capacity. When the capacity has limitations, the actual lead time of the company will also depend on the intake of orders during previous periods. Whether the behaviour of a system is static or dynamic does not only depend on the time-frame but also on constraints embedded in the system's properties.

When we can predict the behaviour of a system entirely, then the behaviour is deterministic whether the nature of the system behaviour is static or dynamic. The responses of control systems in petrochemical plants possess this characteristic by reacting on deviations in the chemical processes. In contrast to deterministic system behaviour, the system might also display

BOX 2.C: GALÁPAGOS ISLANDS: BEHAVIOUR



The unique, relatively stable subtropical climate at the Galápagos Islands has contributed to the study of endemic species. The climate is determined almost exclusively by ocean currents, which are themselves influenced by the trade winds that push them. The marine biota are also affected by these currents. The Galápagos Islands are situated at a major intersection of several ocean currents, the cold Humboldt current (which predominantly influences the climate), the cold Cromwell current (also known as the Equatorial Countercurrent, which is responsible for much of the unique marine life around the Galápagos) and the warm Panama current, see figure above. The unique mixture of relatively cool waters, tropical latitudes and islands with different altitudes produces an ever changing environment that has resulted in flora and fauna found nowhere else on earth.

From a system's perspective, the climate is relatively constant but its behaviour is dynamic and stochastic when predicting the weather for a relatively short period of time, say from days to weeks; the weather can be predicted but there is uncertainty about the exact conditions. This caused by the memory of the system (today's weather conditions depend on yesterday's ones). Taking a time horizon of years, the climate is fairly constant with predictable cycles, in systems theory's terms: the climate system of the islands is in a steady state. Even the El Niño, occurring every four to seven years, has a fairly predictable impact on the climate of the islands. The recent trends in climate change can be labelled as causing a transition; for example, at least 45 Galápagos species have now disappeared or are facing extinction. For the study of endemic species at the Galápagos Islands, the climate constitutes the environment.

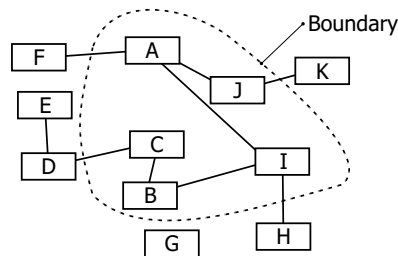


Figure 2.5 *Boundary of a system. The boundary separates the internal elements from the elements that constitute the environment. The relationships that cross this boundary, i.e. relationships between internal and external elements, are called the external structure.*

behaviour with a degree of probability, stochastic system behaviour. For example, fuzzy control systems coming about during the 1990s found their way in home appliances; they do not exerting a predefined action but adjust interventions more or less on a trial-and-error basis depending on the outcomes. Although capturing systems' behaviour becomes more difficult in case of stochastic changes in relationships, tuning of attributes and relationships belongs to the possibilities to alter the behaviour. Another example is given in Box 2.C for the Galápagos Islands for their climate. In all three cases, deterministic or stochastic behaviour, the outcomes of changes in the relationships are predictable, albeit to a varying degree.

In case of recurrent behaviour, either deterministic or stochastic, the system is in a steady-state. The system repeats the same changes in relationships and attributes, mostly related to the fact that similar events act on the elements which requires no adaptations in relationships and elements. When events cause changing the behaviour in course of time, the system is called a transient system. The memory may prevent that particular behaviour appears again as happens during the growth stages of a human being. A steady-state becomes only possible when a homeostasis, a balance, occurs in the relation to the environment (see Section 3.1, and Chapters 5 and 6).

2.7 Systems Boundary

Around a system the investigator will draw a system boundary, separating the elements from the environment (see Figure 2.5). The purpose of study will determine this separation to examine the specific elements (system) within the universe, and the external structure and internal structure. As a way of illustration might serve the study of whales in their habitat in New Zealand. Although this might help to study behaviour of local populations of sperm whales, some whales also follow migratory routes from the Antarctic to the tropics. If the study wants to understand, the behaviour of all whales, it might be necessary to include the migratory routes, resulting in an increase of geographical spread of the system studied. That means that the problem

definition determines mostly the system boundary. To that end, there are a few practical guidelines for setting the system boundary:

- the exchange with the environment concentrates on a few elements. The internal structure has in this case a more dominant role in determining the system behaviour than the external structure. This might result in the practical guideline that the number of internal relationships equals or exceeds the number of relationships in the external structure;
- the exchange with the environment might require more effort than maintaining the internal structure. This indicates the capability of the system to maintain itself within its environment;
- the capability of the system to serve a purpose within its environment. Again, this refers to the capability of the system to maintain itself within its environment but directed at its purposefulness.

Might a system experience difficulties in maintaining itself in the environment than the it has to adapt its behaviour to the events taking place in the external structure or has to adapt its structure matching the (external) event or has to dissolve itself. Such situations might arise from the diffusion of the system boundary, a problem encountered by many companies through the increased capabilities of information and communication technology where customers have a stronger influence on the behaviour of a system; the permeable boundary leads to customers having more impact of the structure of the system, even though the customers may not notice the change. Whether a static or a dynamic systems, or whether it displays static behaviour or dynamic behaviour, the internal structure should match with the performance requirements imposed on it through the external structure.

The interaction with the environment points to so-called open systems. In the case of closed systems, the interaction with the environment is not considered. It is hard to imagine that to be the case, any system has a position in the universe and is interrelated. Nevertheless, if that occurs, the only consideration is the internal structure; the system boundary merely serves as a separator of the internal structure and content from the universe (not just the environment, following the definition of Applied Systems Theory).

2.8 Summary

Looking at systems means purposeful distinction of elements and relationships within the universe (therefore, systems are always part of the universe). The separation should serve the nature of the study and an investigation will take only those elements and relationships within the system into account plus the relationships with its environment, i.e. those elements in the universe with which the internal elements have direct relationships. By describing a system by its contents, its structure and its attributes, it becomes possible to define the state of a system and its behaviour in view of the nature of the study undertaken.

Subsystems and aspectsystems represent two different ways of examining a system in more detail (see Figure 2.6). Subsystems leave the relationships intact in favour of looking at a subset of elements, whereas aspectsystems concentrate on certain type of relationships within the system. Defining an aspectsystem means eliminating elements that have no interrelations of a specific type anymore with any other element present in the system. Practically, it means that a study always considers an aspect, or perhaps some, while at the same time the investigation concentrates at subsystems of a larger set.

Ultimately, most studies look for ways to modify the behaviour of a system, which is the change of the state of a system by events happening in the external structure. The modification of behaviour of technical or organisational systems results either from optimisation of attributes (of elements) or from altering the structure of the system. When the behaviour repeats over time the system has achieved a steady-state. Especially organisational systems show transient behaviour due to the memory caused by earlier events that led to adjustments especially in the structure of the system and, therefore, will hardly reach a steady state.

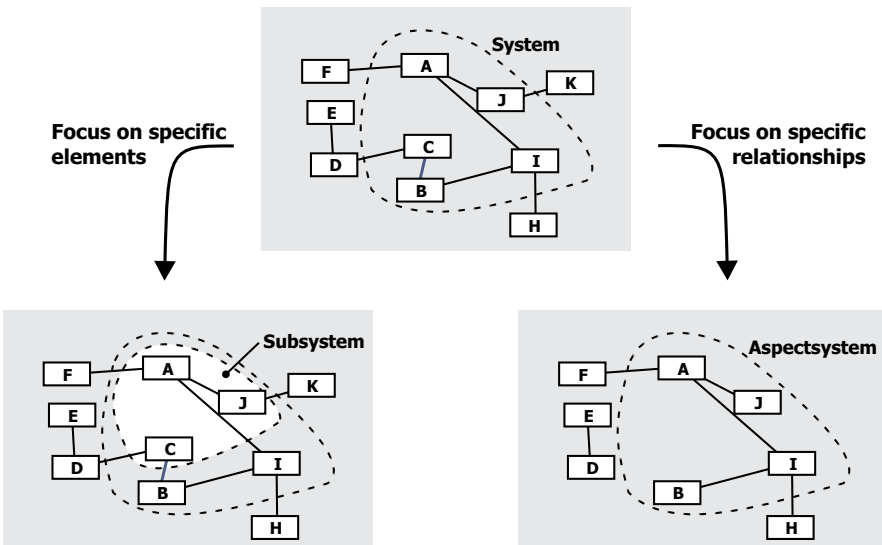


Figure 2.6 Two principles for investigating a system in more detail. When focusing on specific elements a subsystem may be distinguished; in this case, this subsystem is consisting of elements A, C and J. When focusing on a specific relationship only, the elements that have interrelationships of this type are looked at; in the figure these elements of the aspectsystem are A, B, I and J. Note that elements in the system that do not have this particular type of relationship with other elements are omitted; by doing so, an aspectsystem will fulfil the definition of a system. This also means that element D is no part of the environment of the aspectsystem in this case.

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