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Policy Analysis of Multi-Actor Systems

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LEMMA

3 Systems Analysis

'(...) which models to construct, which alternatives to compare, and whether the study outcome is to be a solution feasible under defined uncertainties, a formal optimalization, or a presentation of alternative possibilities, are all decided in the problem-formulation phase.'
Peter Checkland, 1985: 152

This book is concerned with policy analysis and its role in multi-actor systems. We have seen that a policy analyst can have various roles, depending on the demands of the situation and the client. In this book, we provide analytical tools and methods to structure problem situations that were previously ill-structured, messy and wicked. Various perspective and disciplines put forward analytical tools and methods, but a logical place to start is systems analysis. Systems analysis is the approach that evolved in the 1950s and 1960s from the field of operations research. Systems analysis applied scientific, and often mathematical, approaches to investigate and solve problems in large systems. For many policy analysts, especially those working in a rational style, the analysis methods and approaches that were developed for systems analysis form an important part of their toolbox. This chapter provides an introduction to analytic thinking and to some of the methods that are most useful to support problem formulation and problem exploration in the early stages of policy analysis: means-ends analysis, objectives trees, causal maps and system diagrams. However, we will start with a brief introduction to the field of systems analysis and its use for policy analysts.

3.1 Introduction to Systems Analysis

Systems analysis applies scientific methods to analyze large and complex systems. When applied as part of policy analysis processes, the system under study is typically a certain policy domain, seen from the perspective of a policy maker, client, or, more basically, someone who thinks there is a problem (Findeisen & Quade, 1985). Systems analysis applies the scientific method to map and analyze this system, whereby this scientific method is characterized as a structured way of working that is open and explicit, empirically based, consistent with existing knowledge, and for which the results are verifiable and reproducible (Walker, 2000: 12). Furthermore, systems analysis is scientific in that it seeks to develop and test 'theories': causal assumptions of how the world works. Systems and policy analyst 'speak of their theories as models, but the terms are really synonymous' (Miser & Quade, 1985: 19). Despite this emphasis on the scientific method, another key feature of systems analysis is the recognition that the complexity of the systems that are studied is such, that complete certainty is impossible, and that systems analysis is essentially an art and a craft, based on tacit and informal methods, rather than formal and explicit (Miser & Quade, 1985).

The systems analysis approach that we describe in this chapter grew out of the operations research field and is connected to institutes such as the RAND Corporation, a US based think-tank, and the International Institute for Applied Systems Analysis (IIASA). This means that we will not be discussing systems theories such as cybernetics, general systems theory, system dynamics and complex adaptive systems. An overview of system theories and approaches can be found in Jackson (1992) and Bots and Van Daalen (2008).

The advantage of using a systems analysis approach is that it helps to put some structure to complex and ill-defined policy fields. It helps analysts to make their own assumptions and expectations explicit, providing a basis for communication with clients, as well as with fellow analysts. Furthermore, the field of systems analysis provides useful guidelines, tools and techniques that enable an analyst to develop quite detailed and comprehensive models of a policy domain. This in turn may help them to advise their clients about possible courses of action in a particular problem situation. Even if systems analysis cannot provide complete and detailed prescriptions, it can almost always eliminate the really bad alternatives (Miser & Quade, 1985).

A known limitation of systems analysis is that it is necessarily incomplete, not only because of practical limitations in terms of time, money or human resources, but also because it simply cannot study all considerations that may be relevant (Miser & Quade, 1985). This means that an analyst must make choices about what to consider, what to include as part of the analysis, and what aspects are left outside the scope of analysis. As a result, uncertainties remain. They increase are even more when we take into account that many policy decisions apply for long periods of time. How the system will evolve, what it will look like in two, five or ten years time, no-one knows. To address this limitation, Chapter 5 discusses some methods for exploring the future. Also, systems analysis generally works from the perspective of a specific problem owner. It can accommodate some of the multi-actor aspects in its methods, but it is not specifically developed to function in multi-actor policy systems. If the multi-actor complexities are many and pervasive, additional approaches will be needed to incorporate them in a policy analysis. Some of these are discussed in Chapter 4.

3.2 Conceptual Framework for Systems Analysis

Meaningful discussion of systems analysis tools and methods requires a basic description of what we mean when we speak of a system. If our aim is to analyze a certain 'system', then what is this object of analysis, what are the main concepts involved, and how are these structured and related?

3.2.1 The System Diagram and Its Contents

A **system** is defined as a part of the reality that is being studied as a result of the existence of a problem or the suspicion thereof. An analyst will make a **system model** that clarifies the system by (1) defining its boundaries and (2) defining its structure – the main elements and the relationships among them (Walker, 2000: 13). Thus system demarcation and problem formulation are closely linked. The question of which part of reality is relevant for further analysis is directly related to the problem formulation that is being used.

We have seen that a problem is defined as the perceived gap between the desired situation and the actual situation, and the person who perceives the gap wants to know what can be done about it (see Chapter 2; cf. Checkland, 1985). This means that a system model is actor-specific: it describes the system from the viewpoint of a specific actor. It also means that a system is relevant only because it influences the realization of a certain desired situation. The desired situation is generally described in terms of **objectives**. The realization of objectives is measured through the use of **criteria** that are linked to the main outcomes of interest of a system (cf. Walker, 2000: 13).

Another part of our definition of a policy problem concerns the possible means to 'do something about it'. A problem owner should have some **means** (e.g. policy instruments) through which she/he can influence the system, improving the degree to which objectives are being realized.

Finally, there are likely to be some important influences on the system from an external environment, factors from outside the system over which the decision-maker or problem owner has no control (Checkland, 1985; Walker, 2000). These **external factors** are elements that cannot be influenced by the problem owner or by the factors inside the system, but that do place important limitations or constraints on the behavior and outcome of the system.

Combining these main elements provides a basic system diagram, as shown in Figure 3.1. It consists of the system with three groups of factors on its borders: the means of the problem owner, the external factors, and the criteria. The direction of the arrows show that the means and the external factors affect the system and eventually the criteria.

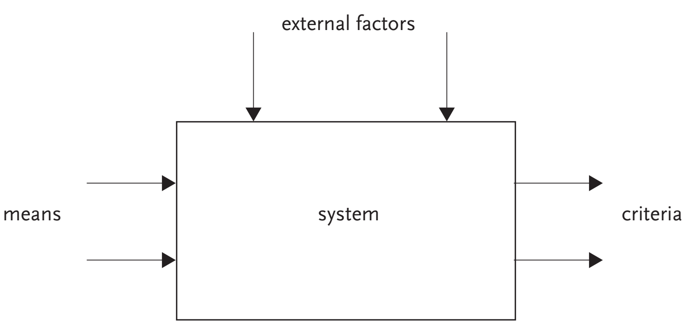

Figure 3.1 System diagram: conceptual framework for systems analysis

Using these basic concepts, a system analysis should provide the problem owner with insight into the behavior of the system, the means and possibilities that the owner has to influence it and the consequences of this for the problem. In this way, the problem owner is assisted in making a reasonable deliberation.

3.2.2 A Note on Terminology

The terms ‘interest’, ‘objective’, ‘means’ and ‘criterion’ all have to do with the normative point of view of one or several actors and they can all be found in relation to problem formulation and systems analysis. Because a lot of confusion exists about the exact meaning of these different terms, we will provide working definitions here.

By **interests** we mean the total of values and desires that an actor finds important, *regardless of the specific situation.* Interests are usually formulated in an abstract way and they are relatively stable over time. They are often referred to as categories: social interests include issues such as equity and social justice, environmental interests include biodiversity and ecosystem welfare, economical interests include economic growth and competitiveness, and so on. There are several different organizations and groups in the Netherlands and most other countries that protect these kinds of interests. Think of human rights organizations, environmental protection organizations, branch organizations of employers and employees, women’s organizations, car owners groups, municipalities, and so on. On an individual level interests such as good health, a good income, and so on can be categorized as interests. These interests are sometimes called ‘*fundamental* objectives’ (Keeney, 1992).

Objectives distinguish themselves from interests because of their actuality. *Objectives belong to a specific problem or project.* Objectives are interests made concrete, which translate to the actuality (to concrete policy issues). An actor will strive to achieve a situation-specific objective in order to ultimately realize his interests. The general interest ‘a healthy environment’ of an environmental protection organization translates to the objectives ‘unpolluted groundwater’ and ‘less use of fertilizers’ when the organization discusses the problem of high nitrate concentrations in groundwater due to over-fertilization. When discussing the planned extension of A4 highway in the green area between Delft and Schiedam in the Netherlands, the same interest ‘a healthy environment’ translates to the objectives ‘conservation of open meadow landscape’ and ‘immediate halt of the construction works’ as an objective. In both cases, the preservation of the environment is the underlying interest; the objectives differ. Given an actual situation, we use objectives to specify what needs to change to attain the desired. The terms ‘goal’ and ‘end’ are often used in the same sense as ‘objective’, but less frequently, and the latter is usually used in conjunction with the term ‘means’.

With **means**[1] we mean anything that can be used in order to achieve an objective. This implies that means and objectives relate to each other. Making this relation explicit is called 'means-ends analysis'. The means-ends relation is similar to the relation between objectives and interests, as an actor strives to reach an objective in order to ultimately realize his interest. Like objectives, means can be described in global terms, such as 'money' or 'legislation', but also be specified more precisely, e.g. 'subsidize biological products' or 'forbid the use of pesticide X'.

Figure 3.2 Meaning depends on perspective

The distinction between objectives and means is not absolute. This ambiguity is similar to that of Figure 3.2: whether the image depicts a bird or a rabbit depends on the perspective one takes. Likewise, what may be a means to one actor can be an objective to another. From a government perspective, subsidizing biological products and forbidding the use of pesticides are possible means to achieve the objective of a more ecologically friendly agricultural sector, while from the perspective of an environmental protection organization, a ban on pesticide X and a subsidy on bio-products are objectives. A single actor may also experience this means/ends ambiguity: an automobile manufacturer may see the safety of a car as an objective (and see installing airbags as a means to achieve this), but also as a means for increasing sales (combined with other means, such as a publicity campaign that highlights the safety features of the car).

Criteria are objectives operationalized in terms of *factors*, i.e. system properties for which a value can be established on a scale via direct or indirect measurement. Objectives can be fairly abstract, for instance better traffic safety. Operationalization of traffic safety produces criteria such as 'number of casualties per year' and 'number of accidents per year' (measured by counting), 'probability of being involved in an accident' (measured as the ratio of accidents in a year over the total distance travelled by all travelers in that year), 'material damages as a consequence of accidents per year' (measured in Euros), and so on. As they can be measured, criteria can be used to determine whether the desired situation has

1 The singular of 'means' is also 'means'; one may look for *a* means as well as for different means to attain a goal.

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been attained. If the objective 'better traffic safety' has been operationalized as 'less than 1000 casualties in 2012', then evidently this objective has been achieved when in 2012 the number of casualties is lower than 1000. When such target values are specified, people tend to use the word 'criterion' also for the tipping point, e.g. 'be over 18', 'have 20/20 vision', and 'have less than 0.2 percent alcohol in your blood'. When a clear distinction between a criterion and its target value needs to be made, the term 'criterion variable' can also be used.

Interests, objectives, means and criteria play an essential part in problem formulations. Knowledge of the interests, goals, and means of actors are necessary in order to reach a meaningful problem formulation. The example in Text box 3.1 illustrates this.

Text box 3.1 Helmets – Example of inventory of interests, objectives, and means
The requirement for riders of motorized cycles to wear helmets: an exploration of a policy problem

In the 1990's, in the Netherlands there was no requirement for riders of motorized cycles to wear a crash helmet. However, these riders are a relatively vulnerable group of road users, and the number of fatal accidents in which they had been involved had risen sharply. With forthcoming elections in mind, a popular politician called for it to become compulsory for this category of road user to wear crash helmets, and for this measure to take immediate effect.

What is the problem here? The answer will depend on who is giving it. What possible different perspectives on this problem exist, and which will be useful to elaborate further?

Is the problem really an excessively high accident rate among the riders of motorized cycles? Or is it more specifically the number of fatal and serious accidents (often involving brain damage) involving them? A number of factors may contribute to the problem: increased traffic, insufficient attention to road safety in primary education, a driving test for young people which does not make sufficient distinction between good and bad road users, youthful overconfidence, alcohol and drug abuse, the use of relatively unsafe 'souped up' machines by youngsters, or perhaps even an overrepresentation of vulnerable older road users who are somewhat slower to react. Some people will see the cost of the compulsory motorized cycle diploma as contributing towards the popularity of the 'buzz bike' (a lighter category of vehicle for which the diploma is not required). Insurance companies complain of the high costs of hospital admissions. Parents will cite the high insurance premiums as a problem, (the premiums having been forced up by the number of accidents), while the police complain of the readily available kits to enhance the performance of the machines concerned, and the lack of manpower to carry out adequate controls.

What then is the problem that the analyst is expected to solve? He must first find out whether the problem actually exists, define it in detail, and then investigate whether any policy measures can be found to contribute to a solution to the problem, over which the client has some form of authority. Assuming that the problem does indeed exist, the analyst will wish to establish its true extent and scope. For example, how many accident victims are there per traveled kilometers, and in which age categories are they to be found? How do these statistics relate to those of comparable groups of road users, using other modes of transport? How long has there been any difference and when did it arise? Such figures will indicate the extent and the boundaries of the problem. For example, is it only the groups of motorized cycle riders over the age of fifty who have a higher-than-average accident rate, or only the group aged 16 and 17? Further information on this point and about, say, the development of the issue over time, can perhaps be gained by consulting the results of similar or comparable studies.

Another part of the problem definition will consist of establishing the position and influence of the various individuals and groups concerned. Who is addressing this problem? Why? What are their interests? What influence do they have on policy? In this example, interested parties may include: the politician who raised the issue to win votes, the National Road Safety Organization, police chiefs with a strong involvement in road safety, the national Brain Damage Foundation and medical specialists who wish to prevent brain damage, insurance companies who wish to reduce treatment expenditure, parents who wish to pay lower insurance premiums, riders who wish to maintain the freedom to ride without a helmet, the manufacturers and retailers of the motorized cycles (who would see their market share decline were helmets to be made compulsory), driving school owners who see a potential market for instruction, and perhaps many others, such as school principals, motorists' organization, the cyclists' federation, etc.

3.3 A Method for an Exploratory Systems Analysis

There are various ways to develop an adequate system diagram and to identify suitable system boundaries as well as the main factors and the important relations among them. Here, we will use the following steps, each of which is supported by a specific technique:

1. Set the initial problem demarcation and level of analysis.
2. Specify objectives and criteria (outcomes of interest).
3. Identify potential means and map the main causal relations and their influence on the outcomes of interest.
4. Provide an overview of the problem area using a system diagram.

Taken together, these steps should help to develop a first system diagram and to perform a first, qualitative systems analysis, supporting a sound problem formulation.

3.3.1 Step 1: Problem Demarcation

In many cases, problems can be formulated at different levels. Choosing the right level from which to start the analysis is not always easy. However, the level at which a problem is formulated largely determines the problem demarcation, the spectrum of aspects/factors and possible solutions that are taken into account. Hence it is worthwhile to spend time at the beginning of an analysis looking at the different levels at which problems can be identified.

The first thing to find out is *why* a problem is important for a client. Means-ends analysis therefore starts out by formulating the client's dissatisfaction with the actual situation as an objective that expresses the desired situation. This objective will typically be at the core of the client's problem, for example, 'to have enough water even in dry summers' for a farmer who sees his crops wither after weeks without rain. The question to pose next is *why* this objective is worth striving for? Does the objective contribute to the realization of a higher objective? Asking this question several times, until a meaningful answer cannot be given anymore, will result in a means-end objectives network (Keeney, 1992; Gregory & Keeney, 1994). This 'why' exercise will reveal that there are fundamental objectives or end objectives, and means objectives. The latter can be seen as objectives, but they are also means to realize other, more fundamental, objectives. In the drought example, the farmer's secondary objective will be to 'have a good crop'. If, when asked why this is worth striving for, he answers 'Because I'm a farmer!' this would indicate that 'have a good crop' is a fundamental objective. If he answers 'To make a living!' this would suggest that switching from farming to another livelihood is conceivable.

Having identified the client's fundamental objective, a means-ends analysis continues in the opposite direction. For each objective identified so far, the analyst now asks *how* (using which means) this objective can be achieved. This may identify additional conditions for the client to be satisfied (e.g. have sufficient arable land, and fertile soil), and at the same time additional means for attaining an objective (e.g. switch to drought resistant crops and store water during wet season). Posing the *how* question is important because if nothing can be done to realize a certain objective, that objective does not provide a very promising starting point for a problem analysis as the problem owner apparently has no means to improve the situation.

By first asking 'why' and then asking 'how', a means-end analysis can, in principle, cover the whole spectrum from concrete to abstract, from very specific actions up to the fundamental objective. The result permits a deliberate choice for one problem level. In the drought example, the problem formulation might range from very broad ('ensure that the client has sufficient income') to very narrow ('create an efficient water storage facility'). The example in Text box 3.2 provides a complete illustration of this process and of how the resulting diagram helps in choosing the level of problem formulation.

Text box 3.2 City metro – Example of means-ends analysis
Suppose that the mayor of a city asks you to help him make more people use the metro. As an analyst, you will first ask the *why* questions, and then the *how* questions.

Q: Why do you want to stimulate the use of the metro?
A: To reduce congestion in the city center!

Q: Why do you want to reduce congestion in the city center?
A: To make the city more attractive!

Q: Why do you want to make the city more attractive?
A: Are you daft? Because I'm the mayor of the city!

Here you have reached a fundamental objective, as it is essential for your client. So now you start asking how questions:

Q: How can you make the city more attractive? Only by reducing congestion?

A: No, there are other ways. We are also considering renovating some of the older city districts, and upgrading parks and other public spaces, but congestion hinders both business and tourism, and therefore should have priority.

Q: Supposing that this is true (but you might want to have this checked!), is the metro line the only means for reducing congestion? Some cities have effectively implemented congestion levies, or have reduced congestion by regulating freight delivery, barring trucks during rush hours.

A: No, but it might be worth investigating. We are considering creating additional Park and Ride facilities in the city's peripheral zone.

You can summarize this dialogue in the means-ends diagram of Figure 3.3. It shows that the problem of getting more people to use the metro is embedded in another problem (the congested city center), which in turn is part of a large problem (the city being unattractive for business and tourists). It might be that some of the other means are more effective than stimulating the use of the metro system. In general, it is sensible to choose an objective on a more fundamental level because then the analysis will include a broader spectrum of important objectives, and hence a broader spectrum of means will be taken into account.

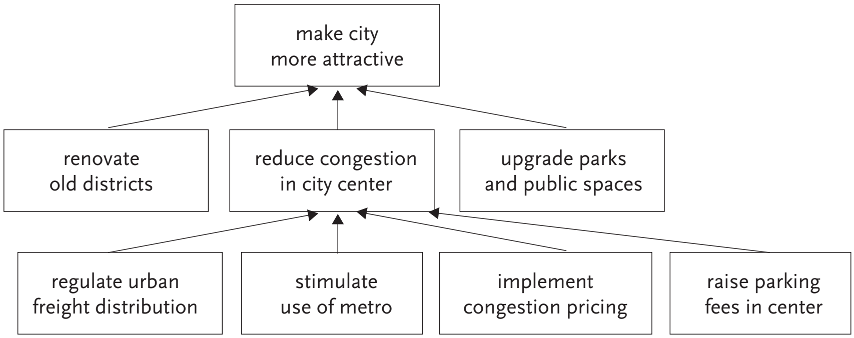

Figure 3.3 Upper part of the means-ends diagram

For a complete means-ends analysis, you would now ask the *how* question for the other two second-level means/ends, and for each of the four third-level means/ends. But assuming that your client (the mayor of the city) prefers to focus on the objective 'stimulate use of metro', repeatedly asking the question '*How* can you realize that goal?' could lead to the means-ends diagram in Figure 3.4.

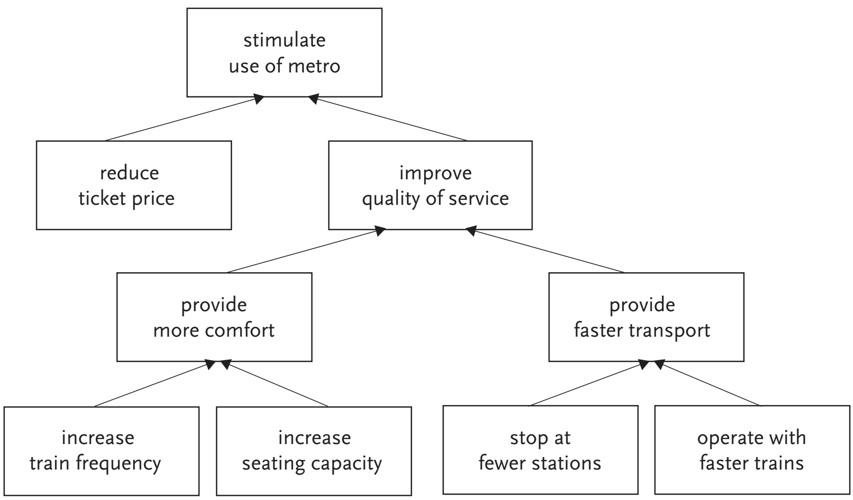

Figure 3.4 Lower part of the means-ends diagram

Rules for Constructing a Means-Ends Diagram

All diagramming techniques require that the analyst obeys certain notational rules. Only when this convention is followed will the diagram be meaningful to other analysts and permit logical interpretation. For means-ends diagrams, the following rules apply:

1. Rectangles denote means/ends. The text in a rectangle should be a verb phrase ('stimulate ...', 'improve ...', 'reduce ...') because this preserves the ambiguity of a means/ends: a verb phrase can be read as a means ('*we can* improve the

quality of service') and also as an objective ('*we want to* improve the quality of service').

2. Arrows denote causal relations: it should be possible to read each arrow X → Y as in 'if we do X, this will help to Y', or (if the causal relation is less certain) 'if we do X, this will probably Y' or 'if we do X, this may Y'.
3. Arrows should point upwards. This rule guarantees that the most fundamental objectives are at the top of the diagram.
4. More than one arrow may proceed from the same rectangle. This rule is useful because it may be that one means can contribute to the realization of several objectives.
5. Each rectangle should have either none or more than one ingoing arrows. This rule prohibits that the diagram suggests that an objective Y can be realized by only one means X. If that were the case, Y could be replaced by X, as the client has no choice. This rule forces the analyst to keep the diagram as simple as possible.
6. The diagram should not contain redundant arrows. An arrow X → Z is redundant if the diagram also contains some indirect path X → Y → ... → Z. Combined with rule 3, this rule forces the analyst to place elements at the correct level, and to keep the diagram as simple as possible.

Interpreting Means-Ends Diagrams

A means-ends diagram can help to choose the appropriate level for analysis by selecting one particular objective in the means-ends hierarchy as the *focal objective*. In general, this objective should be fundamental enough to enable the problem owner to undertake different actions to solve a problem without introducing considerations that are clearly irrelevant and that will add unnecessary complexity to the analysis. Note that this means that you cannot choose one of the lowest means/ends as the focal objective; if you do want to focus on one of these, then you should identify additional means. This is usually possible: looking more closely at even the most straightforward means (for example, 'reduce ticket price' in Figure 3.4) as an objective will still reveal a diversity of means for achieving it (lower fares only outside rush hour, city passes for tourists, free transport for students, ...).

One way to test whether a particular objective Z is suitable as focal objective is to ask the client the following questions:

- 'Do you agree that it is desirable to Z? And that when you succeed in achieving Z, your main problem is solved?'
- 'Do you agree that Z can be achieved by doing M_1, M_2, ... (the means immediately below Z)? And that you indeed have the means to do this?'
- Do you agree that at this moment you lack the knowledge to decide whether you should either M_1 or M_2 or ..., or a combination of these means?

These questions test whether the conditions for a policy problem mentioned in Section 1.2.2 are met: the gap between an existing or expected situation and a norm (the objective Z), and the dilemma: the expectation that something can be done about the gap, but uncertainty about the best way to proceed. If the client disagrees on some of the questions, you shift the focus to another objective in the means/ends diagram.

It is important to realize that even an elaborate means-ends diagram is only a 'quick scan' of the client's problem. Even when you agree on what should be the focal objective, it is wise to also make problem formulations based on the goals on the immediately adjacent levels because this will bring out the dilemmas involved. The arrows in a means-ends diagram represent only the desirable causal relations; potential side effects of means are ignored. A problem formulation of the form 'How can the client achieve [focal objective Z] without [undesirable side effects of the means immediately below Z]?' makes the dilemma explicit. Taking the objective 'stimulate use of metro' in Text box 3.2 as the focal objective, this might result in something like:

> 'How can metro use be stimulated *without* incurring operating losses?'

or, if the mayor is concerned with the safety of passengers:

> 'How can metro use be stimulated *without* people getting crushed during rush hour?'

The objective on the next higher level in the means-ends diagram would produce different dilemmas. Considering the side effects of regulating freight traffic, a possible problem formulation could be:

> 'How can the traffic congestion in the city center be reduced without hampering commercial transport?'

The idea of congestion levies may raise concerns regarding the high investments needed to implement large-scale congestion mitigating measures:

> 'How can the traffic congestion in the city center be reduced without incurring large financial costs?'

As raising the parking fees in the city center may lead drivers to look for parking space in the peripheral districts, this means introduces yet another dilemma:

> 'How can the traffic congestion in the city center be reduced without causing nuisance in other parts of the city?'

Discussing these problem formulations with the client will be very helpful in deciding on which problem the analysis should focus on.

Other Aspects of Problem Demarcation

Demarcations do not only comprise the relevant level of analysis in terms of the means- and end objectives to be considered but also demarcations in space and time.

Spatial demarcations focus on the physical scope of the problem field. The geographical area affected by the problem is relevant when it comes to closer analyses. For example, is it wise to consider only the traffic congestion in the city center? Here, again, a critical attitude is desirable: has the question of whether the problem is local, regional or national been considered; which spatial scale is most appropriate for the best solutions? Could it be that the causes of the problem lie outside the area where the problem is felt? Then that is where the most interesting solutions can be found, so the geographical area should be widened. And even if only local measures are taken, do these have consequences for a larger area? If so, this would also call for a wider demarcation.

Temporal demarcations focus on the time frame within which one analyzes the problem. This demarcation is not always as clear because there is a strong interdependency between the different choices in problem formulation. The time frame is not only determined by the question of when the problem arises, but also by the characteristics of the solutions that are being looked at. For example, changing the metro fares can be done within months whereas constructing a new metro line is a matter of five years or more.

3.3.2 Step 2: Specify Objectives and Criteria

The means-ends analysis will have helped to determine the focal objective for the problem analysis. When this objective is abstract or encompasses multiple aspects, it needs to be defined in more specific terms. For this, an additional method for analyzing objectives is used: the objectives tree.

Objectives trees help analysts to find, in a relatively simple way, an answer to the question: *what exactly* does the actor want? It helps the analyst to define a high-level, abstract objective in terms of more specific lower-level objectives. The lowest-level objectives in the tree provide the criteria to be used for measuring the degree to which the client's objectives are being met. These criteria can then be used to compare and evaluate different means and combinations of means.

Constructing an objectives tree begins by considering the focal objective selected in the means-ends diagram and then making one or more problem formulations that make the client's dilemmas apparent. The next step is to define both the desired change (the client's focal objective) and the undesirables side effects (the 'without' part of the problem formulations) as objectives. Since the aim is to obtain criteria, these objectives should be defined in such a way that they show what *factors* are concerned (see Section 3.2.2). Taking again the example of the problem of the mayor who would like to see more people use the metro (see Text box 3.2), we could decide to define only one objective: 'more passengers', which would then give us a single criterion: the number of passengers, measured in passengers per year. However, the problem formulations we made revealed that the mayor not only wants to see many passengers on the metro, but also wants to keep the operating loss within limits, and avoid the metro becoming so crowded that people get crushed during rush hour. The objectives tree in Figure 3.5 reflects that these three objectives together define the mayor's main objective: *better* use of the metro line in her city.

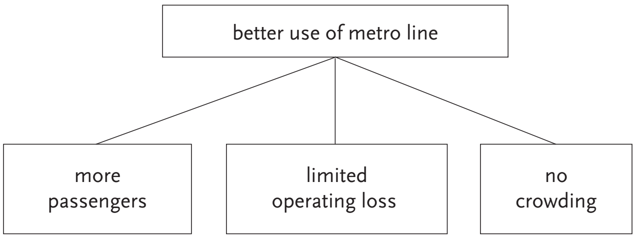

Figure 3.5 An objectives tree with two levels

This rather simple objectives tree illustrates how the abstract qualification 'better' is defined in terms of targets for concrete, measurable factors: the number of passengers (should increase), the operating loss (i.e. the cost of operating the metro minus the revenue from tickets, measured in euro; this amount should be relatively small), and the occurrence of crowding (e.g. the number of times per year that there are more than 3 people per m^2 on a train; this number should be zero).

If we apply the same method to the mayor's higher-level objective to reduce traffic congestion in the city center, we might again settle for a single objective: less traffic congestion. This would produce the simplest objective tree possible: a single rectangle. We would then still need to operationalize the factor 'traffic congestion', for example by measuring it as the total length of time (in hours per year) for all main streets that the traffic in these streets moves at less than 15 km/h. By doing so we would have properly defined the single criterion for measuring the extent to which the congestion problem has been solved. But here, too, the different problem formulations we made revealed several dilemmas, and these should be articulated in the objectives tree. The upper part of the tree in Figure 3.6 summarizes that the mayor wants to reduce congestion, but without restricting commercial traffic and causing nuisance in other city districts, and with low financial risk. Note that the main objective now does not mention the factor 'congestion'; this is because the four second-level objectives span a much broader range of factors. As the objective 'no nuisance for other city districts' is still rather abstract, it has been elaborated further.

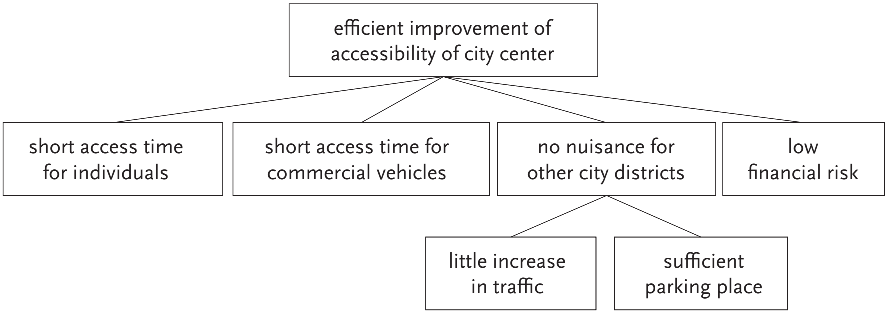

Figure 3.6 An objectives tree with three levels

Constructing an objectives tree is a process of 'finding the right words'. Having expressed the client's dilemmas in one or more problem formulations, the analyst defines a first level of objectives that represents what the client wants to achieve and what the client wants to avoid. The next step is to define a more abstract objective that encompasses all of this, and yet is as specific as possible. This then becomes the 'root objective' for the objectives tree. The analyst then checks whether each objective at the lower level is operational, i.e. that the factor it entails can be measured and expressed on some unit scale. If so, then this factor is a usable criterion, and no further elaboration of the objective is needed. Otherwise the analyst tries to formulate two or more objectives that clarify its meaning. If in this way new objectives have been added, the procedure is repeated.

Rules for Constructing an Objectives Tree
For objectives trees, the following rules apply:
1. Rectangles denote objectives. The text in a rectangle should be a noun phrase that indicates a desired state (e.g. 'high …' or 'good …') or a desired state change (e.g. 'less …', 'faster …'). To avoid confusion with means (i.e. actions the client can take), verbs should *not* be used.
2. Connecting lines denote definition relations: lower-level objectives specify the meaning of the higher-level objective to which they are directly connected.
3. Each objective should have either zero or more than one sub-objectives. If an objective Y can be defined in terms of a single sub-objective X, then Y should be replaced by X. This rule forces the analyst to keep the diagram as simple as possible.
4. The lowest-level objectives should be operational: the noun phrase in these rectangles should make clear which factor is to change (or not change) as well as the direction of the desirable and undesirable changes, and the factor concerned should be measurable on some scale (preferably ISO standard units).

Objectives Tree ≠ Means-Ends Diagram!
As both diagrams relate to objectives, and both consist of rectangles that are arranged in levels and linked by edges, the objectives tree is easily confused with a means-ends diagram. However, the two serve very different purposes: a means-

ends diagram is used to decide which problem to focus on; an objectives tree is then used to define the criteria for evaluating alternative solutions for this problem. Given these different functions, the diagrams must be constructed and interpreted following different principles.

Because objectives can also be seen as ways to realize some higher level objective, a means-ends diagram can be read in two directions. When read from top to bottom, a means-ends diagram clarifies for each objective *how* that objective can be achieved. Reading a means-ends diagram from bottom to top clarifies *why* it is desirable to realize an objective. The relation denoted by an edge $X \rightarrow Y$ is a *causal* relation: it is a *directed* relation (up!) to reflect that X leads to Y, and not the other way around.

An objective tree should only be read from top to bottom, and then it clarifies the meaning of a still abstract objective by specifying two or more concrete objectives that can be considered as 'composing elements'. The relation denoted by the edges is a *definition* relation: a cluster of edges departing from a higher-level objective X to two of more lower-level objectives Y_1, Y_2, ... reflects that the extent to which objective X is realized can be measured by measuring the extent to which Y_1, Y_2, ... are realized.

Interpreting an Objectives Tree

The main function of an objectives tree is to define the objectives of an actor (the client or some other stakeholder in the policy problem) in such detail that the analyst can infer the set of criteria that need to be considered when evaluating alternative solutions. In essence, the interpretation of an objectives tree consists of compiling this set of criteria. Assuming that the objectives tree has been properly constructed (i.e. following the rules mentioned earlier), all of the 'leaves' of the tree (i.e. the objectives that are not defined in terms of more concrete subobjectives) each produce one criterion, while the 'internal nodes' of the tree (i.e. all objectives that are not 'leaves') can be ignored. Interpreting an objectives tree thus consists of listing the criteria that should be used in the problem analysis. For each criterion, a suitable unit scale should be specified. These units are usually denoted between brackets. Text box 3.3 shows the criteria lists derived from the objectives trees in Figures 3.5 and 3.6.

Text box 3.3 Different problem formulation $\Rightarrow$ different criteria

Criteria derived for the problem of stimulating the use of the metro:

- number of metro passengers [passenger / day];
- operating loss [€ / year];
- number of crowding incidents [crowding incident[a]].

[a] A crowding incident is defined as a situation in which the density of passengers in a metro train exceeds 3 persons per m^2.

Criteria derived for the problem of traffic congestion in the city center:

- access time for individuals [minutes[b]];
- access time for commercial vehicles [minutes[b]];
- number of vehicle entering/leaving a district [vehicle / day];
- availability of parking space [% vacant places[c]];
- estimated project cost [€].

[b] Average time needed to cover the last 2 km to destination in city center.

[c] Average of vacant places / total parking places, measured at 11 a.m.

Being a factor, a criterion should be denoted as a noun phrase that refers to a specific system property. For typical objectives like ‘lower nitrate emissions to groundwater’, ‘higher crop yield’, ‘more profit’, and ‘less litter on the streets’, the criteria are easily obtained by omitting the word ‘lower’, ‘higher’, ‘more’ or ‘less’. For objectives ‘more passengers’ and ‘fewer drop-outs’, the factors are tallies (i.e. they count discrete entities), in which case the word ‘more’ or ‘fewer’ should be replaced by ‘number of’ to obtain a well-defined criterion. An objective that needs a little more translation effort is ‘less frequent power failures’. The criterion would then be ‘frequency of power failures’ (measured in failures per year), but one could also opt for ‘mean time between power failures’ (measured in days). Note that for the first criterion, low values are better than high values, whereas for the second criterion, high values are better than low values. The commonly made mistake to operationalize ‘traffic safety’ by measuring it in terms of casualties per year highlights that the analyst should take care in choosing an appropriate unit of measurement for a criterion.

While interpreting the objectives tree, the analyst should also pay specific attention to the *independence* of the criteria. When criteria are not independent of each other (e.g. ‘NO_x emission’ and ‘NO_x concentration in the air’, or ‘average duration of traffic jams’ and ‘length of traffic jams’), or when a criterion is included in another, broader criterion (e.g. ‘concentration of aerosols’ and ‘concentration of small particle matter’), this entails that this system characteristic will ‘count double’ when alternative solutions are evaluated using the list of criteria. In that case, a choice will have to be made between accepting the aggregated criterion ‘quality of air’, or elaborating the quality of air into a number of suitable parallel criteria. Such problems of overlapping criteria, or criteria that are causally related, are less likely to occur when the objectives tree has been properly constructed.

Using Proxies as Criteria

Some criteria are intrinsically difficult to measure. In such cases, it can be useful or even necessary to work with proxies. A proxy is a measurable factor that is believed to give a good indication of the realization of the actual objective.

Text box 3.4 Using proxies as criteria

The use of fertilizers in agriculture constitutes a problem for the environmental movement because the residues of fertilizers seep into surface waters, degrading the environment. In this case, one might suggest as a criterion the quantity of fertilizers that seeps into the surface water yearly. However, this factor will be hard to measure or observe directly, as this would require the installation of monitoring equipment next to every agricultural plot. Alternatively, the quantity of fertilizers that is introduced onto the land could be used. This would be justified under the assumption that the quantity that is seeps into the system is proportional with the amount of fertilizer.

A similar choice for a proxy as criterion can be made when analyzing the problem of environmental damage as a consequence of freight transport over the road. In principle, indicators for the *eventual* environmental consequences of freight transport – for example, respiratory problems for humans – should be used as criteria. Knowing that respiratory problems correlate with the concentration of certain substances in the air (aerosols, nitrogen oxides), the yearly emission of these substances may be chosen as a proxy for environmental damage.

The examples in Text box 3.4 clarify that the use of a proxy as a criterion leads to a narrower demarcation of the system that needs to be analyzed, and therefore to a less complicated analysis: the mechanisms in the natural environment do not have to be taken into account. The danger of using proxies is that they may not be representative of the degree to which the objectives are actually achieved. For example, death rate could well serve as a proxy for the status of public health. The death rate gives a fair indication, but there are many more factors at stake in public health! When the death rate is taken as proxy for public health, the analysis will overlook increases in health risks that are not immediately fatal (e.g. obesity). A similar problem occurs when the chosen proxy reflects the degree to which certain means have been put to use, rather than the degree of goal achievement. Consider for example using the number of doctors or hospitals per 1000 persons as an indicator for the public health. These kinds of faulty substitutions that produce misleading results occur more often than you would think!

The Multi-Actor Situation

We may find ourselves in the situation where we have to take into account *several* actors who may have different interests, and possibly conflicting objectives. This multi-actor aspect is addressed in detail in the next chapter, but we should mention here that its importance has also been recognized by systems analysts. For instance, Ralph Keeney indicates in his book *Value-Focused Thinking* (1992), which is almost entirely devoted to the analysis of objectives and means, how a so-called 'overall objectives hierarchy' can be deduced by combining and structuring the criteria from the objectives trees of different actors in a problem context. This kind of joint hierarchy of objectives allows the analyst to evaluate alternatives while considering the objectives of all stakeholders involved.

The following small example illustrates this approach. Three actors are stakeholders in the issue of further developing a local airport A near city C. The management of airport A wants to construct a second runway in order to improve its turnover and its competitive position. The city council of C wants more employment, but also a good living environment for its inhabitants, more specifically no noise nuisance, and good air quality. The environmental organization E wants to protect the bird species that breed in the area, and therefore no noise nuisance and no more air pollution. An operationalization of these objectives could result in the following list of criteria:

- turnover of airport A [€ / year];
- number of new jobs near C [job];
- number of houses exposed to more than 70 dB(A) [house];
- emissions of small particle matter [kg / year].

The environmental organization is hardly interested in the effects on the first two criteria. As a firm, the airport is interested in the last two criteria only because neglecting this aspect is bound to lead to lengthy legal procedures that would lead to delays. The municipality will be interested in the last three criteria. By working with the whole set of criteria, the analyst can perform research and prepare evaluations that are interesting and acceptable for all three actors.

3.3.3 Step 3: Identify Means and Map Causal Relations

Now that it is clear what we want to achieve, through the identification of objectives and the specification of associated criteria, we should investigate the elements that influence the realization of these objectives. The means-ends diagram constructed at the beginning to support the first problem demarcation and identification of an appropriate level of analysis provides a starting point. However, in almost all cases, it is sensible to develop a more elaborate 'map' of the causal chains in the system that link means to criteria.

A causal map depicts the causal relations between the factors that are relevant to the problem. It supports a qualitative form of 'what if?' analysis that is helpful in understanding the effects of means and/or external factors on other factors, notably the criteria (Montibeller & Belton, 2006). Furthermore, a causal map often provides a good starting point for quantitative models that might be developed later in the process of problem solving.

The basis for a causal map is a 'theory' about how a system works. Usually, this theory is a mental model produced by the researcher/analyst, complemented with knowledge from literature research, interviews and experts about the essential causal mechanisms of the system that are relevant to the problem. The criteria resulting from the objective tree and the means identified in the means-ends analysis offer good starting points for the construction of the causal map. Potential solutions are aimed at changing the criteria in the desired direction, and by doing so close the gap that is at the heart of the problem. Reasoning backwards from the list of criteria is therefore a sensible approach when elaborating a causal map. Here the same question keeps being asked: which factors influence X?

During the problem formulation and problem demarcation, a causal map should remain limited to those factors that are most relevant to the problem and its solution. It is easy to get carried away while drafting a causal map, trying to represent all aspects of the problem in detail. However, excessive detail renders the map useless as a tool for clarification and communication. It is therefore advisable to choose a rather high level of aggregation. A general rule of thumb is that a causal map becomes difficult to interpret when it contains more than twenty elements. If the system is so complex that more factors are really needed to capture its main elements and structure, it is advisable to develop different causal maps for different 'subsystems' and for different levels of aggregation.

When thinking about which factors to include in a causal map, keep in mind that causal analysis is about understanding how changes in one factor result in changes in other factors. This implies that you should focus on factors that can change; constants can be ignored. A second consideration is that only those factors that have a significant influence on one or more criteria need to be included.

The causal map in Figure 3.7 shows the intermediary result of starting a causal map from the criteria derived from the objectives tree in Figure 3.5, and then for each of these factors X repeatedly asking the question 'what factors can cause X to change?'. Each newly identified factor Y is then added to the map, and the causal relation $Y \rightarrow X$ is depicted by an arrow. This arrow is then labeled with a sign: a '+' to denote that if the value of Y increases, the value of X will also increase (positive correlation), or a '–' to denote that if the value of Y increases, the value of X will decrease (negative correlation). This process is repeated for all factors that can *not* be directly influenced by some means of the client.

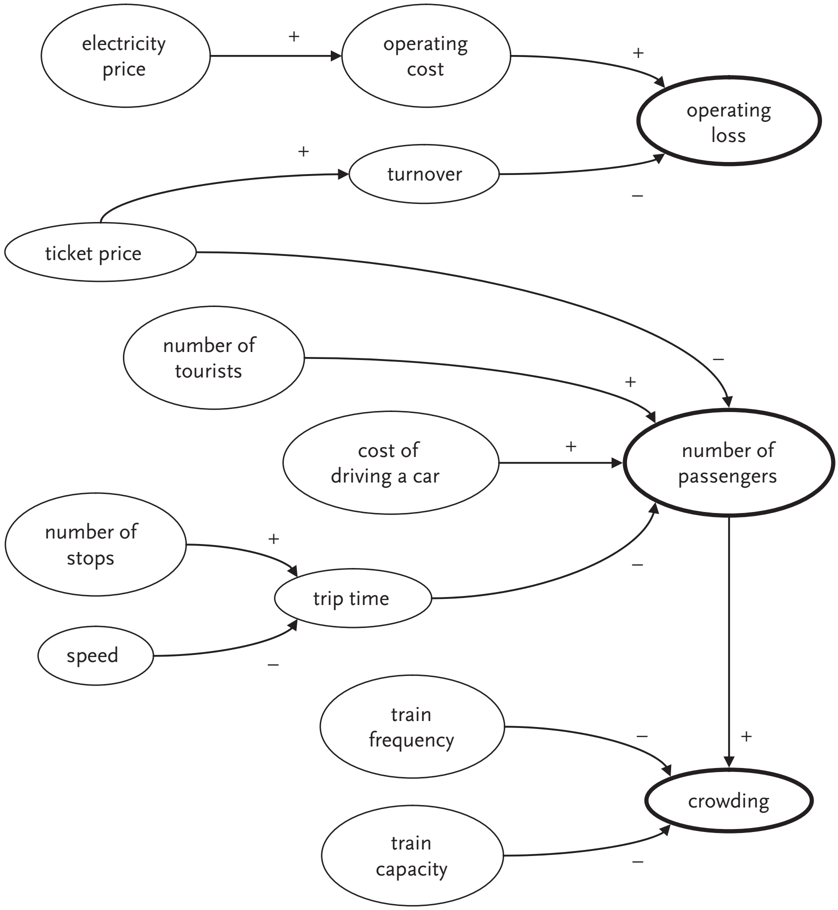

Figure 3.7 Intermediate result of causal mapping

The process of 'backwards reasoning' is then followed by a process of 'forwards reasoning' by asking for every factor X 'what other factors change when X changes?'. As can be seen in Figure 3.8, this can lead to adding numerous causal relations. Thinking in this way may also reveal additional side effects (new factors), and if these turn out to be of interest to the client, they should be added to the list of criteria. When constructing a causal map, it is advisable to document the underlying assumptions, because causal assumptions that may seem self-evident to the analyst may not be obvious to others.

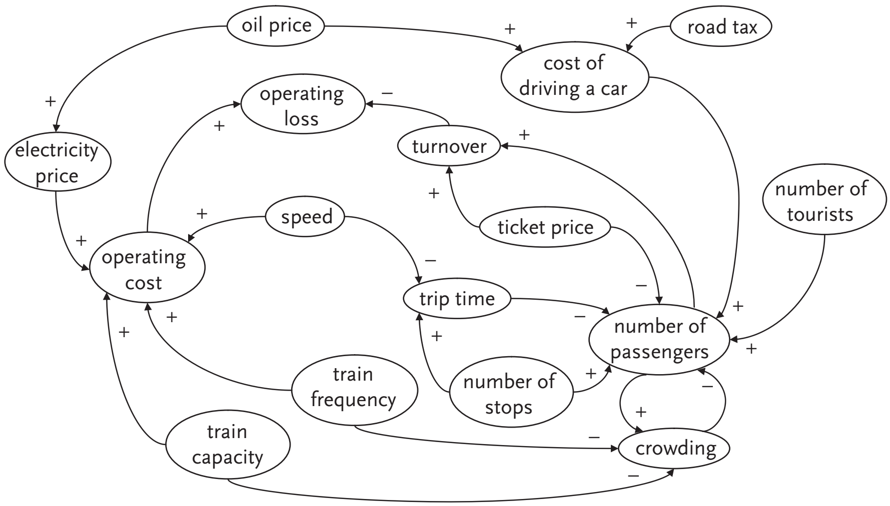

Figure 3.8 A completed causal map

Rules for Constructing a Causal Map

For a causal map, the following rules apply:

1. Ovals denote factors. The text in an oval should be a noun phrase that denotes some variable system property. Each noun phrase F should be such that the sentence 'F increases.' is grammatically correct and meaningful.
2. Arrows denote causal relations. Each arrow X → Y should signify that a change in X will result in a change in Y.
3. Each arrow X → Y should be labeled with either a plus (to denote that the values of X and Y are positively correlated) or a minus (to denote a negative correlation).
4. Each oval should be connected to at least one other oval.
5. To enhance legibility of the diagram, crossing arrows should be avoided as much as possible.
6. If the diagram contains an arrow X → Z and also some indirect path X → Y → ... → Z, then the analyst should justify this multiple causality by explaining that the two paths have different underlying causal mechanisms. This rule forces the analyst to keep the diagram as simple as possible.

Interpreting a Causal Map

The main function of a causal map is to provide an overview of the factors and causal relations that are relevant for the client's problem and therefore need to be considered in the problem analysis. The analyst uses the diagram first to find out to what extent the client distinguishes the same factors and, if not, what the differences are, and whether this has implications for the problem formulation and system demarcation.

Having established that all elements of the causal map (factors and relations) make sense, the analyst should verify whether the causal relations denoted by the arrows occur within the time frame set by the problem demarcation. If an effect is expected to occur so slowly that it is not significant on the time scale selected for the analysis, it is advisable to remove the arrow involved.

The next step is to scan for loops: causal paths that start from some factor X and eventually join this same factor X again. Figure 3.8 contains one such loop, involving only two factors: 'number of passengers' and 'crowding'. Such loops denote a dynamic feedback mechanism. The type of feedback can be determined by counting the number of minus signs along the cyclic path. An even number (this includes 0) indicates positive feedback, and odd number indicates negative feedback. Positive feedback means that over time the effects of changes that affect any of the factors involved in the loop may be amplified; negative feedback means that these effects may be reduced. The loop in Figure 3.8 suggests the latter: when more people start using the metro, this increases crowding, and this is expected to deter people from using the metro, which reduces crowding.

Having checked for loops and the ensuing possibility of non-linear system behavior, the analyst should also check whether the causal map contains factors X and Y linked by more than one causal path X → ... → Y. If these paths have opposite signs (as is the case for 'number of stops' and 'number of passengers' in Figure 3.9), this raises the question of which influence is stronger.

Besides providing an overview of factors and relations, a causal map facilitates the search for means for attaining objectives. The set of means identified while constructing the mean-ends diagram is usually incomplete. The causal map permits a more systematic search: for each factor X, the analyst poses the question 'How can the client change the X?'. For some factors, this may reveal several means, for others none. Some factors may be affected by the same means. The resulting list of means can be integrated with the results of the other analyses (criteria, causal map) in a system diagram.

3.3.4 Step 4: Overview of the System and Its Boundaries

The primary function of a system diagram is to summarize the system demarcation by showing the elements that are relevant for the problem analysis. These elements come in four categories: **criteria** (the factors whose values indicate to what extent the problem has been solved), **external factors** (factors that cannot be influenced by the client, but do affect one or more criteria), **means** (actions of the client that affect one or more criteria), and **internal factors** (all other factors that play a role in the causal chains that affect the criteria). The first three categories (criteria, external factors, and means) are often said to be *on* the systems boundary, as they are depicted as such in the system diagram. As mentioned at the start of this chapter, the means are placed on the left side of the diagram, external factors at the top, and criteria on the right side of the diagram. Being a complete summary of the results of the exploratory systems analysis, it constitutes the basis for further analysis, but also a useful tool for communicating about the system demarcation with the client, fellow analysts or other actors.

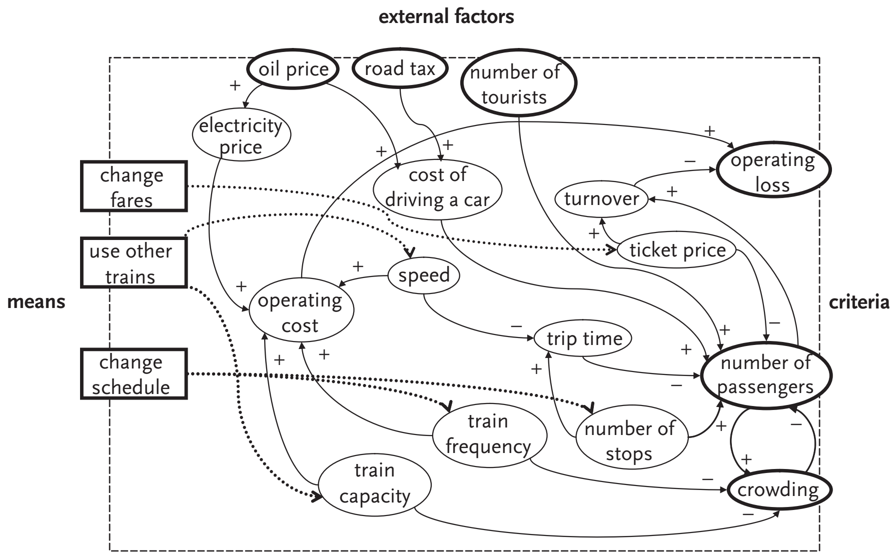

Figure 3.9 The system diagram

Figure 3.9 depicts a system diagram that summarizes the results of the city metro example. It shows that three means have been identified, and that these allow the client to directly affect the factors 'ticket price', 'speed', 'train capacity', 'number of stops' and 'train frequency'.

Because the system diagram also represents means, and because the placing of factors is more constrained than for a causal map (means on the left, criteria on the right, external factors at the top), it can become unclear due to crossing edges. For complex problems, it is advisable to hide clusters of factors by depicting them as 'subsystems' as shown in Figure 3.10. In this case, only the factors that link two or more subsystems (with unsigned arrows, as the '+' and '–' only make sense between two factors) are shown. The factors and relations that remain hidden in this 'upper level' system diagram should be shown in separate diagrams, one for each of the subsystems.

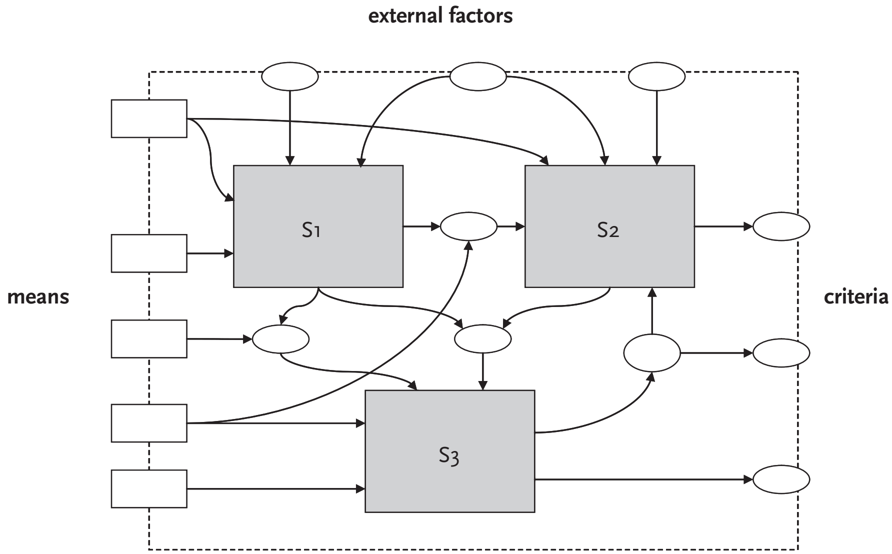

Figure 3.10 A system diagram with subsystems

Interpretation of a System Diagram
A system diagram is used in the first place to summarize the findings from the means-ends analysis, the client's objectives tree and the causal analysis. It can also be used for qualitative analysis of the effect of using particular means, or of changes in external factors, on the criteria. To this end, the analyst selects a means or external factor X, and investigates, by following the causal path(s) from X, which criteria are eventually affected, and in what way. For each affected criterion Z, the effect (an increase or decrease of the value of Z) is assessed by taking into account the signs along the arrows as discussed in the previous section. Alternatively, the question 'How can we increase criterion Z?' can be answered by following the causal chains back to specific means and/or external factors. It may be useful to tabulate the findings in a consequences table like the one in Table 3.1, to see in a glance which means affect which criteria in which way.

Table 3.1 A qualitative consequences table

Criteria→ ↓ Means	**C1**	**C2**	**C3**	**C4**
M1	+		–	
M2	+	+		
M3	–			+
M4		+	+	
M5		+/–	–	
M6			+	+
M7				–

Systems

The Multi-Actor Situation
In Section 3.3.2, we showed how a broader set of criteria can be defined by taking into account the problem perceptions of several actors, typically the client and a selection of stakeholders. This broader set may of course also be used as the starting point for making a causal map, and eventually result in a system diagram that comprises the means and criteria of all of these actors. This multi-actor system diagram can be constructed and interpreted following the same principles. However, the following points are worth pointing out.

When a system is viewed from a single actor's perspective, all actions of all other actors are represented using factors and causal relations. For example, when the client is a local water authority that considers enforcing anti-pollution laws more strictly, other actors, such as the industry that discards its wastewater into the river, are assumed to comply, for example by installing filters. In a causal diagram, this would typically be represented as a minus-labeled causal link 'enforce more strictly' → 'emissions from industry'. When the analyst also wants to include the perspective of the industry in the system diagram, the possible actions of this new actor (e.g. installing filters) should be added as means. To properly represent the interplay between the local water authority and the industry, the rationality of the industry should be made explicit. The extended diagram should reflect that installing filters costs money and hence negatively affects the industry's main criterion: profit. So why would the industry install filters? The answer could be that the local water authority can fine the industry if it does not comply with the anti-pollution act. To articulate that the industry is sensitive to this financial incentive, the diagram could be extended further by adding a link from the industry's means 'install filters' to a factor 'compliance with norms', followed by a link from this factor to the industry's profit criterion to reflect that non-compliance also costs money. Adding a link from the means 'enforce more strictly' to 'non-compliance' then reflects that when the local water authority uses this means, the industry's profit will decrease unless the industry installs filters.

In a single-actor system diagram, actions of other actors (or rather, the immediate effects of these actions) will typically be represented as external factors if the client has no means to control these other actors. When the system diagram is extended to include the perception of such an actor, the actions of this actor become means (and hence should be represented at the left side of the diagram), while the factors that represent the effects of the actions move 'inside' the system: they change from external factors to internal factors.

Finally, when interpreting a multi-actor system diagram, it is important to keep track of which actor takes an interest in which criterion, as different combinations of means may distribute the costs and benefits differently across actors. The methods for identifying and dealing with this multi-actor aspect will be discussed in detail in the following chapter.

References

The contents of this chapter are also discussed, more extensively, in the book *Inleiding technische bestuurskunde* by A. de Haan et al. (published by LEMMA, The Hague, 2009), and the lecture notes 'Introduction to Systems Engineering, Policy Analysis, and Management' by P. W. G. Bots (published by the Faculty of Technology, Policy and Management, Delft University of Technology, Delft, 2003).

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