Embedded Case Study Methods

Integrating Quantitative and Qualitative Knowledge

Embedded Case Studies involve more than one unit, or object, of analysis and usually qualitative and quantitative methods. In the sub-units, which focus on different salient aspects of the case, a multiplicity of different methods can be applied. This book presents a number of such Methods for Embedded Case Studies.

The case and the problem to be investigated and the objectives of the investigation determine the selection of the method. The selection depends on the characteristics of the sub-units whether they require

- a description of the problem or an evaluation of possible solutions
- a determining perspective of the study team or the case agents, or
- a mainly objective scientific attitude towards the case.

The road map below shows which methods of embedded case studies are appropriate, if a certain combination of these characteristics occurs.

Distinctions are made between four different types of knowledge integration: Disciplines, Systems, Modes of Thought, and Interests.
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THE RATIONALE

Formative Scenario Analysis is a scientific technique to construct well-defined sets of assumptions to gain insight into a case and its potential development. Scenarios can be constructed for any kind of case. The term *scenario* originates from the Greek word σχέδιο, which was used to refer to an outline of a play or a stage script. Formative Scenario Analysis provides a script describing steps that a study team must take in response to the current state and possible future states of a case. Because the term *scenario analysis* is often overused and applied inaccurately in science and everyday language, the adjective *formative* is added to indicate that we are presenting a technique that is organized in a strictly systematic way.

The scenario technique was developed by Herman Kahn soon after World War II. At that time, Kahn was working for the RAND Corporation. RAND (an acronym for Research and Development) was one of 11,000 independent think tanks that advised the U.S. government in strategic planning (see Cooke, 1991). The scenario technique has been widely used in business, technology assessment, and environmental sciences (Batelle-Institute, 1976; Brauers & Weber, 1988; MacNulty, 1977; Minx and Mattrisch, 1996). However, it can be transferred easily to other fields.

Scenarios can answer two kinds of questions: "How might some hypothetical situation come about (step-by-step)?" and "What alternatives
exist at each step to prevent, divert, or facilitate the process [of case development]?" (Kahn & Wiener, 1967, p. 6). Scenarios are constructed for the purpose of focusing attention on causal processes and decisive points.

A scenario describes a hypothetical future state of a system and provides information on its development up to this state. This is done by introducing so-called impact factors. An impact factor is simply a system variable that describes the current state and dynamics of the case. Impact factors are also called impact variables. The art of scenario analysis consists of creating a sufficient set of impact variables and linking the variables in such a way as to gain a valid case description.

A scenario may contain qualitative and/or quantitative statements. Techniques for judging the probability of scenarios have been developed (see Helmer, 1977), as we will see. Nevertheless, the focus in scenario analysis is clearly on possibility. It is noteworthy that Kahn, who understood the basis of decision making and probability theory quite well, considered both approaches inadequate because complex case analysis is usually performed in groups, and the result relies on the opinions, assumptions, hypotheses, and suppositions of the groups' collective reasoning (Mieg, 2000, p. 75). However, concepts such as subjective probability and subjective utility were constructed for an individual, and the classical theory of probability and utility does not offer any procedures for assessing joint group probability or utility function (Cooke, 1991, p. 10). Simple averaging of event probabilities is not allowed, as the example of conditional probability shows (Scholz, 1987, p. 29). Although these arguments may be disputed, probability statements do not play a significant role in the scenario-analytic approach. In general, scenario analysis provides consistent hypothetical future states of a case and should not be mixed with traditional methods of prognosis, such as time series. A specific method for analyzing continuous case dynamics will be presented in Chapter 10 on System Dynamics.

The starting point for a scenario analysis is the case in its existing state. The state of the case varies depending on the changes in and development of its internal and external system variables. The more time that has passed, the greater the change and deviation from the case's initial state. This is displayed in the scenario trumpet (Figure 9.1). Disturbances or interventions can affect the discourse and future state of a case.

The Formative Scenario Analysis procedure guides the study team toward a differentiated and structured understanding of a case's current state and its dynamics. It is usually performed by small groups with
specialized expertise about different aspects of the case, which they share with one another.

According to the concept of the Brunswikian Lens Model (see Figures 4.2 and 9.2), the procedure requires that the study team specifies the case clearly, identifies its problems, and poses relevant questions. In Brunswikian terminology, the case and its problems are called the initial focal variable, whereas the study team’s construction of future states is labeled the terminal focal variable. It is crucial that the whole study team knows what the focal variables are and remains aware of them throughout the study. This holds particularly true for the terminal focal variable because a common fixed future date is required in all constructions.

In the analytic decomposition, the study team is required to construct a sufficient set of impact factors or impact variables (see Box 9.1). Impact variables are used to construct a simple system model of the case. When
selecting impact variables, the study team should particularly strive for sufficiency. As Brunswik's label *stray causes* implies, complete reliability does not exist in the process of constructing and selecting impact variables. However, the process of vicarious mediation provides an opportunity to organize the synthesis in a robust way. As mentioned before, vicarious mediation can be achieved if the impact variables are constructed in such a way as to partially supplement each other. Thus, there will be some redundancy, which allows for mutual substitutability, or vicarious functioning. The process begins by creating networks of the impact variables. In order to attain an encompassing system model of the case and organize vicarious mediation, the impact variables must be interlinked by a network.
In the course of a case study, the study team is required to construct a sufficient set of variables or factors for case modeling and/or evaluating the case.

The term sufficient is defined precisely in statistics (see Mood, Graybill, & Boes, 1974, p. 300). In general, a statistic denotes a function of observable random variables that does not contain any unknowns.

Let us consider a random variable, \( q \), that provides the sample \( X_1, X_2, \ldots, X_n \). If we find a function \( f(q) \) that tells us as much about \( q \) as the sample itself, this function is called a sufficient statistic. Let \( X_1, X_2, \ldots, X_{100} \) be a random sample provided by a normally distributed random variable. We know that a function, \( f(q) \) that maps these measurements into the two-dimensional set of real numbers providing the mean, \( \bar{x} \), and the standard deviation, \( s \), is a sufficient statistic.

Although in complex, real-world problems, the term sufficient may not be used in its strictest sense, the case analyst looks for a construction (this means, in an abstract sense, a function) that yields a set of variables that allows for sufficient system description, modeling, or evaluation. During this process, the case analyst has to obey the satisficing, rather than the optimizing, principle. This means that he or she has to seek a sample that satisfies his or her aspirations for precision and completeness in a robust way.

The whole study team usually performs the selection of the impact factors. However, definition of the impact factors and elaboration of the relations between the variables should be investigated individually or in subprojects. Thus, Formative Scenario Analysis usually requires an embedded case design (see Figure 4.1).

One key issue in the synthesis is the change in representation. This means that the synthesis process starts by confronting the study team with alternate representations of what has been constructed in the process of analytic decomposition and variable networking.

The construction of a consistent set of scenarios to fill the scenario trumpet is the final stage. In Formative Scenario Analysis, a scenario is formally defined by a combination of levels of all impact factors. Thus, the case study team also portrays those possible future states of the case, which could result as stray effects of the impact factors.
Formative Scenario Analysis is a nine-step procedure that should be worked through sequentially (see Figure 9.3). When describing the method, we will refer to the ETH-UNS case study on urban development, Zurich North, as an example (see Chapter 5).

**Step 1: Case and Goal Definition**

First, the study team must find a clear answer to the question “What is the case?” Sometimes, this question is not simple to answer. Many cases have fuzzy margins. In the case of the Zurich North site, for instance, the study team had to clarify whether or not Oerlikon Station was part of the case. Initially, the station owner, the Swiss Railway Company, was a member of the planning cooperation, and thus the station property was included in the case. However, before the beginning of the case study, the railway company withdrew, and so the case area became smaller.

Experience shows that it is best to specify the time and space limitations of a case. This is best done by providing a clear physical definition of the case. For the Zurich North site, we considered the case area to be the properties of those parties who, on April 1, 1996, were registered
members of the planning cooperation. A crisp physical case definition is an essential component of the initial focal variable.

Second, a specific perspective on the outcome of the case analysis (i.e., the terminal focal variable) must be determined. The critical question for this step is “Why is the scenario analysis being performed?” The answer to this question will define the terminal focal variable in the Brunswikian Lens Model. Note that different terminal focal variables require completely different system variables. We will illustrate this by introducing different levels of consideration of the case.

In the ETH-UNS case study Zurich North, we wanted to determine which future realizations of the case might be judged sustainable. However, this required a two-level scenario analysis. Because two-level scenarios are typical constructions for many case studies, what follows is a brief introduction into multilevel scenario analysis.

It is important for the future of a case to reflect on both the larger context in which development takes place (i.e., its frame, or shell) and the inner case activities and developments. This requires separating the variables of the case into two groups, those that are global in scope and those that are local. Defined bundles of levels of global impact variables provide shell scenarios (see Figure 9.4). For example, in the case of the ETH-UNS case study Zurich North, the shell of the case was the evolution of the Greater Zurich area. An example of one of the variables in the shell scenarios was Switzerland’s membership in the European Union.
The majority of the second group of variables often results from the decisions of the local case agents. Constructed sets of possible outcomes of these local variables are called variants.

Because many local decisions are dependent on the outcomes of global decisions, it is necessary to link the variants with the shell scenarios. The combination $V_m \times S_k$ of the variants, $V_m$, with the shell scenarios, $S_k$, is labeled $\text{set}_{m,k}$ (see Figure 9.4).

The distinction of case variants from global scenarios is also motivated by epistemological reasons, because the linkage of global variables (e.g., whether or not Switzerland will join the European Union) with microlevel issues (e.g., what level of architectural quality the buildings on the site should have) in one and the same model is not recommended.

Scenarios are often the objects of further evaluation. In order to have the appropriate information available for the evaluation procedure, the study team should already have thought about which evaluation criteria/variables are crucial at the very beginning of the study (see Box 9.2). In the ETH-UNS case study Zurich North, the specific perspective taken was provided by the guiding light of sustainable urban development. However, the reader may also think about more specific terminal focal variables, such as the lowering of the crime rate or the optimization of the water flux on a small site.

**LESSONS TO BE LEARNED**

- A concise case definition is indispensable. Even seemingly well-defined cases, such as companies, are often interpreted differently by different people. Often, physical characterization provides the best case definition. Each scenario of the case must be constructed for the same common fixed future date.

- Scenario construction must be functional. This implies that the question "What is the analysis for?" has to be answered at the very beginning of the study.

- It is often useful to construct local and global scenarios separately and then link them in a later step.
Box 9.2  Dependent and Independent Variables

The terms dependent variable and independent variable will be used throughout this book. Within Formative Scenario Analysis, for instance, scenarios act as independent variables, and the evaluations are considered dependent variables (see Hays, 1963, p. 39).

Scenarios are considered independent because the study team is free to construct a scenario in the domain of future possible states of the case. However, given a well-defined scenario, an evaluation of it is completely determined, making it a dependent variable.

Formally, the scenarios are denoted $S_k$ and the evaluations $v(S_k)$.

Step 2: System Properties

The scenario analyst must mentally delve into the case in order to determine the factors that establish the current state of the case and its dynamics. There are two proven strategies for determining these crucial impact variables.

One strategy is to perform a plus-minus analysis. Table 9.1 presents a cutout of the plus-minus analysis done for the Zurich North shell scenario analysis. Note that there is ambivalence over some issues. For instance, for certain financial transactions, Zurich's nonmembership in the European Union is positive because the Swiss franc has traditionally guaranteed a stable currency; however, the nonmembership hinders liberal trade and employment. Similarly, from the long-term perspective, high environmental standards should be considered positive, even though they may yet harm quick, environmentally questionable, but profitable constructions.

Sometimes, it makes sense to perform separate plus-minus analyses, because what may be considered strengths from an economic perspective might be considered weaknesses from a social or environmental perspective. Thus, two or more plus-minus analyses should be performed. Table 9.1 was developed while studying the salient documents of the municipal authorities (City of Zurich, 1995; Hochbaudepartement der Stadt Zürich, 1996) and business organizations (Bignasca, Kruck, Maggi, Schellenbauer, & Schips, 1996; Bretschger et al., 1995) on the future urban development of the Zurich area. The more extended version of plus-minus analysis is the Strengths-Weaknesses-Options-Threats (SWOT)
Table 9.1  Cutout of the Zurich North Plus-Minus Analysis

<table>
<thead>
<tr>
<th>Plus</th>
<th>Minus</th>
<th>Ambivalence Over</th>
</tr>
</thead>
<tbody>
<tr>
<td>• International finance and trade center</td>
<td>• Not perfectly integrated into the European railway net</td>
<td>• Switzerland is not a member of the European Union</td>
</tr>
<tr>
<td>• High living standard</td>
<td>• High cost of living</td>
<td>• High environmental standards</td>
</tr>
<tr>
<td>• Excellent research and development units, universities, etc.</td>
<td>• High wages in Europe</td>
<td>• ...</td>
</tr>
<tr>
<td>• International airport</td>
<td>• Outsourcing of industrial production</td>
<td></td>
</tr>
<tr>
<td>• Attractive and safe downtown areas</td>
<td>• ...</td>
<td></td>
</tr>
<tr>
<td>• High environmental awareness</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

analysis, which also can be conducted at this step of Formative Scenario Analysis.

Another strategy for grasping the case structure and its dynamics is to study formerly planned projects or interventions. Usually, several plans for improving the case already have been proposed. Each plan generally provides insight into the structure and dynamics of the case, highlighting the case's potential while revealing sensitive features and factors that could have an impact on case development.

For the ETH-UNS case study Zurich North, studying the booklet Ziele der Stadtentwicklung (Goals of Urban Development) (Hochbauamt der Stadt Zürich, 1996) was very helpful. It contained a list of more than 50 helpful plans and suggested actions, such as ensuring work permits for foreign specialists, securing the existing supply of apartments, and improving the quality of residential areas. Because the booklet was written about the specific region in which the case is located, reviewing the list helped to identify many local impact factors relevant to the case. Such sources can provide the scenario analyst with clues for describing and modeling the case that may not be found anywhere else.

**LESSON TO BE LEARNED**

- Studying a case's weaknesses, deficiencies, and any former interventions provides insight into its structure, dynamics, and history.
**Key Definitions in Formative Scenario Analysis**

*Impact variables:* The impact variables, \( d_i, i = 1, \ldots, N \), are also called system variables, impact factors, or case descriptors.

*Impacts:* The mutual impacts between the variables \( d_i \) and \( d_j \) are \( a_{ij} \). In general, impacts are positive because only the absolute values of the impacts are rated.

*Impact matrix:* The impact matrix \( A = (a_{ij}), i, j = 1, \ldots, N \), contains the direct impacts of \( d_i \) on \( d_j \).

*Levels of impact variables:* Each impact variable \( d_i \) has at least two levels \((N_i \geq 2)\). The levels are discrete and denoted by \( d_i^{n_i}, \ldots, d_i^{N_i} \).

*Scenario:* A scenario is formally a vector \( S_k = (d_1^{n_1}, \ldots, d_i^{n_i}, \ldots, d_N^{n_N}) \)

with \( k = 1, \ldots, k_0 \); the number of scenarios is \( k_0 = \prod_{i=1}^{N} N_i \).

*Consistency matrix:* The consistency matrix \( C = [c(d_i^{n_i}, d_j^{n_j})] \) contains the consistency ratings, \( c(\cdot, \cdot) \) for all pairs of impact variables at all levels \( c , (i, j = 1, \ldots, N, i \neq j, n_i = 1, \ldots, N_i, n_j = 1, \ldots, N_j) \).

*Consistency value:* For each scenario, the consistency value \( c^*(S_k) \) is a conjoint measure of all of the different consistency ratings, such as

\[
c^*(S_k) = \sum_{i,j=1,\ldots,N, i \neq j} c(d_i^{n_i}, d_j^{n_j}) \in S_k \]

**Step 3: Impact Variables**

In general, the aim of this step is to develop a set of impact variables sufficient for valid description and modeling of the current state of the case and its dynamics. The selection and definition of impact variables or impact factors is the most crucial and time-consuming step of a scenario analysis. We formally define the impact variables as \( d_i (i = 1, \ldots, N) \). We use the letter \( d \) because impact variables also act as descriptors of future states of the case (see Box 9.3).

To answer the question “What are the most decisive factors for the Greater Zurich area regarding sustainable urban development?” the study team chose a top-down procedure. First, four different domains of
Table 9.2  Impact Variables From the Zurich North Case Study

<table>
<thead>
<tr>
<th>Society</th>
<th>Economics</th>
<th>Policy</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social Classing</td>
<td>Job Market Supply</td>
<td>Switzerland's Membership in the</td>
<td>Traffic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>European Union</td>
<td></td>
</tr>
<tr>
<td>Populousness</td>
<td>Segmentation of</td>
<td>Energy Price</td>
<td>Environmental</td>
</tr>
<tr>
<td></td>
<td>the Job Market</td>
<td></td>
<td>Protection</td>
</tr>
<tr>
<td>Values</td>
<td>Innovation</td>
<td>Environmental Regulations</td>
<td>Impacts and</td>
</tr>
<tr>
<td>Living Standards</td>
<td>World Business</td>
<td>Equalization of Burdens</td>
<td>Emissions</td>
</tr>
<tr>
<td></td>
<td>Cycle</td>
<td></td>
<td>Parks and</td>
</tr>
<tr>
<td></td>
<td>Real Estate Pricing</td>
<td>Regional Planning</td>
<td>Greens</td>
</tr>
<tr>
<td></td>
<td>Centralization of</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Investments</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

impact variables were determined: society, economics, policy, and environment. Then, a long list of potential impact factors were considered in a brainstorming session and condensed into a list of 19 items.

For each impact variable, the study team had to create a crisp definition. One good way of doing this is to provide a one-page description. The study team tried to relate these variables to key concepts that are used in different branches of science. In this step, reference to state-of-the-art knowledge is required.

What follows are short definitions, extracted from their one-page descriptions, along with the level classifications of each of the variables in the Society domain of Table 9.2.

- **Social classing**: Social classes, distribution of incomes/salaries (levels: polarization vs. normal distribution-like mixture)
- **Populousness**: Inhabitants per square kilometer in the Greater Zurich area (levels: increase of more than 10% in the next decade, decrease of more than 5% in the next decade, less than 10% increase and 5% decrease in the next decade)
- **Values**: Willingness to change perspectives, public participation, commitment toward urban living (levels: active vs. passive)
• Living standards: Extent to which individual needs will be fulfilled, such as emissions, safety, number and quality of job positions, availability and frequency of cultural events (levels: high vs. low)

The reader can easily see that different qualities of scaling are necessary for each variable. Some of the variables are rated on a nominal scale, and others on an interval scale.

The variable Centralization of Investments presumably is not understandable to readers who are not acquainted with the political constraints of Zurich. In Switzerland, taxes are assessed by the communities. Due to the extra costs of urban infrastructure, the City of Zurich must demand higher taxes than do small, rural communities. At the time of the ETH-UNS case study Zurich North, the trend was toward decentralization. Many companies preferred the lower taxes charged by the small communities in the vicinity of Zurich. The variable Equalization of Burdens is a reference to this issue with two levels—one where there is an equalization of burdens between the city and the surrounding communities, the second where there is not.

Usually, it is best if the study team ends up with no more than 20 variables. From these, according to the satisficing principle (see Box 9.1), not more than a dozen impact variables should be created. We will introduce a strategy for condensing impact factors when introducing the bottom-up approach to selecting impact factors.

A typical bottom-up procedure for the creation of impact variables is organized in the following way. After the study team has explicitly recalled the goal of the study, each team member is asked to think about potential impact variables and then write them down on cards. All of the cards are compiled and then grouped and regrouped sequentially on the floor or pinned on a wall. If the grouping yields (hierarchically) separable clusters, one may presumably end up with a list such as that in Table 9.2. Usually, this list is very large, presumably containing 40 or more variables. In order to reduce the list, the following strategy works well.

First, the study team cancels variables that are considered secondary.

Second, the study team decides whether some impact variables are already represented implicitly by others, and cancels them. In the Policy column of Table 9.2, for instance, one would consider whether Energy Price is already covered by Environmental Regulations. Similarly, one might cancel the variable Impacts and Emissions, considering it subordinate to Environmental Protection.
Third, new variables are created that encompass and replace a set of existing variables. For instance, Social Classing and Quality of Life could be fused into a new impact variable called Welfare.

Of course, selection and construction of impact variables is best done cooperatively with case experts by organizing a roundtable, questionnaire, or Delphi study (see Linstone & Turoff, 1975).

**LESSONS TO BE LEARNED**

- The construction of impact variables is the most important step in the whole process of Formative Scenario Analysis. It corresponds to the construction of perceptors in the Brunswikian Lens Model.

- Analytic decomposition has to be performed with the functionality of the specific goal of the analysis in mind. The study team has to construct a sufficient set of variables that depicts the current state of the case and its dynamics.

- There are top-down and bottom-up procedures for clustering, ordering, and eliminating impact variables. Which procedure is recommended depends on the knowledge of the study team.

**Step 4: Impact Matrix**

The formation of an impact matrix initiates the actual synthesis process (see Figure 9.5). The matrix is defined as $A = (a_{i,j}), i, j = 1, \ldots, N$. A cell, $a_{i,j}$, of the matrix assigns (the absolute value of) the direct impact strength of one variable, $d_i$, on another variable, $d_j$ ($i \neq j$).

In constructing the impact matrix, the study team has to determine the scale for the impacts. Because there is no natural scale for judging impact strength, the rating has to be assessed on a subjective scale. To formulate a scale for impact strength, the scenario analyst must link his or her case-specific knowledge with the available textbook or scientific knowledge about the variables under consideration. The scaling may have different degrees of refinement. Theoretically, any kind of scale between a simple, nominal 0,1 coding and an absolute scale using arbitrary rational numbers is possible. Figure 9.5 presents an excerpt from the impact
Figure 9.5. Excerpt From the Impact Matrix of the Synthesis Group “Urban Development of the Greater Zurich Area”

NOTE: The impacts, $a_{ij}$, are rated on a 3-point scale (0, 1, 2). Activity refers to the sum of the impacts that one variable, $d_i$, has on every other variable, $d_j$ ($i, j = 1, \ldots, N, i \neq j$). Likewise, denoted as a sum, Passivity reflects the impacts that all the other variables, $d_j$, have on $d_i$.

The matrix of the ETH-UNS case study Zurich North. For this study, the following three-level scale was chosen: 0 = no or very little impact, 1 = medium impact, 2 = high impact.

In practice, the impacts should be rated on a 3- to 7-point scale, but within this range, no general rule exists that clarifies which scaling is the most appropriate. When rating the impacts between variables, the scenario analyst must be aware of several prerequisites and acknowledge potential biases. The following list outlines the six most important ones.

1. The analyst needs to assess the direct impact of one variable on another (e.g., Impact and Emissions on Job Market Supply), which is not a simple task. It is particularly important that the analyst exclude any indirect impacts that a variable has via any other variable that has been defined (see Figure 9.5). This requires that in the course of rating the mutual
impacts, the analysts always remain aware of any other variables that are involved. For instance, if, in a subsequent step, the number of impact variables would be reduced and a variable (such as Populousness) canceled, the ratings of some impacts could change, and, in principle, all ratings should be repeated! This is because the partial impact of a variable (Impact and Emissions) on another (Job Market Supply) via Populousness has to be subsumed in the rating after the elimination of the intermediate variable. Therefore, if the impact variable Populousness would have been deleted as a result, then the impact of the variable Impact and Emissions on Job Market Supply should be 1 instead of 0.

2. The analyst has to construct causalities instead of correlations. This issue refers partly to the previous argument in that the judgment switches from being one of causality to one of correlation if indirect impacts (the canceling of the variable Populousness) are included in the rating. This can also happen when confounding the impact of one variable on another with the opposite impact of the other variable on the former one.

3. The analyst needs to rate the current impacts, not those that were present previously.

4. The analyst should provide a judgment that includes as much information as possible. In other words, do not rate all impacts as medium (given a scale with more than two levels). The analyst should not forget that the informativeness of an impact matrix is zero if all of the ratings are on the same level.

5. The analyst should make sure that the impacts are rated with respect to the specific case being considered, rather than rating general relations. This task is often made easier by encountering the case visually.

6. The analyst needs to be aware of judgment shifts in the course of filling out the impact matrix, two of which should be corrected explicitly. One is the burnout phenomenon. If the impacts for 15 impact variables have to be rated, the analyst will need to consider 210 impacts. A good strategy for coping with the burnout phenomenon is to define blocks of 10 to 20 impacts, which will subsequently be rated. If there is a study team, the blocks to be rated should be presented in a random order by all members.

The other shift is the group choice shift (see Asch, 1956; Stoner, 1961; Zuber, Crott, & Werner, 1992), which has been investigated recently for judgments about impacts between system variables (see Crott, Grotzer, Hansmann, Mieg, & Scholz, 1999). This shift shows that, on the average,
the longer the group spends discussing a certain impact relation, the higher its rating will be. Certainly, this is an artifact that has to be corrected in a suitable post hoc procedure.

Before the impact rating starts, the study team must make sure that it is well prepared for the rating procedure. As Reibnitz (1992) suggested, one should strive for each impact judgment being reasoned. In practice, this is both difficult to accomplish and time-consuming. From our experience with Formative Scenario Analysis, we recommend the following reference procedure for study teams of 3 to 10 analysts.

First, the group has to discuss all impact variables qualitatively. Reference should be made to state-of-the-art textbook knowledge if such knowledge is available (e.g., for the business cycle’s impact on environmental attitudes, specific publications should be consulted). The rating for the impact should be specific to the case and not represent the relationships between the impact variables in general. If the group feels that it lacks solid knowledge, case or subject experts should be consulted.

Second, each member of the study team must fill out the impact matrix individually (see Box 9.4). Standard statistics (mean, variance, etc.) of all group members’ ratings should be calculated, compared, and discussed. Furthermore, the study team should also be presented with the total distribution of ratings and should check whether it shows unwanted properties, such as too many medium-range ratings. Naturally, each analyst should check whether he or she was affected by one of the biases reported earlier. If necessary, the case members should review the ratings individually and make adjustments.

Finally, the study team has to visualize all distributions of impact ratings that exceed a certain degree of heterogeneity. The criteria for heterogeneity have to be assessed according to the scaling, the group size, and so on. Those ratings that are considered divergent or heterogeneous should be discussed by the group, and, subsequently, adjustments should be made for them. The group should correct for impact shifts (see Item 6 in the list above) by, for instance, adjusting post hoc the mean of the discussed impacts to be compatible with the overall mean of those not yet discussed.

Clearly, not all of the problems that could occur in the course of constructing an impact matrix will be discussed here. For instance, we do not address the self-referential dynamics that some variables show.
The cells of an impact matrix $A = (a_{ij})$, $i, j = 1, \ldots, N$, provide information on how different system variables of a case are interrelated. The numbers $a_{ij}$ indicate how strongly the variable $d_i$ affects $d_j$. If we calculate the sums of the rows and the columns, we gain insight into the relative influence of $d_i$ and the dependence of the variable $d_j$. The following figure represents the formal notation of an impact matrix $A$ and some indicators.

We will now discuss the final impact ranking of the ETH-UNS case study Zurich North’s study team. The ranking reveals the study team’s perspective.

At first glance, it appears that World Business Cycle and Environmental Regulations are the two impact variables judged highest in importance, with both scoring 17. From a sustainable development perspective, however, Environmental Regulations, Impacts and Emissions, Values, and Populousness are also regarded as having a high impact (see Table 9.3).

But a closer look at the cells of the impact matrix reveals that most people rated global variables such as the World Business Cycle or Switzerland’s Membership in the European Union to be of medium impact on a 3-point scale (0, 1, 2). If the medium ratings are downgraded and just a
The subsequent descriptions are helpful to better understanding the case model.

Activity: The activity of a variable (i.e., the extent to which a variable’s impact on other variables is active), \( d_i \), is the row sum of all of the impacts that this variable has on all other variables \( d_j \) formally \( a_{ij} = \sum_{i=1}^{N} a_{ij} \). Activity correlates to the medium impact of a variable on other variables.

Sensitivity/passivity: The sensitivity/passivity of a variable, \( d_i \), is calculated by summing up the cells of the column \( i \), that is, the impacts that all of the other variables have on it. Formally, \( a_{ii} = \sum_{j=1}^{N} a_{ij} \). The sensitivity is correlated with the medium dependency of a variable on other variables.

The subsequent indexes provide some further information on the relative importance of variables according to the study team’s ratings.

Impact strength: If we calculate the ratio between activity and sensitivity, \( a_{ij} / a_{ij} (a_{ij} > 0) \), we get a summary indicator of the medium impact strength of a variable on the case.

Involvement: The involvement of a variable, \( d_i \), is the product of activity and sensitivity, \( a_{ij} \cdot a_{ij} \), and indicates how strongly the variable \( d_i \) is interlinked with the system. It should be noted that some researchers consider the difference and sum to be more appropriate than the quotient or product. Regardless, these indexes shed light on certain aspects of the variables and their positions in the system model.

dichotomous 0-1 rating is considered when transforming the ones to zeros and the twos to ones, a more concise shell model appears. The activity of the general factors, World Business Cycle and Switzerland’s Membership in the European Union, become tremendously downgraded. Conversely, the relative importance of Populousness and Energy Price rise.

**LESSONS TO BE LEARNED**

- The impact matrix initiates the synthesis process by rating the variables’ current, direct, mutual impacts. The outcome is as good as the rating and depends on the study team’s worldview, knowledge, and methodological awareness of potential biases and fallacies.
Table 9.3 Activity Ranking of All Variables in the Zurich North Case Study

<table>
<thead>
<tr>
<th>Rank 1-5</th>
<th>Rank 6-10</th>
<th>Rank 11-15</th>
<th>Rank 16-19</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. Values</td>
<td>10. Real Estate Pricing</td>
<td>15. Innovation</td>
<td></td>
</tr>
</tbody>
</table>

NOTE: This ranking was taken from the Formative Scenario Analysis of the synthesis group “Sustainable Urban Development of the Greater Zurich North Area.”

The assessment of mutual impacts requires being knowledgeable about the case and recognizing the system variables’ dependencies. The study team should make sure that at least state-of-the-art textbook knowledge is applied in rating the mutual impact strengths.

The assessment of impacts in groups has many advantages, but because of potential shifts and other effects within the groups, it can also contain some risks. The case study team should discuss and deal with these effects explicitly.

Step 5: Graphical Representations:
System Grid and System Graph

We all know that a switch from words to numbers may cause a crucial change in communication even when the message that is sent is inten-
Formative Scenario Analysis

activity

Figure 9.6. A System Grid of the Activity and Sensitivity/Passivity Scores

tionally the same. Step 5 simply provides a transformation of the information from an algebraic impact matrix to a geometrical system grid and system graph. The step is exploratory in nature and resembles strongly the procedures used in exploratory data analysis (Tukey, 1977).

Activity and sensitivity ratings are displayed in a system grid. A system grid is a conjoint display of the column and row sums. In Figure 9.6, the plane is divided by a vertical and a horizontal line through the mean activity and sensitivity/passivity scores. Hence, the impact variables are partitioned into four sets.

The variables Values and Impacts and Emissions are considered above average in both sensitivity and activity, which places them in the Ambivalent quadrant. Five variables in Figure 9.6 are both above average in activity and below average in passivity; they are located in the Active quadrant.

In contrast, eight variables are in the Passive quadrant because they are below average in activity but above average in passivity. Finally, four variables are called Buffer Variables because they are below average in both activity and sensitivity/passivity.

The system graph is a structured network that presents a structural view of the system model. It visualizes how the different variables are interlinked. If only a few impact variables are present, the different
strengths of the impacts can be displayed by varying the boldness of the lines and arrows.

The impact matrix of the ETH-UNS case study Zurich North produced too many arrows when the medium impacts were also drawn. Thus, a new dichotomous scaling was established in which low and medium impacts were combined and labeled “0,” and those that had formerly been rated “2” became “1.” If we enter the data into a suitable software program for networking (e.g., Krackhardt, Blythe, & McGrath, 1994), we get a graph like that in Figure 9.7, which provides comprehensive insight into the study team’s system model of the case.

Because a system grid with 19 variables is still rather confusing, we have supplemented the network slightly by inserting the activity and passivity values of the variables and displaying the impact variables in differently marked boxes. We now receive a clearer image of the frame of the Zurich North site shell model.

According to the study team, the variables found to play the most active role in sustainable development were Environmental Regulations, Values, and Impacts and Emissions. Of secondary importance were Populousness, Energy Price, and Regional Planning. Those variables that were clearly on the passive side were Living Standards, Traffic, Innovation, and Impacts and Emissions.

**LESSONS TO BE LEARNED**

- System grids and system graphs are visualizations of a “grainy” case model through impact variables. They provide insight into the study team’s assessment of the relative importance and mutual relationships of all the variables.

- Graphical representations should be used in an exploratory manner. Changes in a variable’s relative importance resulting from an overall coarsening of impact levels should be viewed as clues. The study team should reflect these in the overall process of synthesis.
Figure 9.7. A System Graph of the Impact Matrix of the Zurich North Shell Scenario

NOTE: Only strong impacts are displayed to prevent information overload. In order to support the reader's conception of the system model, the sum of low, medium, and strong impacts that a variable has on other variables is noted on the top right. Conversely, the number of impacts that a variable receives from other variables is noted on its top left. The most active variables are framed, the most passive variables, shaded. Impacts and Emissions is considered to be the core variable for sustainable development in the Zurich North shell scenario.
Step 6: MIC-MAC Analysis

Until now, we have considered only the direct impacts between system variables. Furthermore, our considerations were static. The goal of the MIC-MAC (Matrice d’Impact Croisés-Multiplication Appliquée à un Classement, or Cross Impact Matrix-Multiplication Applied to Classification) Analysis (Godet, 1986, 1987) is to take the indirect impacts into account in order to gain a more detailed insight into the impact variables’ importance from a System Dynamics perspective.

The starting point of analysis is the impact matrix (see Box 9.4). For the MIC-MAC Analysis, this matrix needs to be coarsened, such that it contains information only on whether there is a (strong) direct impact or no impact. To take into account the indirect impacts, the impact matrix is multiplied with itself repeatedly, and after each multiplication, the column sums and row sums are calculated. If this has been done often enough, the rankings of the column and row sums mostly become stable. The row sum is generally considered to be indicative of a variable’s activity, including indirect impacts. Similarly, the column sum is indicative of a variable’s passivity, including indirect impacts.

The procedure can be described formally as follows. The impact matrix $A = (a_{i,j})$, $i, j = 1, \ldots, N$, is coarsened by setting the coefficients $a_{i,j}$ to 1 (strong impact) or 0 (no impact). For reasons of simplicity, we will label this matrix $A$ as well. Matrix $A$ is then multiplied with itself

$A^2 = (a^2_{i,j}) = \left( \sum_{k=1}^{N} a_{i,k} \cdot a_{k,j} \right)$

(where the 2 in $a^2_{i,j}$ denotes a superscript, not an exponent). The cells $a^2_{i,j}$ of the matrix $A^2$ are the number of direct impacts of second order, that is, the number of indirect impacts that a variable $d_i$ has via any other variable $d_k$ ($i \neq k$) on $d_j$. The product $a_{i,k} \cdot a_{k,j} = 1$ if, and only if, the variable $d_i$ has a strong impact on $d_k$ and $d_k$ has a strong impact on $d_j$. If we sum up along $k$, we attain all second-order impacts of $d_i$ on $d_j$.

Similarly,

$A^3 = (a^3_{i,j})$

denotes all third-order impacts that a variable $d_i$ has along the variables $d_j$ and $d_k$:
\[
A^3 = \sum_{i=1}^{N} a_{i,i} \cdot a_{i,j}^2
\]

\[
A^3 = A \cdot A^2 = \sum_{i=1}^{N} a_{i,i} \cdot \sum_{k=1}^{N} a_{i,k} \cdot a_{k,j}
\]

In general, the cells of \(A^n\) contain the number of indirect impacts of length \(n\). If \(n\) is sufficiently large, the rankings of the column and row sums of \(A^n\) mostly become stable.

The scores of direct and indirect impact activity (or passivity) have to be compared. The greater the difference between an impact variable’s direct and indirect activity ratings, the more attention should be paid to it in scenario construction (see Step 6). If a variable’s scores for its indirect impacts are higher than those for its direct ones, one might conclude that this variable is of higher importance than the study team had supposed.

A MIC-MAC Analysis was performed for the ETH-UNS case study Zurich North. The impact variable World Business Cycle was judged to be more important than Environmental Regulations when their indirect impacts were considered, although they had had the same score when their direct impacts were assessed. Furthermore, the variables Impacts and Emissions, Values, and Environmental Protection showed lower rankings in the MIC-MAC Analysis than they had based on direct activity. At this point, we can conclude that ranking of the variables World Business Cycle and Regional Planning increased, but so did Segmentation of the Job Market and Job Market Supply. This latter increase alarmed the study team, which was composed mainly of environmental science students, into checking whether they had overstressed the environmental perspective in their direct ratings.

Clearly, the procedures in Steps 5 and 6 are rules of thumb. Their value should not be judged only according to classical criteria, such as validity or objectivity. Rather, the value of these representations has to be seen in terms of the aid they provide in understanding the case and reflecting on one’s own opinions.

Most of the methods are semiquantitative, and variables, which do not have a rational scale, are sometimes multiplied. Thus, the study team should watch out for artifacts based on scaling. This can best be done by performing a sensitivity analysis on the ratings of the initial impact matrix \(A\).
MIC-MAC Analysis can also be considered a simple model for case dynamics. This is best done by referring to automata theory (Hopcraft & Ullman, 1979), because the multiplication of matrices can be considered a spreading of impulses on a discrete time scale, assuming that there is a multiplicative amplification of impact strength over time. The MIC-MAC Analysis provides access to the indirect impacts of a case and a rough model for its dynamics.

The rank in importance of a variable based on the assessment of its indirect impacts may differ from the rank based on its direct impacts. Special attention should be paid to those variables that score higher in the activity of their indirect impacts than they do in the activity of their direct impacts.

Step 7: Scenario Construction

In the ETH-UNS case study Zurich North, the variable Populousness has three levels. To construct one of the possible scenarios, the second level of Populousness was combined with the first level of the impact variable Social Classing, and so on. Hence, a scenario is simply a combination of levels of all impact variables.

If there are 10 impact variables and each of them has only two levels, we will have $2^{10} = 1,024$ different scenarios. If we have 15 impact variables with three levels each, there will be $3^{15} = 14,348,907$ formally constructed scenarios.

For each impact variable $d_i$, we have defined different levels $d_i^{n_i}$ ($n_i = 1, \ldots, N_i$), where $N_i$ denotes the number of different levels that we have allowed for the impact variable $d_i$ (see Step 3). For instance, the three levels of the variable Populousness are as follows:

$\begin{align*}
    d_i^1 &= \text{increase of more than 10\% in the next decade} \\
    d_i^2 &= \text{decrease of more than 5\% in the next decade} \\
    d_i^3 &= \text{less than 10\% increase and 5\% decrease in the next decade}
\end{align*}$
Formally, a scenario, $S$, is simply a complete combination of levels of impact factors $(d_1^{n_1}, \ldots, d_i^{n_i}, \ldots, d_N^{n_N})$ for all factors $d_i$ ($i = 1, \ldots, N$). Thus, a scenario is a vector

$$S = (d_1^{n_1}, \ldots, d_i^{n_i}, \ldots, d_N^{n_N})$$

At this point in the analysis, it becomes apparent that scenario analysts should be parsimonious in defining impact factors and their levels from the very beginning. Even so, for Step 7, the number of variables should be reduced out of the differentiated insight gained from the MIC-MAC Analysis. This can best be done by referring to the system grid and system graph (see Figures 9.6 and 9.7). An impact variable’s activity is the most decisive criterion of the selection procedure. In the ETH-UNS case study Zurich North, we retained the nine impact variables with the highest activity scores. The variable Centralization of Investments was kept as well because it was thought to be crucial to the future of the Zurich North site.

LESSONS TO BE LEARNED

- Scenario construction relies on parsimony in the number of impact variables and their levels.
- The insights provided by the MIC-MAC Analysis and the system graph may help in selecting the variables most important to the System Dynamics of the case.

**Step 8: Consistency Analysis and Scenario Selection**

Consistency analysis is an analytic procedure for cleaning up a set of scenarios. The rationale behind this cleaning procedure is logical consistency. For a given scenario, specific combinations of levels may be relatively inconsistent. If, for one scenario, all pairs of impact variables are rated, whether their levels are consistent or not, we get information about the scenario’s logical consistency. In order to provide a better understanding of the objectives of consistency analysis, we want to remind the reader of the difference between possibility and probability. A scenario might be
considered logically consistent, and thus possible, without being probable. However, a prerequisite of probability is possibility.

Scenario selection is a two-step procedure for assessing possibility. First, we produce consistency measures for each scenario. These allow us to distinguish between consistent and inconsistent scenarios. For instance, on the Zurich North site, a doubling of Populousness was judged to be inconsistent with a reduction of resource use. The remaining set of consistent scenarios is what fills the funnel of the scenario trumpet. Second, we have to screen this set in order to select a small number of scenarios that represent the set of future states of our case. The following is a brief outline of the technical procedure.

Let \( S_k \) be one scenario of the set of all possible scenarios \( \{S_k\} \). For each pair of impact variables, a consistency measure

\[
c(d_i, d_j)
\]

is assessed. Abstractly formulated, the function \( c(.,.) \) is a mapping from the set of possible combinations of impact variables into the space of (judged) logical inconsistencies.

As with impact rating, the question of which scaling is appropriate arises again. No definite answer to this question exists. A scaling with few (three to four) levels is generally recommended. It is advantageous to penalize strong inconsistencies by giving them drastically low ratings. In the Zurich North case, for instance, the following ratings were applied:

\[
\begin{align*}
c(.,.) & = 3 & \text{Complete consistency, the levels of the impact factors are coherent and support each other} \\
c(.,.) & = 1 & \text{Partial or weak inconsistency} \\
c(.,.) & = 0 & \text{Inconsistent} \\
c(.,.) & = -99 & \text{Strong inconsistency, scenarios including combinations of logically contradictory levels of impact variables are not considered thinkable}
\end{align*}
\]

Then, a consistency matrix (see Table 9.4), which includes all combinations of levels of impact factors, has to be filled out by the study team. This task is time-consuming and should be done in a well-organized and structured group process (see Chapter 16).

To construct a value \( \psi(S_k) \) that assigns a conjoint consistency measure for each scenario, the consistency matrix is defined as
Table 9.4  Excerpt of the Consistency Matrix for the Zurich North Scenario Analysis

<table>
<thead>
<tr>
<th></th>
<th>(d_1^i)</th>
<th>(d_2^i)</th>
<th>(d_3^i)</th>
<th>(d_4^i)</th>
<th>(\ldots)</th>
<th>(d_N^i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(d_1^i)</td>
<td>Strong environmental regulations</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(d_2^i)</td>
<td>Weak environmental regulations</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(d_3^i)</td>
<td>Low impacts and emissions</td>
<td>0  -99</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(d_4^i)</td>
<td>High impacts and emissions</td>
<td>3  0</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\ldots)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(d_m^i)</td>
<td>Populousness strongly increasing</td>
<td>0  1  3  0</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\ldots)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(d_N^i)</td>
<td>High living standards</td>
<td>0  1  0  0  1</td>
<td></td>
<td>-</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NOTE: The study team judged the combination of weak environmental regulations with low impacts and emissions to be strongly inconsistent \((c(d_2^i, d_3^i) = -99)\).

\[ c = c(d_m^i, d_N^i) \]

There are several different options for the calculation of \(c^*(S_k)\). The above scaling is arranged for an additive value. Thus, we simply add up all the \(\binom{n}{2}\) consistency values for pairs of a scenario \(S_k\):

\[ c^*(S_k) = \sum_{n_i, n_j \leftrightarrow S_k, i \neq j} c(d_m^i, d_N^i) = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} c(d_m^i, d_N^i) \]

The sign "\(\leftrightarrow\)" is used for indicating that the level \(n_i\) of an impact variable \(d_i\) and the level \(n_j\) of an impact variable \(d_j\) are part of scenario \(S_k\). Table 9.4 shows how the data may be organized.

There are also other consistency values offered in the scenario analysis literature (see Missler-Behr, 1993, p. 33). We will not deal with this problem in detail. However, a multiplicative structure might also be considered appropriate. The case study should deal with the consistency analysis in an exploratory manner. This means that if the study team is of two minds about the consistency of several pairs of variables, the application of different measures is recommended. There are several computer
programs available that support consistency analysis (von Nitsch, 1989), but most of the operations are easily programmable with spreadsheet software.

Of course, no specific rules define when a scenario is consistent, but various techniques are commonly used. One technique is to define a threshold value below which a consistency measure should not drop. Another technique is to take the 10, 20, or 100 most consistent scenarios, or the upper 1%, 2%, or 5%. However, there are no general criteria for this threshold. Thus, we will introduce an inductive, exploratory approach that provides a small set of scenarios with high consistency filling the funnel of the scenario trumpet.

When selecting representatives for the scenario funnel, a distinction can be made between data-driven, bottom-up strategies and concept-driven, top-down strategies. For the bottom-up procedure, the study team should have a well-organized spreadsheet at its disposal (see Table 9.6). We suggest Table 9.6, which is partially derived from Table 9.5 by rotating the matrix. Furthermore, only the levels of the impact variables (being the upper indexes in Table 9.5) are listed in order to reduce the complexity of notation. In the first two columns of Table 9.6, both the labels and the levels of the impact variables are noted to provide semantic information for facilitating the interpretation and comparison of different scenarios.

One option is that the study team starts with the most consistent scenario and compares it with the subsequent ones successively. Often, the study team will notice that the top scenario differs from the next highest in the levels of only one or two impact variables. The team has to decide whether this difference is semantically important (which means defining a new type of scenario), or whether it just represents gradual change and modification. In the example given in Table 9.6, the radical change occurs when switching from Scenario $S_4$ to $S_5$.

**Data-Driven, Bottom-up Procedure.** It is possible to successively classify scenarios by concentrating on their “sign level” for a long period of time. This means that the grouping of similar scenarios and the choice of a representative scenario for every group initially is done exclusively by comparing similarities in the consistency ratings on the number level. Once a coherent group has been identified, however, the essence of the class has to be identified semantically. In the end, the representative that allows for the best interpretability and best matches the label of a class should be chosen. Usually, between three and five scenarios will result.
### Table 9.5 The Schema of a Consistency Spreadsheet After Consistency Assessment

<table>
<thead>
<tr>
<th>Rank</th>
<th>Consistency Value</th>
<th>Scenarios (Sk)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>c*(S₁)</td>
<td>d₁₁ d₁₂ .... d₁ₙ</td>
</tr>
<tr>
<td></td>
<td></td>
<td>...</td>
</tr>
<tr>
<td>k</td>
<td>c*(Sₖ)</td>
<td>dₖ₁ dₖ₂ .... dₖₙ</td>
</tr>
<tr>
<td></td>
<td></td>
<td>...</td>
</tr>
<tr>
<td>k₀</td>
<td>c*(Sₖ₀)</td>
<td>d₁ᵢ d₂ᵢ .... dₙᵢ</td>
</tr>
</tbody>
</table>

NOTE: The k₀ scenarios (see Box 9.3) are renumbered according to their consistency ranking c*(Sₖ₀). In order to avoid overly complicated notation, specific levels are chosen (e.g., two for d₁₁, two for d₂₂, and three for dₙₙ in scenario S₁) for the scenarios S₁ and Sₖ₀. For row k and column i, the general notation is written in the upper indexes.

### Table 9.6 Spreadsheet of Scenario Selection

<table>
<thead>
<tr>
<th>Scenario</th>
<th>S₁</th>
<th>S₂</th>
<th>S₃</th>
<th>S₄</th>
<th>S₅</th>
<th>Sₖ₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental Regulations</td>
<td>strong (1), weak (2)</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Impacts and Emissions</td>
<td>low (1), high (2)</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Populousness (x)</td>
<td>x &lt; 5% (1), 5% &lt; x &lt; 10% (2), x &gt; 10% (3)</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Living Standards</td>
<td>low (1), high (2)</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>(Additive) consistency measure c*(Sₖ)</td>
<td>24</td>
<td>23</td>
<td>23</td>
<td>19</td>
<td>19</td>
<td>-91</td>
</tr>
</tbody>
</table>

NOTE: Without any loss of generality, the scenarios are numbered according to their consistency ranking.
Clearly, there is the option of supporting the bottom-up procedure with multivariate statistical analysis. One such analysis, the cluster analysis method (see Aldenderfer & Blashfield, 1984), is a very flexible instrument that permits different measures of defining similarities between different scenarios. Actually, cluster analysis is nothing more than a procedure that establishes classes of items automatically.

**Concept-Driven, Top-Down Procedure.** Often, the study team has conceptual ideas about the future of the case. For example, in the Zurich North case, a long-standing economic depression and increase in the unemployment rate in Zurich’s metropolitan area gave rise to a belief that there was, at the time, a trend toward polarization (see Box 9.5). Generally speaking, a study team should first reflect on the case and its dynamics, then identify a small set of scenarios that are characterized by certain ideas, knowledge, and designations. Scenario identification has deep roots in the understanding and conceptualizations of the case.

In both the bottom-up and top-down procedures, the study team has to identify which combinations of impact factor levels are compatible with the study team’s (previously) formed ideas about the future state of the case. Thus, a notion (i.e., a conceptual, semantic idea) is transferred into the semiotic framework of Formative Scenario Analysis. Some notions will provide small sets of formally defined scenarios that are subsets of the set of consistent scenarios. Of course, certain techniques and criteria for defining the set of consistent scenarios have been provided (see above). These criteria, such as taking the top 1% most consistent scenarios, fall into the category of rules of thumb. Note that these rules of thumb depend on the number of impact variables, their numbers of levels, and the structure of the consistency ratings.

It should be noted that for any certain scenario idea, more than one formatively assessed scenario may be considered appropriate, because some impact variables within one scenario idea are ambiguous. In the ETH-UNS case study Zurich North, the variable Living Standards is ambiguous given the idea of a polarized society, in that polarization may be accompanied by a mean higher or mean lower standard of living.

Each of the two procedures, bottom-up and top-down, has strengths and weaknesses. On the surface, the top-down approach seems to be the more economic and sophisticated, although it has the obvious danger of overlooking crucial scenarios. Furthermore, even if levels of pairs of
Switzerland has been integrated into the European Union (EU) (7). Poorly paid jobs are covered by women and immigrants (8). However, the living conditions of immigrants have changed because of membership in the EU; they may now live together with their families.

There is liberal regional planning (3) in the Zurich area, and the municipal and cantonal authorities control the granting of construction permits for offices and housing in areas formerly declared as industrial zones. Environmental regulations are of about the same rigor as today. Environmental issues, however, have lost their importance. Because of high economic uncertainty, people are much more concerned with money and everyday problems (5).

The job market shows high polarization (4), and the service industry is booming. There is a lot of pressure on the middle class. In the service industry, extraordinarily well-paid positions for management contrast with many low-wage jobs for cleaning, security, and so on. Time-sharing is promoted to save on social security (14).

No commercial center can be localized. Many companies settle in peripheral or suburban areas. There are only a few offices, for representational purposes, in the old downtown area (16).

Environmental emissions are rather high (4). This is due to fairly liberal environmental regulations (2). Furthermore, industry has few investments motivated by environmental reasons (12). Companies do not care about resource efficiency or recycling (11).

Living standards (9) and job market supply (13) are low. Polarization especially is increasing because of sociocultural issues. There is little low-income housing in the vicinity of the companies. Compared to other regions, the job supply in the Greater Zurich area is still favorable (1). Thus, there is an increase in population (6).

impact variables are considered consistent in this approach, the combined consistency of levels of three or more impact variables may not hold true. This kind of problem arises at many places in scenario construction (see also Box 9.6).
Cross-Impact Analysis refers to a group of methods by which one can determine the probability of the occurrence of a scenario (see Brauers & Weber, 1988; Götze, 1993). The aim is to go beyond consistency analysis, which yields assessments on the logical consistency $C^*(S_k)$ of a scenario $S_k$.

In order to assess overall probability $p(S_k)$, most cross-impact techniques try to assess inductively the conditional or conjoint probabilities of pairs of impact variables, that is, the probability of the impact variable $d_i$ having level $m$, given that variable $d_j$ has level $k$ (i.e., $p(d_i^m \land d_j^k)$), and the conjoint probability of variable $d_i$ having level $m$ and $d_j$ having level $l$ (i.e., $p(d_i^m \land d_j^l)$).

Papers on Cross-Impact Analysis recommend that these probabilities be rated by experts or with a Delphi procedure.

Most Cross-Impact Analysis procedures try to derive the overall probability for a scenario $S_k$ from knowledge about pairwise probabilities.

However, according to the rules of probability, it is generally true that knowledge about all pairwise conditional and conjunctive probabilities is not sufficient for the calculation of conditional or conjuncture probabilities entailing more than three events.

This has important consequences for an assessment of the probability of a scenario $S_k$. There is only one way of getting the probability of the occurrences of the scenario; there must be access to the likelihood of all combinations of different impact variables and their levels (pairs, triples, etc. up to length $k - 1$). In practice, this is impossible.

Furthermore, it is well-known that human beings, including experts, are not good probability estimators. They are inconsistent and do poorly, particularly if they are rating the probability of nonobservable events or events with only slight probability. Nevertheless, various procedures have been developed to provide estimations. Generally speaking, we do not think that these procedures are suitable tools for case analysis.

The process of scenario selection is at the core of the synthesis in Formative Scenario Analysis. By the time the study team reaches this step, it will certainly be well prepared in trend extrapolation from the previous steps of analysis. The crucial issue in scenario construction is, without a doubt, the attribution of meaning. The selected scenarios should be regarded as representatives or prototypes of future states of the case. This is
why an encompassing verbal scenario description is indispensable. The scenarios should also receive indicative labels.

In the ETH-UNS case study Zurich North, the shell scenarios were derived through a combination of top-down and bottom-up strategies. The study team formulated a set of intuitive ideas about what could be or what should be. Then, it split into two groups, one starting with the top-down approach, the other with the bottom-up approach. In this way, the previously formulated ideas were revisited, shaped, and modified. Finally, the study team ended up with four scenarios: economic uprising ($S_1$), crises—loss of orientation ($S_2$), polarization ($S_3$), and new societal values ($S_4$). A crucial step in scenario construction is creating a novelistic case description to assist in the interpretation of a scenario. Box 9.5 provides an excerpt from the polarization scenario description. The links between the descriptions and the levels of impact variables tied to the scenarios are documented in the text (see Box 9.5).

**LESSON S TO BE LEARNED**

- Consistency analysis yields possible, logical, coherent scenarios that represent future states that a case could have. Because possibility is a necessary, but not sufficient, prerequisite for probability, special techniques must be applied in rating the likelihood of a scenario (see Box 9.6).

- There are no definite normative rules for determining when a scenario is consistent or not. Likewise, there is no maxim to decide whether two scenarios should be considered the same. Thus, decisions on scenario selection have to rely not only on formal criteria, but also on rules of thumb, which must be appropriate to the crispness of information inherent in the whole procedure.

- The part of the synthesis process that occurs through consistency analysis is characterized by a permanent transformation from operations on numbers to operations on concepts, or to express it in epistemological terms, by a complementarity in the expression of information between the sign level and the object level (or meaning). The crucial issues in scenario selection are the assignment of meaning to formally assessed sequences of numbers and the interaction between the different aspects of semiotics (i.e., syntax, semantics, sigmatics, and pragmatics).
Step 9: Scenario Interpretation

We will describe briefly four ways of interpreting scenarios.

Conversation. The most natural way of interpreting scenarios is by simply discussing them—their differences, their genesis, and their quality with respect to certain criteria and perspectives. This seems trivial, but in our experience—gathered from about a half-dozen formative scenario analyses—this step is not sufficiently acknowledged by some study teams. A lot of time needs to be reserved for in-depth discussions about the scenarios. Scenario descriptions should provide concise patterns to facilitate a much more elaborate discussion of possible future states than had been possible before the analysis.

Evaluation. Evaluation can be thought of as a specific form of interpretation. Usually, evaluations are inherent parts of most case discussions, but there are both soft and hard methods of evaluation.

We call an evaluation soft if the criteria and procedure for evaluation are not explicitly revealed, but rather are implicitly involved in the inferences and conclusions. In contrast, we consider an evaluation procedure hard if the criteria and procedure are made explicit. This means that they are displayed in a way that allows at least enough objectivity for there to be a high probability that another evaluator who starts with the same premises would end up with the same conclusion. As an example of a hard method, in Chapter 11, we introduce the Multi-Attribute Utility Theory, a highly formative procedure of scenario evaluation.

Many scenarios are constructed intentionally for an evaluation procedure. As previously stated, the scenario should be constructed such that, at least implicitly, it conveys the information necessary to judge its favorability.

Best Reply Strategies. Another way of working with scenarios is to think about which intervention or strategy would be the best for the case in response to a certain scenario. A procedure for linking local interventions (also called variants or strategies) with global scenarios was already introduced earlier in Figure 9.4.

To optimize evaluations, a value function must exist that evaluates each set, or each combination of a local and a global scenario (see Figure 9.4). Then, for every global scenario, the best variant can be determined.
There are many ways to determine, and many criteria for defining, which of a set of strategies is the best. A well-known robust strategy is the max-min strategy. This strategy presumes that, for all the possible intervention options (i.e., variants), the worst global scenario will occur. Under this (pessimistic) assumption, the maximizing variant is chosen.

If every global scenario is considered to have some known likelihood, one option for determining the best strategy is to choose the variant that maximizes the average expected evaluation. We will not go into detail here; we want only to show that new questions arise at the end of a scenario analysis that had not been present before the study.

The formal representations of the best reply strategies are as follows. If the value function is \( v(.) \), then for each \( S_k \), the optimum can be obtained as \( \max_m \{ v(set_{m,k}) \} \).

The max-min strategy is formally: \( \max \min_k \{ v(set_{m,k}) \} \).

If \( p_k \) is the probability of the global scenario \( S_k \), then the maximum of the expected evaluation is \( V_k = \max_m \left\{ \sum_k p_k \cdot v(set_{m,k}) \right\} \).

**Scenario Manipulation.** One way of understanding a scenario is through studying and interpreting it by manipulating the impact strengths. This manipulation provides information about the sensitivity of the case structure and, therefore, where the case can be affected. In Formative Scenario Analysis, because only the absolute values of the impacts are assessed (and not their higher functional relationships), this approach seems to be more promising when the System Dynamics are modeled in a more differentiated manner, as introduced in the next chapter.

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**LESSONS TO BE LEARNED**

- Interpretation of scenarios is time-consuming. Through the process of Formative Scenario Analysis, the study team will have already penetrated the case. Interpreting the results of this analysis is a challenging task that leads to new questions and perspectives that provide a higher level of case understanding.

- Both the construction and the interpretation of scenarios should be functional. Thus, preferences are inherent in the interpretation of scenarios (i.e., in discussing the future states of a case).
Scenario interpretation often employs explicit or implicit evaluation processes. This holds true for both the discussion of future states of the case and the development of strategies for coping with desirable or undesirable states of the case.

Scenario interpretation and evaluation can be organized qualitatively and/or quantitatively.

NOTES

2. The numbers refer to the enumeration of impact variables in Table 9.3.