Contributions to Management Science

Wolfgang Weimer-Jehle

Cross-Impact Balances (CIB) for Scenario Analysis

Fundamentals and Implementation

Springer

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Wolfgang Weimer-Jehle
ZIRIUS
University of Stuttgart
Stuttgart, Germany

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Contents

Abbreviations

ABM	Agent-based modelling
BASICS	Batelle Scenario Inputs to Corporate Strategy (scenario method)
C	Consistency score of a descriptor or scenario
CO_2	Carbon dioxide
CIB	Cross-Impact Balances (scenario method)
D	Diversity score of a scenario portfolio
FAR	Field Anomaly Relaxation (scenario method)
Gt C	Giga tons (billion tons) of carbon
IC	Inconsistency score of a descriptor or scenario
IC_S	Significance threshold of a scenario inconsistency
IL	Intuitive Logics (scenario method)
IPCC	Intergovernmental Panel on Climate Change
KSIM	Kane's Simulation Model (simulation method)
m	Number of matrices of a matrix ensemble
MINT	A group of academic disciplines, consisting of mathematics, informatics, natural sciences, and technology
N	Number of descriptors of a cross impact matrix
OECD	Organization for Economic Co-operation and Development
q	Quorum applied in an ensemble evaluation
SD	Systems Dynamics (simulation method)
SRES	Special Report on Emission Scenarios
TIS	Total impact score
V_i	Number of states of descriptor i
Z	Number of possible configurations of a morphological field

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Chapter 1
Introduction to CIB

Keywords Cross-Impact Balances · CIB · Scenario · Foresight · Qualitative impact network

Dealing sensibly with future indeterminacy and uncertainty is increasingly important in a world where organizations at all levels of society must make long-term, high-stakes decisions and where these decisions must prove their correctness in an increasingly turbulent environment. Because they enable us to identify the scope for action and examine the prospects of our strategies, plans, and decisions, scenarios, i.e., sketches of alternative futures, have emerged in recent decades as a key tool for systematic preparation for an unknown future.

Scenarios are generated by different actors for different purposes using different methods. The methods range from simply thinking about the future to complex mathematical simulations. Surprisingly, there is a rather limited stock of methods for the middle range between mental reflection and mathematical simulation. This is all the more surprising when we realize that in our preparations for the future, we often must cope with "systems" that, on the one hand, are too complex to be penetrated by mental reflection but that, on the other hand, we understand (at least in part) only qualitatively, making a credible mathematical simulation difficult.

In this middle ground between simple and mathematically treatable questions about the future, cross-impact balances (CIB) has established itself since its publication (Weimer-Jehle, 2006) as a method for the algorithmic construction of qualitative scenarios and for qualitative systems analysis. With its help, scenarios and systems analyses have been produced on the topics of waste, the working world, education, biotechnology, energy, societal change, health and health infrastructure, industry and services, information technology, innovation, climate, management, mobility and transport, sustainability, politics, risk and security, urban and spatial planning, technology management, behavior change, and water supply. This range of application fields underscores that CIB has been accepted as a generic method of analysis despite its origin in energy economics research: CIB was originally

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developed in 2001 as a scenario tool in a study by the Center for Technology Assessment in Baden-Württemberg on the liberalization of European electricity markets.[1]

About this Book

In the meantime, an extensive and steadily growing body of literature on CIB applications, methodological research, and methodological reflections has emerged.[2] However, a cohesive presentation of the method and its most important evaluation and interpretation approaches is lacking. This is a disadvantage for application practice because, on the one hand, CIB analysis is, contrary to its simple appearance, by no means without difficulties and pitfalls, while on the other hand, it offers much more analytical potential than mere scenario construction, which has been the focus of application practice in the past. Optimal use of the CIB method, including an exhaustive data evaluation and an appropriate interpretation of the results, requires a thorough understanding of the method and a sensible selection and application of evaluation approaches.

The present volume is intended to provide this comprehensive presentation and, as an introduction, is also aimed at users who have little or no experience with CIB. It is intended as a guide for them in their first applications of the method, providing them with the tools required for solid basic use and for the interpretation of results. It refrains, however, from discussing in-depth methodological issues or addressing the more complex analytical procedures that have only recently been developed, such as hybrid scenarios (Weimer-Jehle et al., 2016), the combination of CIB with structure-seeking statistical procedures (Pregger et al., 2020), or the coupling of CIB analyses performed at different regional levels (Schweizer & Kurniawan, 2016; Vögele et al., 2017, 2019). Additionally, the CIB concept of scenario succession and the related interpretation issues and analysis opportunities are only briefly discussed in an appendix. These and other advanced issues and possible applications of the CIB method are to be addressed in a subsequent volume.

Scenarios

As mentioned, scenario construction is the most common application of CIB thus far. It is therefore to this field of application that the descriptions in this book refer, with a few exceptions. This focus is not intended to disregard the value of CIB for qualitative systems analysis but is motivated by the expectation that the transfer of the methodological descriptions and considerations formulated here for scenario analysis to the field of qualitative systems analysis be straightforward.

To fulfill their function as instruments for preparing for the future, scenarios must be well constructed. They must capture what we can reasonably assume today about the future and the forces that will shape it. Taken together, well-constructed scenarios must express the different directions in which these forces can steer events. There have been differing views about how best to achieve this purpose since the early days

[1] Method development: Weimer-Jehle (2001). First method application: Förster (2002).

[2] See the CIB bibliography at www.cross-impact.org/english/CIB_e_Pub.htm

of scenario making in the 1950s and 1960s, from which two distinct "scenario cultures" developed.

Simply Thinking

Herman Kahn, the creator of the modern scenario concept, argued that the most important thing is to "think about the problem" (Schnaars, 1987: 109), in other words, to prepare scenarios without the use of formal construction methods. From Kahn's perspective, formal construction techniques are perceived as a distraction and an impediment to inspiration, intuition, and free thinking. Following Kahn's approach, the intuitive logics (IL) method emerged (Huss & Honton, 1987; Wilson, 1998), according to which scenarios are designed "by gut feeling" in expert discussions.[3] The first groundbreaking successes of the scenario technique are due to this approach,[4] and it is by far the most widely used scenario methodology to date, except probably in the area of scientific scenarios.

The Magical Number Seven Plus/Minus Two

Almost simultaneously with the preceding approach, however, another view of scenario construction emerged, which emphasized the value of formal methods in the collection of information and in actual scenario construction. One of the founders of this school of thought is Olaf Helmer, co-developer of the Delphi method for structured collection of expert assessments (Dalkey & Helmer, 1963) and co-inspirer of the first cross-impact techniques for formal analysis of expert judgments (Gordon & Hayward, 1968).

Advocates of formal scenario construction can draw on weighty arguments from cognition research. In a 1956 essay that would become one of the most frequently cited publications in psychology textbooks,[5] American psychologist George Miller evaluated a series of cognition experiments (Miller, 1956). He concluded that there is an upper limit to our mental capacity to accurately and reliably process information about simultaneously interacting elements[6] and that this limit is seven plus or minus two elements. The essay triggered extensive and continuing research on the question, with the result that Miller's "magical number" must be regarded as optimistically high (Cowan, 2001).

The transfer of these findings of cognition research to the problem of scenario construction is inevitable and sobering. If a scenario analysis addresses ten factors that will define the future (a rather modest number), then 90 potential interactions

[3] Schnaars (1987:106): "Scenario writing is a highly qualitative procedure. It proceeds more from the gut than from the computer, although it may incorporate the results of quantitative models. Scenario writing assumes that the future is not merely some mathematical manipulation of the past, but the confluence of many forces, past, present and future that can best be understood by simply thinking about the problem."

[4] This refers in particular to the Shell scenarios on the eve of the oil crisis (Wack, 1985a, 1985b).

[5] According to Gorenflo and McConnell (1991).

[6] According to the interpretation of Saaty and Ozdemir (2003). Specifically, the cognitive tasks in the experiments analyzed by Miller were, for example, the identification of n discriminable stimuli and the ability to correctly reproduce n items from a read-out list.

arise between these ten factors. If only about half of the potential interactions actually matter (which, as we will see in Sect. 6.3.2, is about average), persons attempting the mental construction of a scenario will have to keep in mind and weigh approximately 45 interrelationships to extract from them a scenario that considers all relevant interrelationships. Given the limits of our mental capacities shown by cognition research, can we hope to do justice to this task by intuitive scenario construction?

A challenge for mental scenario construction also arises from another angle, that is, from the combinatorial weight of the task. Even if we content ourselves with a rough analysis and grant each of the ten factors three conceivable future developments, which we then must combine into meaningful scenarios, this process results in 3 to the power of 10, i.e., approximately 59,000 combinatorial alternatives, each of which must be considered a possible scenario until disproven. How many of these alternatives can be evaluated by mental reflection, and how many relevant scenarios with potentially massive implications go unnoticed when we finally find ourselves at the end of our time resources after intuitively identifying a few plausible combinations? Incidentally, as we will see later, combinatorial spaces with 59,000 combinatorial alternatives are among the lesser challenges faced in scenario analysis.

However, the question of intuition-based versus formal construction of scenarios is not the only fundamental controversy in the scenario community. A second controversy is whether (or for what purposes) scenarios should rely essentially on quantitative data or whether they should also build substantially on qualitative bodies of knowledge.

If You Can't Count It, It Doesn't Count

This phrase represents the viewpoint that analyses of the future should focus on quantitative methods (e.g., mathematical system models) and quantitative data.[7] The use of qualitative methods is perceived as a loss of mathematical rigor, and qualitative information as a "gateway" for data that in the worst case are ill-defined or ambiguous to interpret or that, it is argued, too often put forward without a solid evidential base. Many advocates of this perspective acknowledge that unquantifiable factors can have an important influence on future events, particularly in systems whose evolution is shaped by human decisions. Nevertheless, they consider the disadvantage of the loss of rigor when opening the analysis to qualitative aspects to be more serious than the disadvantage of not taking such factors into account.

Better Approximately Right than Precisely Wrong

This phrase summarizes the counterperspective.[8] Its advocates argue that the rigor of mathematical methods and quantitative data are meaningless and produce

[7] Huss (1988:378), for example, reports the prevalence of this perspective among forecasters during the 1980s.

[8] The phrase is attributed to various individuals, including economist John Maynard Keynes and philosopher Karl Popper. However, the oldest published source known to the author refers to the British philosopher Carveth Read (1920:351) ("Better to be vaguely right than precisely wrong").

pseudoprecision if essential factors are excluded because they are incompatible with the preferred analysis technique. From this perspective, an approximate but, in essence, accurate picture of the problem is considered more helpful than a picture that is drawn in detail but misleading because of insufficient problem scoping.

Action research teaches that ignoring important problem aspects in favor of "working convenience" is not uncommon among decision-makers. In *The Logic of Failure*, German psychologist Dietrich Dörner analyzed experiments on the behavioral patterns of decision-makers. He found various patterns that can easily lead to failure when one is dealing with complex real-world problems. Among typical causes of failed problem-solving, he found the tendency to tailor the problem view to one's familiar arsenal of methods (rather than the other way around), noting critically: "We do not solve the problems we are supposed to solve, but the problems we can solve."[9]

Many perceptive future researchers have long been aware that this danger also exists in their own research domain. The old master of French future research, Michel Godet, a proven friend of mathematical methods, nevertheless deplored in his article *Reducing the Blunders in Forecasting* the tendency of his professional colleagues to exclude the poorly quantifiable factors from consideration to the disadvantage of forecast reliability and wrote of the "... dangers of excessive quantification (the ever-present tendency to concentrate on things which are quantifiable to the detriment of those which are not)...".[10]

CIB and the Concept of "Mechanical Reasoning"

It is pointless to argue about which positions in these discourses are better-founded. However, it is not the case that the truth lies somewhere in the middle and that "everyone is a little bit right." Rather, in future research, we encounter an immense variety of very different topics. The challenge lies in recognizing anew from case to case which arguments carry the greater weight in the application at hand.

At its core, CIB analysis consists of collecting qualitative information on "cross-impacts," i.e., the influence relationships between scenario factors, and coding these relationships using an ordinal scale. A software-supported simple balance algorithm is then applied en masse to determine which system developments form a self-stabilizing trend network and can thus be accepted as consistent scenarios. Therefore, with respect to the previously described discourse, the application area of CIB is research questions that (a) are too complex for exclusively mental treatment and at the same time (b) urgently require the inclusion of qualitative knowledge. When synthesizing the overall system picture, CIB combines the collected partial information about the pair relationships between system elements and assembles them into coherent constructions.

[9] Dörner (1997), own translation from German edition.

[10] Godet (1983), pages 181, 182, 189. Godet does not conclude from this view to renounce quantitative methods but, rather, recommends a combination of qualitative and quantitative methods for prognostics. These considerations are transferable to the field of scenario methodology.

Correspondingly, American knowledge integration researcher Vanessa Schweizer compares CIB analysis with the procedure of *mechanical reasoning* (Schweizer, 2020). She refers to a discourse initiated by the psychologist Paul Meehl in 1954 and conducted for decades on how case predictions in psychology can best be obtained from case data (e.g., “Does therapy X have prospects of being successful in case Y?” or “Will offender Z recidivate or rather not?”). Are such case predictions best made through expert assessments and case conferences? Or are they better based on formal (today, we would say algorithmic) evaluation of case data, i.e., mechanical reasoning? In psychology, the evidence points to the superiority of mechanical reasoning, and Schweizer refers to the analogy to the process of creating and evaluating scenarios either through intuitive-discursive processes in expert workshops (“case conferences”) or through CIB (“mechanical reasoning”).

Human reasoning is without question much deeper, more multifaceted and more adaptive than any form of mechanical reasoning. However, this comes at the price that far fewer factors and alternatives can be considered. Whenever the mass application of simple reflections yields more benefit than a small number of selectively deepened reflections, mechanical reasoning is likely to have an advantage over human reasoning. This is especially true for combinatorial problems, i.e., problems that are characterized by a large number of successive forks, each with several alternatives. Combinatorial problems arise, for example, in chess, where computer programs today can defeat any human opponent, and also in scenario construction.

How to Work with This Book

The structure of this book follows the concept of a self-study course. Chapter 2 presents a short introduction of the scenario technique and the position of CIB with respect to this technique.

Chapter 3 Chapter 3 presents the technical basics of CIB. We follow step by step how the workflow of a simple CIB analysis is structured and describe the concepts that are applied in it. The core of the chapter is a detailed explanation of the CIB algorithm, which, as experience shows, requires some time to understand despite its structural simplicity and the absence of complex mathematics. The reader should persist in this effort until success is attained because only a detailed understanding of how CIB evaluates cross-impact data allows access to the full application potential of the method and a solid interpretation of its results.

Chapter 4 After “basic training” has been completed, Chap. 4 takes a detailed look at the application of the method by presenting various analysis procedures with examples. This presentation of the spectrum of possible analyses is important to overcoming the narrow focus on scenario generation, which remains observable in CIB practice, and bringing the other, diverse analysis opportunities offered by the method to the reader’s attention.

Chapter 5 For most users, the desired result of a CIB analysis is probably a manageable portfolio of perhaps 3–6 clearly different scenarios. Such a result is in fact not atypical for a CIB analysis. However, CIB does not return a result with standardized properties. Rather, the scenario portfolio it generates is an expression of the systemic relationships formulated in the cross-impact matrix. The consequent result from a system-analytical perspective can be a small or large, diverse or rather monotonous scenario portfolio—independently of the wishes and expectations of the user. Chapter 5 therefore addresses the case in which the result of a CIB analysis does not meet expectations. It describes using other or supplementary analysis approaches to arrive at a result that meets one's needs or at least at an understanding why one's expectations are at odds with the system picture that was input into the CIB analysis.

Chapter 6 Now that it is clear how CIB functions in principle and what can be achieved with it, it is time to take a closer look at the three central data objects of the method: descriptors, descriptor variants, and cross-impact data. Hidden beneath the surface of the technical application are many differentiations and design decisions that can be handled well or poorly, unconsciously or purposefully. Chapter 6 therefore presents four "dossiers" that compile key information about these data objects and how to collect them. The dossiers are designed to provide in-depth information and can be dispensed with when reading the book for the first time. However, the reader is then advised to read the chapter in a second pass.

Chapter 7 Theory is followed by a visit to the workshops. Chapter 7 outlines four selected studies in which CIB was used by different research teams to analyze the future, to analyze systems or to critically review existing scenarios. The selection of examples is intended to reveal the thematic diversity of the application of the method. The examples also make clear that it is precisely in disciplines with entrenched methodological traditions that new perspectives can be gained by using this still young method.

Chapter 8 The final chapter is dedicated to reflection. Based on the literature and the author's own practice, the chapter describes CIB's strengths but also the challenges it poses. The limitations of CIB are also addressed because a comprehensive understanding of the method has only been acquired when it has also been understood in which cases the use of this method is not promising.

Some of the book's content is presented in forms that require explanation. Where it seems useful, statistical analyses of method practice are presented in *statistics boxes*. These boxes are intended to enable the reader to position his or her own application within the spectrum of method applications. *Nutshells* are compact, self-contained presentations of selected analytical procedures. *Memos* (M for short) highlight important principles that one should remain aware of in method practice.

Several small examples of cross-impact matrices are used to illustrate methodological issues. Occasionally, these matrices are adopted from the literature, which is indicated accordingly. Mostly, however, *CIB miniatures* developed especially for didactic purposes are used. These miniatures do not claim to treat their respective topics substantially, and the analysis results they present should not be misunderstood as solid statements about the subject. The purpose of the miniatures is exclusively to demonstrate the method. The use of abstract matrices would prevent these demonstrations being misunderstood as content-oriented statements about the topics of the miniatures, but this approach would have reduced the miniatures' vividness.

The practical implementation of CIB analysis requires specialized computer software. At the time of printing this book, the free software *ScenarioWizard* is used almost exclusively in the published literature.[11] All CIB evaluations in this book were performed using Version 4.4 of this software. As an invitation to reproduce the method demonstrations, the *ScenarioWizard* project files for all miniatures used in the book are provided at https://cross-impact.org/miniatures/miniatures.htm.

Since this book is only intended as a support for CIB users and not as a general textbook about scenario methods, it makes little mention of other methods, and comparative methodological considerations are limited to a brief discussion of method alternatives in Sect. 8.5. The sole purpose of the text is to explain the CIB method, and it avoids burdening readers with explanations that are not necessary for this purpose. For more detailed information on other methods and for comparative analyses, I refer the reader to the general literature on scenario techniques and to more specifically focused research literature.

For the same reason, there is little discussion in the book of how scenarios, once created, can be used to prepare for the future by organizations or academics. This question is not CIB-specific and therefore does not require a CIB-specific discussion, and there are many good descriptions of the question in the general scenario literature.[12] The task of this book essentially ends with the completion of scenario analysis in the narrow sense, i.e., the development and analysis of scenarios.

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[12] E.g., Kosow and Gaßner (2008), Ringland (2006), Fink et al. (2002).