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Cross-impact balances
Applying pair interaction systems and multi-value Kauffman nets to multidisciplinary systems analysis

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Abstract

Cross-impact analysis is the name for a familiar method for multidisciplinary systems analysis in social sciences and management sciences, especially in technology foresight, technology assessment and scenario planning. A recently proposed form of cross-impact analysis, CIB, may be of interest for physicists, sociophysicists and complex network researchers because the CIB concept reveals considerable relations to some concepts of these research fields.

This article describes the basics of CIB analysis framework, its applications in the social sciences, and its relations to the equilibrium points of pair interaction systems, random graphs, and generalized Kauffman nets.

Therefore CIB can be seen as a merger of concepts originating in utterly different scientific fields. This may prove to be fruitful for both sides: For sociophysicists as an example of the application of complex network concepts in the social sciences and for cross-impact practitioners as a source of theoretical insights in the background of their tool.

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1. Introduction

The application of mathematical simulation methods in a social science context is fraught with difficulty. Probably the most critical aspect is that essential knowledge about economic, technological, social, and political systems and their interdependence is often restricted to qualitative insights and implicit mental models produced by experts. On the other hand, there is clearly a need for a suitable mathematical approach, because the state of extreme interdependence inside and between these systems frequently excludes the possibility of intuitive systemic understanding.

In the past, several techniques have been developed to meet the needs of interdependence analysis under the special conditions of multidisciplinary systems that include social systems. One of the most popular is a group of techniques

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denoted as *cross-impact analysis*. In these techniques, expert judgements about the interdependence of the main system variables are collected in a matrix scheme, and a more or less heuristic evaluation procedure is used to compute scenarios of probable system behaviour. Section 2 provides a short overview of the basics of cross-impact analysis.

Cross-impact analysis achieved considerable popularity among those concerned with projecting and analysing scenarios to do with political, economic, technological, or social change. However, the method has also been the focus of criticism. One major criticism was based on the fact that over the decades cross-impact research did not succeed in constructing a clear theoretical foundation for the different evaluation procedures used by this method. This begs the question whether the results of cross-impact analysis contain arbitrariness to an unknown degree.

In this context it should be noted that a recently proposed cross-impact method (cross-impact balance analysis, in short CIB analysis, cf. Section 3), shows considerable affinity with various mathematical objects well known in mathematical systems theory, physics, complexity research, and theoretical biology.

The main purpose of this paper is to make the method known to physicists and sociophysicists because it can be understood as a fruitful application of theoretical concepts to social sciences and management sciences. It will be shown in Section 4 that cross-impact data can be related to generalized forces, and the solutions of a CIB matrix can be associated with equilibrium states of a pair interaction system. Furthermore, CIB can be understood as an automata network with close links to well known automata net classes, such as INCAs (inhomogeneous cellular automata) and Boolean (Kauffman) nets (cf. Section 5).

2. Cross-impact analysis

The expression "cross-impact analysis" was the name given by Gordon and Hayward to a simulation method designed to calculate the basic impact of a political, social or technological event on the occurrence probability of other events [1]. The database of the method is the "cross-impact matrix", a matrix scheme which lists all relevant events in rows and also in columns. The matrix cells contain numbers which describe how the occurrence of the row event would affect the probability of the column event. Some events increase the probability of another event to a greater or lesser extent. Sometimes the probability of the other event is decreased, sometimes the impact is neutral. The idea is to collect the cross-impact data using expert judgements. The simulation procedure iterates the following steps: (1) choose an event by random; (2) decide if the event occurs by comparing a random number with the current event probability; (3) if the event occurs: recalculate the event probabilities of all remaining events using the cross-impact matrix; (4) discard the event from the list of events subject to further iteration. The repetition of this procedure yields statistical data about event probabilities, correlations and event sequences ("scenarios"). Gordon and Hayward demonstrated the application of the method to two examples which analysed *ex post* the political and technological pre-history of the implementation of the Minuteman nuclear missiles in the US and constructed future transportation sector scenarios.

In the years that followed, cross-impact analysis received considerable attention, positive as well as negative. Many modifications to the basic idea – using expert judgements on pair interactions within a system to calculate plausible scenarios – were suggested. Modified simulation algorithms were also proposed, e.g. in Ref. [2]. The analysis of trends and event/trend combinations were included [3–8]. Ways in which to inform special types of coupled dynamic systems using cross-impact data were developed [9–12]. More recently, some researchers proposed using fuzzy numbers as cross-impact data in order to deal with the uncertainty of expert judgements [13–15]. Other approaches use estimated conditional probabilities, joint probabilities or implausibility indices in order to characterize the relation between each pair of states [16–28].

As the theoretical research continued, many reports were written on the application of various methods to the development of business scenarios, political analysis and economic scenarios. To give some examples, Ref. [29] analysed the Dutch construction sector. Ref. [30] developed environmental protection policy scenarios. Ref. [31] reported the development of building scenarios for a power company. Ref. [32] used cross-impact analysis as a multicriteria decision aid (MCDA) to assist land evaluation authorities. Ref. [33] described the application to the future of the European automobile industry. Ref. [34] produced a case study on the textile industry in Indore, India. Ref. [35] demonstrated the usage of the method in project management. Refs. [36–38] applied cross-impact analysis to an analysis of the global and regional post-Kyoto climate protection policy.

In the past, it proved to be difficult to design evaluation procedures free of arbitrariness. It is for instance a mathematical fact that the set of conditional probabilities of event pairs does not fully determine the probability of a event sequence. All cross-impact methods with this aim require additional explicit or implicit assumptions that can be questioned (e.g. see the bitter debate about *SMIC74* [25,39–44]). Simulation type cross-impact methods are