Hypothesis-Driven Simulation Studies

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Assistance for the Systematic Design and Conducting of Computer Simulation Experiments

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Till dig.

Preface and Acknowledgements

This dissertation proposes an approach that facilitates the conducting of "Hypothesis-Driven Simulation Studies". It has been written in fulfillment of the requirements for the degree of *Doctor of Natural Sciences* (Dr. rer. nat.) at Faculty IV (Business Administration, Economics, Mathematics, Computer Science, Business Informatics) of Trier University, Germany. From 2014 to 2019, during the writing of this thesis, I have worked as research assistant at the chair for *Business Information Systems I* of *Prof. Dr.-Ing. Ingo J. Timm*, who also was my doctoral supervisor. The research of the chair mainly focuses on the design of intelligent assistance systems by means of distributed artificial intelligence and computer simulation techniques.

Even though the circumstances under which I finished my master's studies and started to work as part of the research group were devastating and uncertain, I received friendly and loving support and encouragement from a number of great persons, to whom I would like to express my sincerest gratitude. At first I would like to thank my doctoral supervisor *Ingo Timm*, who first introduced me to computer simulation, got me enthusiastic about its systematic scientific use, and generously provided me with an inspiring and unrestricted research environment. In the course of the following years, the efforts and investments in various research initiatives paid off and we had the pleasure of watching the group grow and to welcome a number of new great colleagues. I am grateful for the support, exchange, experiences, and encouragement *Jan Ole Berndt*, *Tjorben Bogon*, *Sarah Gessinger*, *Sebastian Görg*, *Bernhard Heß*, *Axel Kalenborn*, *Lukas Reuter*, *Stephanie Rodermund*, and *Ralf Schepers* provided me with. With respect to the subject of thesis, my special thanks go to *Colja Becker* for his valued contributions as part of his master's thesis and for many fruitful discussions that led to the development of the *FITS* language.

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Abstract

Computer simulation has become established in a two-fold way: As a tool for planning, analyzing, and optimizing complex systems but also as a method for the scientific instigation of theories and thus for the generation of knowledge. Generated results often serve as a basis for investment decisions, e.g., road construction and factory planning, or provide evidence for scientific theory-building processes. To ensure the generation of credible and reproducible results, it is indispensable to conduct systematic and methodologically sound simulation studies. A variety of procedure models exist that structure and predetermine the process of a study. As a result, experimenters are often required to repetitively but thoroughly carry out a large number of experiments. Moreover, the process is not sufficiently specified and many important design decisions still have to be made by the experimenter, which might result in an unintentional bias of the results.

To facilitate the conducting of simulation studies and to improve both replicability and reproducibility of the generated results, this thesis proposes a procedure model for carrying out *Hypothesis-Driven Simulation Studies*, an approach that assists the experimenter during the design, execution, and analysis of simulation experiments. In contrast to existing approaches, a formally specified hypothesis becomes the key element of the study so that each step of the study can be adapted and executed to directly contribute to the verification of the hypothesis. To this end, the *FITS* language is presented, which enables the specification of hypotheses as assumptions regarding the influence specific input values have on the observable behavior of the model. The proposed procedure model systematically designs relevant simulation experiments, runs, and iterations that must be executed to provide evidence for the verification of the hypothesis. Generated outputs are then aggregated for each defined performance measure to allow for the application of statistical hypothesis testing approaches. Hence, the proposed assistance only requires the experimenter to provide an executable simulation model and a corresponding hypothesis to conduct a sound simulation study. With respect to the implementation of the proposed assistance system, this thesis presents an abstract architecture and provides formal specifications of all required services.

To evaluate the concept of Hypothesis-Driven Simulation Studies, two case studies are presented from the manufacturing domain. The introduced approach is applied to a NetLogo simulation model of a four-tiered supply chain. Two scenarios as well as corresponding assumptions about the model behavior are presented to investigate conditions for the occurrence of the bullwhip effect. Starting from the formal specification of the hypothesis, each step of a Hypothesis-Driven Simulation Study is presented in detail, with specific design decisions outlined, and generated intermediate data as well as final results illustrated. With respect to the comparability of the results, a conventional simulation study is conducted which serves as reference data. The approach that is proposed in this thesis is beneficial for both practitioners and scientists. The presented assistance system allows for a more effortless and simplified execution of simulation experiments while the efficient generation of credible results is ensured.

Keywords: Automation of Simulation, Hypothesis Testing, Simulation Studies, Epistemology of Simulation, Assistance System.