

Automatic Generation and Validation of Simulation Based Digital Twins

A Data-driven Framework and Case Study Application

Author: Daniel Fischer

Supervisor: Prof. Christian Schwede

Program: Research Master Data Science

Institution: Hochschule Bielefeld (HSBI)

Submission Date: February 18, 2025

Contents

Glossary	—	5
1 Introduction	—	6
1.1 Problem Statement		6
1.2 Objectives of the Thesis		6
1.3 Motivation and Relevance		6
1.4 Research Questions and Hypotheses		6
1.5 Thesis Structure / Methodology		6
2 Theoretical Foundations and State of the Art	—	7
2.1 Digital Twin: Definition and Concepts		7
2.1.1 Types of Digital Twins		7
2.2 Data-Driven Modeling: Principles and Methods		7
2.3 Material Flow Planning and Simulation		7
2.4 Validation and Verification in Simulation		7
3 State of Research	—	8
3.1 Existing Approaches for Validation and Verification of Digital Twins		8
3.2 Automatic Model Generation and Its Reasons/Challenges		8
3.3 Limitations of Current Standard Formats and Data Structures		8
3.4 Gaps and Open Questions in the Research		8

4	Methodology and Framework Development	9
4.1	Requirements Analysis (Functional, Technical Data Format)	9
4.2	Conceptualization	9
5	Implementation of the Framework	10
5.1	Technical Implementation of Model Generation . . .	10
5.2	Automatic Validation of the Generated Model	10
5.3	Use of External Information Sources for Model Verification	10
5.4	Interfaces to Material Flow Systems and Data Collection	10
6	Case Study: Validation of a Digital Twin in the Production System	11
6.1	Description of the Production System and Available Data	11
6.2	Construction of the Digital Twin for the Scenario . .	11
6.3	Conducting the Validation Experiments	11
6.4	Results and Interpretation: Limitations and Errors of the Model	11
6.5	Limitations and Falsifiability of the Model Based on Real Data	11
7	Discussion of the Results	12
7.1	Critical Reflection on the Framework Development .	12
7.2	Limitations of Automatic Validation	12
7.3	Significance and Robustness of the Developed Methods	12
7.4	Implications for Research and Practice	12
8	Conclusion and Outlook	13

Contents	4
8.1 Summary of the Key Results	13
8.2 Answering the Research Questions	13
8.3 Outlook: Possible Further Development of the Frame- work	13
8.4 Recommendations for Practical Application	13

Glossary

computer is a programmable machine that receives input, stores and manipulates data, and provides output in a useful format 1

FPS Frame per Second. 1

Linux is a generic term referring to the family of Unix-like computer operating systems that use the Linux kernel. 1

real number include both rational numbers, such as 42 and $\frac{-23}{129}$, and irrational numbers, such as π and the square root of two; or, a real number can be given by an infinite decimal representation, such as 2.4871773339... where the digits continue in some way; or, the real numbers may be thought of as points on an infinitely long number line. 1

Chapter 1

Introduction

1.1 Problem Statement

1.2 Objectives of the Thesis

1.3 Motivation and Relevance

1.4 Research Questions and Hypotheses

1.5 Thesis Structure / Methodology

Chapter 2

Theoretical Foundations and State of the Art

2.1 Digital Twin: Definition and Concepts

2.1.1 Types of Digital Twins

2.2 Data-Driven Modeling: Principles and Methods

2.3 Material Flow Planning and Simulation

2.4 Validation and Verification in Simulation

Chapter 3

State of Research

- 3.1 Existing Approaches for Validation and Verification of Digital Twins**
- 3.2 Automatic Model Generation and Its Reasons/Challenges**
- 3.3 Limitations of Current Standard Formats and Data Structures**
- 3.4 Gaps and Open Questions in the Research**

Chapter 4

Methodology and Framework Development

4.1 Requirements Analysis (Functional, Technical Data Format)

4.2 Conceptualization

Waswani et al., 2017

Chapter 5

Implementation of the Framework

5.1 Technical Implementation of Model Generation

5.2 Automatic Validation of the Generated Model

5.3 Use of External Information Sources for Model Verification

5.4 Interfaces to Material Flow Systems and Data Collection

Chapter 6

Case Study: Validation of a Digital Twin in the Production System

6.1 Description of the Production System and Available Data

6.2 Construction of the Digital Twin for the Scenario

6.3 Conducting the Validation Experiments

6.4 Results and Interpretation: Limitations and Errors of the Model

6.5 Limitations and Falsifiability of the Model Based on Real Data

Chapter 7

Discussion of the Results

7.1 Critical Reflection on the Framework Development

7.2 Limitations of Automatic Validation

7.3 Significance and Robustness of the Developed Methods

7.4 Implications for Research and Practice

Chapter 8

Conclusion and Outlook

8.1 Summary of the Key Results

8.2 Answering the Research Questions

8.3 Outlook: Possible Further Development of the Framework

8.4 Recommendations for Practical Application

Bibliography

Waswani, A., Shazeer, N., Parmar, N., Uszkoreit, J., Jones, L., Gomez, A., Kaiser, L., & Polosukhin, I. (2017). Attention is all you need. *NIPS*.