Thesis 1 I have created a multidimensional network model to model the broad spectrum of production systems. The method supports the production flow analysis and even pinpoints the development potentials. With the clustering of similar components and machines the method achieves similar manufacturing optimization as the most advanced manufacturing cell algorithms[1].

A multilayer network model for the exploratory analysis of production technologies had been proposed. To represent the relationships between products, parts, machines, resources, operators and skills, standardized production and product-relevant data was transformed into a set of bi- and multipartite networks. This representation was beneficial in production flow analysis (PFA) that was used to identify improvement opportunities by grouping similar groups of products, components, and machines. It had been demonstrated that the goal-oriented mapping and modularity-based clustering of multilayer networks can serve as a readily applicable and interpretable decision support tool for PFA, and the analysis of the degrees and correlations of a node can identify critically important skills and resources. The applicability of the proposed methodology had been demonstrated by a well-documented benchmark problem of a wire-harness production process. The results confirm that the proposed multilayer network can support the standardized integration of production-relevant data and exploratory analysis of strongly interconnected production systems.

Thesis 2 I have created a method, that can automatically transform a system dynamics model to a network, enabling the network science methods to capture key elements, similar elements and modules, and it could also capture the dynamics between modules. The transformed network supported view of stock and flow diagram to map the network, the state space view and the views were separately analyze to support both the modeler and the communication of the model. The method enabled comparation between system dynamics models[2].

As the complexity of sustainability-related problems increases, it is more and more difficult to understand the related models. Although tremendous models have been published recently, their automated structural analysis is still absent. This study provided a methodology to structure and visualise the information content of these models. The novelty of the present approach was the development of a network analysis-based tool for modellers to measure the importance of variables, identify structural modules in the models and measure the complexity of the created model, and thus enabling the comparison of different models. The overview of 130 system dynamics models from the past five years had been provided. The typical topics and complexity of these models highlighted the need for tools that support the automated structural analysis of sustainability problems. For practising engineers and analysts, nine models from the field of sustainability science, including the World3 model, were studied in detail. The results highlighted that with the help of the developed method the experts could highlight the most critical variables of sustainability problems (like arable land in the Word3 model) and could determine how these variables are clustered and interconnected (e.g. the population and fertility are key drivers of global processes). The developed software tools and the resulted networks all have been made available online.

Thesis 3 I have created a method to analyze Linked Data by network science methods. I have introduced a new multidimensional

multidimensional network notation to support this method, by introducing the dimensions of the nodes. I demonstrated that frequent pattern mining can be applied to reveal statistically significant correlations between layers[3].

Triplestores or RDF stores are purpose-built databases used to organize, store and share data with context. Knowledge extraction from a large amount of interconnected data requires effective tools and methods to address the complexity and the underlying structure of semantic information. We proposed a method that generates interpretable multi-layered network from an RDF database and utilises frequent itemset mining of the edge and node dimensions to extract informative segments of the resulted multidimensional

multidimensional network. To demonstrate the usability and effectiveness of the methodology, we analysed how the science of sustainability and climate change are structured using the Microsoft Academic Knowledge Graph. The results confirmed that frequent itemset mining provides an informative sampling of RDF databases. In the case study the algorithm has formed networks of disciplines to reveal the significant interdisciplinary science communities in sustainability and climate change. The constructed multi-layer network then enabled an analysis of the significant disciplines and interdisciplinary scientific areas. To demonstrate the proposed knowledge extraction process, we searched for interdisciplinary science communities and then measured and ranked their multi-disciplinary effects. The analysis identified discipline similarities, pinpointing the similarity between atmospheric science and meteorology as well as between geomorphology and oceanography.

[1] T. Ruppert, G. Honti, and J. Abonyi, "Multilayer Network-Based Production Flow Analysis," *Complexity*, vol. 2018, p. 6203754, Jul. 2018, doi: 10.1155/2018/6203754.

[2] G. Honti, G. Dörgő, and J. Abonyi, "Review and structural analysis of system dynamics models in sustainability science," *J. Clean. Prod.*, vol. 240, p. 118015, 2019.

[3] G. Honti and J. Abonyi, "Frequent Itemset Mining and Multi-Layer Network-Based Analysis of RDF Databases," *Mathematics*, vol. 9, no. 4, Art. no. 4, Jan. 2021, doi: 10.3390/math9040450.