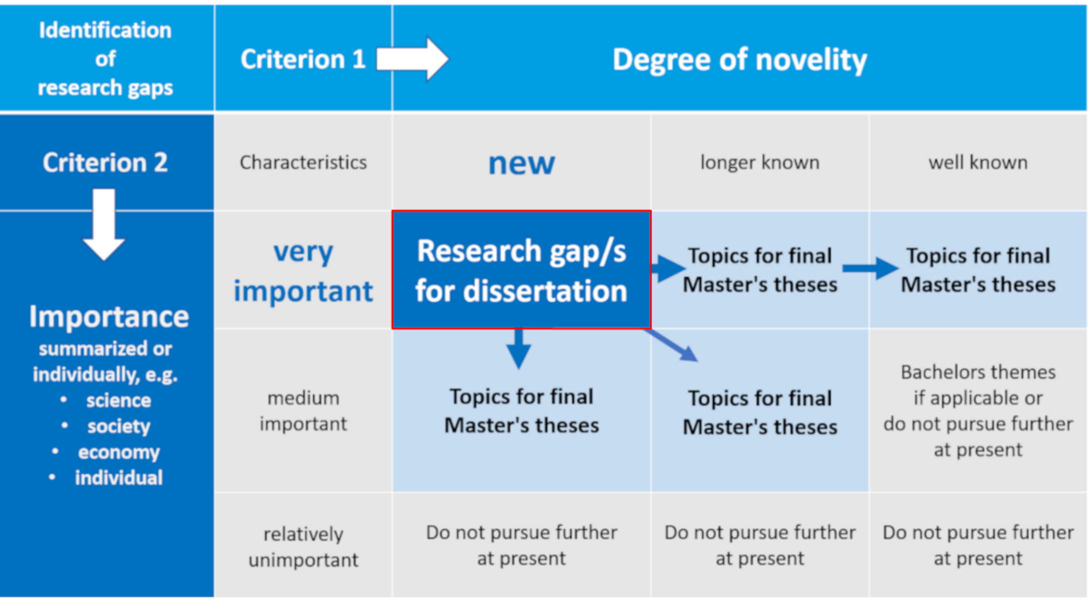

Questions

Procedures

Methods

Results

Application

17th International Doctoral Students Workshop on Logistics, Supply Chain and Production Management

18 June 2024, Magdeburg

Conference Proceedings

Institute of Logistics and Material Handling Systems

OTTO VON GUERICKE UNIVERSITÄT MAGDEBURG

&

Promotionszentrum Sozial-, Gesundheits- und Wirtschaftswissenschaften

17th International Doctoral Students Workshop on Logistics, Supply Chain and Production Management

June 18, 2024

Magdeburg

Editors:

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Impressum

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June 18, 2024 Magdeburg

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an der Otto-von-Guericke-Universität Magdeburg
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Foreword

Dear Ladies and Gentlemen,
Colleagues and Friends,

We are thrilled to announce the 17th International Doctoral Students Workshop on Logistics in 2024. As a gesture of our appreciation, we are delighted to present you with a comprehensive collection of conference proceedings.

How do the participating doctoral students benefit from our international doctoral workshop?

Recognising important aspects, logical sequence and argumentation in the dissertation:
The format templates of our workshop (paper, presentation) stringently ask about the motivation, the research gap and the research questions as well as the reasoned selection and, if necessary, modification of the research approach and research methods.
The research results achieved are evaluated, the benefits determined and further steps derived. This forces the doctoral students to explicitly address these aspects and apply a targeted, professional argumentation. This enables doctoral students to articulate their entire dissertation project linguistically (in writing and orally) and convey it in a compact manner.

Formulation, presentation and discussion in English:
The presentation and discussion will be in English. This also constitutes training for the doctoral candidate in the English language.

Reflection:
The workshop offers the opportunity to evaluate and self-reflect on one's own work status, the research path and the results of the dissertation. This should strengthen confidence in one's own work and promote self-confidence.

Suggestions and tips:
The scientific discussion with international, sometimes interdisciplinary colleagues usually provides new insights, new suggestions and useful tips. This should enrich the quality of your own work and ultimately lead to a successful conclusion with a high-quality result.

Social aspects:
One of the purposes of the workshop is to build networks between the participating national and international doctoral students. Forms such as the joint dinner the evening before, the technical discussions in the room and the breaks and individual discussions spent together on the day of the workshop serve to get to know each other.
In this way, the dissertation as an individual doctoral candidate should be accompanied by a stronger sense of togetherness. The exchange of people via Erasmus +, the Eastern Partnership Programme, the Pannonia Programme, DAAD Scholarship and other research projects can subsequently be used to deepen and consolidate the relationship. Joint online meetings or appointments for conferences are also typical.

Looking ahead, we eagerly anticipate hosting the 18th International Doctoral Students Workshop on Logistics, Supply Chain and Production Management on 16. & 17. June 2025. We sincerely hope to have the pleasure of welcoming all of you to Magdeburg, the captivating capital city of Saxony-Anhalt, next year.

Sincerely,

Prof. h. c. Dr.-Ing. Dr. h. c. (UCLV)
Elke Glistau

Prof. Dr.-Ing.
Sebastian Trojahn

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Scientific Papers

Self-Evaluation of the Dissertation: Guidance and Checklists

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Abstract

The International Doctoral Workshop for Logistics, Supply Chain and Production Management offers a good and proven presentation and reflection platform for the presentation and discussion of your own research work with international colleagues, both in the early stages of your doctorate and in the development process up to the preparation of your degree. In addition to coaching and valuable advice, the aim is to establish new international contacts and initiate networking, e.g. for the development of joint research work and subsequent publications. In addition, it aims to sharpen the focus on quality criteria for evaluating the dissertation and the entire doctoral process. This is to enable and encourage self-evaluation and thus targeted improvement by the doctoral candidate prior to the assessment by the examiners at the end of the doctoral phase. This paper qualifies and complements the publications [1] & [2] from 2011 and 2018.

1. Introduction and Motivation

First, two short and simple definitions:

- 'Doctorate' refers to the whole process of obtaining a Ph.D. degree, while
- Dissertation' refers to the written work that forms part of a doctorate.

When you start a doctoral project, you initially have an infinite number of tasks ahead of you.
A structured way of working and the ability to organise yourself helps to keep track and minimise the workload, even when interrupted.

This paper provides:

- the assessment criteria for a doctoral thesis / dissertation
- the principles of scientific work
- tips for efficient self-organisation
- different formats of a dissertation (classical monograph, cumulative dissertation) and
- a general overview of a structured doctoral process and relevant research activities.

2. Forms of doctorate / dissertation

We (Otto-von-Guericke-University Magdeburg & Universities in Saxony-Anhalt / Germany) currently offer two different forms of dissertation for doctoral programmes in our subject areas (cf. [3] & [4]):

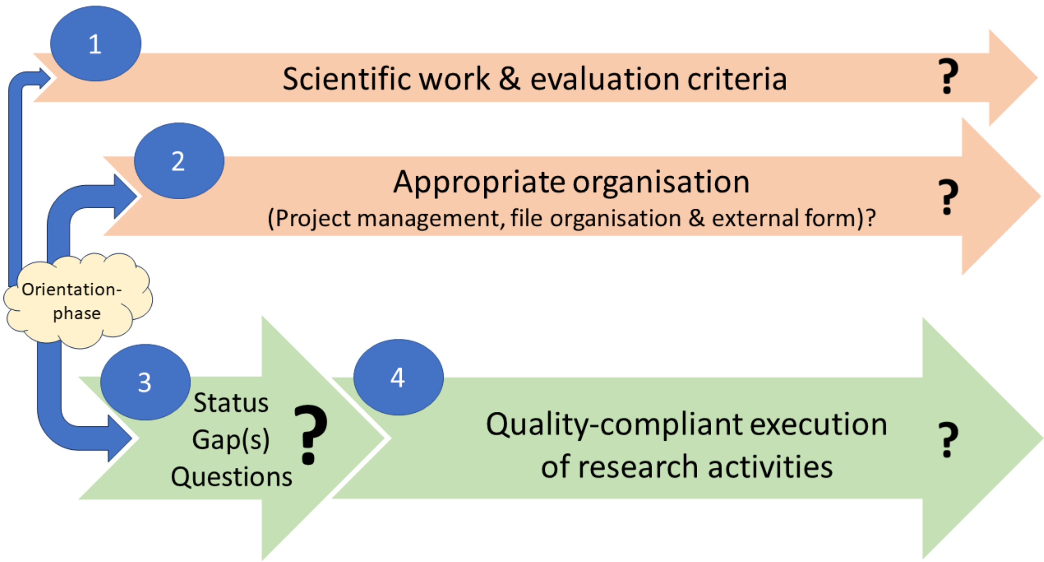

Figure 1: Content focus of this paper with regard to the dissertation

Form A: Doctorate with a classical dissertation:

- Monograph of about 120 pages in the main part (plus appendices),
- additional publications and discussions at internationally recognised conferences and doctoral workshops,
- optional journal publications.

Form B: Doctorate with cumulative dissertation:

- At least 3 publications in high-impact, peer-reviewed journals.
- A manuscript of about 40 pages

Both forms A and B have in common that high quality scientific work is practised and that written work must be produced during the doctoral process. After a positive assessment of the written work, a colloquium with a presentation and discussion takes place. For details on this and on the overall assessment, see e.g. [3], [4].

The process that accompanies the publication is of enormous importance, as it iteratively publishes the research gap(s) and the methods for solving them, in order to ensure the quality assurance of the thesis and to avoid the submission of a thesis that has been worked on in the meantime, e.g. by someone else using a similar methodology.

This generally leads to the following questions for the doctoral candidate:

1. What are the important criteria for scientific work? When am I working in a recognised scientific way?
2. What formal mistakes can I avoid in my written work?
3. How can I identify a research gap?
4. When have I carried out each research activity to a high standard? What is assessed?

Figure 1 shows the focus areas of this paper as a timeline to illustrate their categorisation and context within the overall dissertation project.

3. Note 1: General criteria for scientific work

A short definition of scientific work is: "Scientific work is the search for reliable knowledge." [5]

This is not the place for a full scientific discussion of this topic.
This paper is limited to providing important information and food for thought. Each doctoral programme also formulates its own quality criteria for the doctorate and the dissertation. Merseburg University of Applied Sciences (Germany) [6], for example, specifies these criteria:

- Quality during the preparation of the dissertation at all stages of the research process (e.g. topic identification, research gap, method selection and implementation).
- Relevance of the topic
- Methodology (descriptive statistics, independent familiarisation)
- Duration of the doctoral project
- Quality of results

- Degree of independence (especially for cumulative dissertations)
- Type and size of sample for empirical studies
- Acceptance at prestigious conferences (with a high rejection rate, well-known keynote speakers and organised by scientific associations)
- Good ratings in submissions and reviews, and de facto acceptance in high-impact journals (for cumulative theses)

These individual quality standards are initially based on the quality criteria for scientific work with a high degree of general validity. (cf. e.g. [5])
Based on [5], Table 1 characterises twelve important quality criteria of a scientific paper from [5], which are summarised and visualised in Figure 2.

Table 1: Checklist of important scientific quality criteria (extract from [5], see also Figure 2)

A General ethical criteria:
Honesty
• No plagiarism, deception, manipulation of data, fabrication of results
Objectivity
• Independent of personal preferences and attitudes, free from political and economic influences and interests • Be objective and neutral! • Choose your sources impartially! • Quote accurately and completely!
• **Fairness and fair play**
• Collegiality, mutual respect and recognition of others' achievements, teamwork, interdisciplinary exchange, global cooperation • Open communication
Responsibility
• Personal responsibility, responsibility to the team, to science and to the consequences of knowledge, • Measuring the impact of research
Requirement for novelty and importance of the topic & the results:
Originality
• What's new? How much is new? • New concept, new model, new solution, new method, new field of application to be developed? • Creation of new knowledge, linking of knowledge, lateral thinking? • Originality and quality take precedence over quantity!

First continuation of table 1:

Relevance
• **Scientific relevance:** Content with high informational value for basic, hybrid and applied research in my field or possibly other fields • **Practical relevance:** Solving practical problems • **Social relevance:** Solving problems with a social dimension (e.g. energy, climate**)** • **Personal relevance:** Relevance in terms of my development and building my own expertise
Ensuring traceability as an overall quality criterion:
Validity
• Checks whether what is to be measured (researched) is being measured (researched): • Clearly defined and delimited research question, • Representative samples • How meaningful are the results?
Reliability
• The same results should be obtained if the test is repeated! • Suitability of the measurement/test method, • Are the results stable and reliable?
Comprehensibility
• Scientific papers are published so that others can inform themselves and examine and utilise the new knowledge. This requires • Completeness • Systematic structure • Clear linguistic design, • = simple, short, concise, structured • Definition of important and new terms • Clear layout • Appropriate visual aids (headings, bulleted lists, illustrations, tables, formulae) • Explanation of abbreviations, symbols, formulae and illustrations
Logical argumentation
• Structuring arguments • Link arguments logically • Draw conclusions • Deductive arguments (the conclusion follows from the reasoning) • Inductive arguments (one infers the whole from individual observations) • Testing: Is the reasoning sufficient to draw conclusions? • Have I avoided wrong conclusions?

Second continuation of table 1:

Verifiability
• Something that cannot be verified cannot be confirmed or refuted => • Sources, solutions, evidence and results must be clearly disclosed and documented. • Courage to make mistakes: Mistakes and errors are part of the cognitive process and progress

4. Note 2: Projectmanagement and external form of the font

The efficiency of the process is also important for the success of the dissertation.

Project management: A doctoral project is an individual research project and therefore all project management methods and approaches known from the programme or new ones to be developed can and should be used.

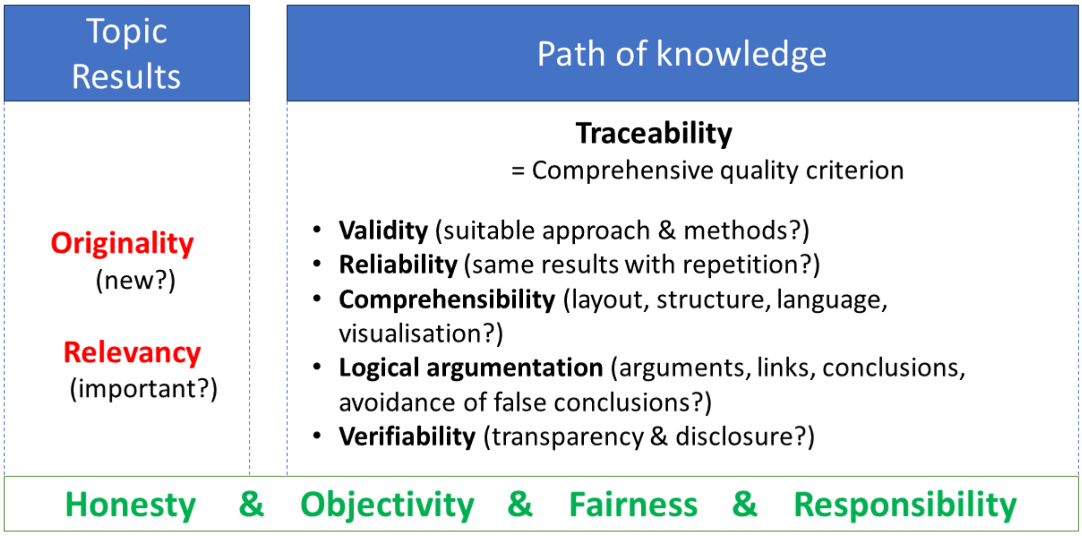

Figure 2: Scientific quality criteria (Own design using terms from [5])

This includes both the classical methods and procedures as well as agile methods and procedures.
For example, agile project management keeps the planning process open and changeable, dividing work packages into 'planned', 'in progress' or 'completed', define short deadlines (e.g. 4 weeks) after which a specific result should be available, and build in evaluation loops to improve this result.
Individual universities, colleges and doctoral centres provide support for project management. One example is the model plan of the Doctoral Centre of the Universities of Saxony-Anhalt (H2, Anhalt, Harz and Merseburg) (cf. [7]), which contains, among other things, work steps, forms of work and milestones and thus ensures a goal-oriented, continuous processing of the individual within a defined framework.

A second important point concerns the **organisation of writing** and includes one's own data management. By organising your own writing efficiently, you can avoid data loss, unnecessary rework, unnecessary errors and unnecessary unproductive search time.

In particular, it is always important to focus on the desired result.
This concerns the form of the dissertation with a systematic basic layout, the definition of the structure and lists, the figures, tables, enumerations and formulae, the linguistic design, etc.

This paper discusses this **form of written work** in more detail:
For publications in conferences, journals and books, templates are usually provided by the organiser or publisher and must be followed.

For a dissertation, there are usually no such specifications in the form of templates. Therefore, recommendations for the overall layout of the dissertation and for working with enumerations, figures, tables, formulae and references, as well as all lists, should be given here.

It is advisable to define an individual, outwardly appealing format template at the beginning of the dissertation and to edit and file all resulting work results in the correct format of the dissertation or manuscript in a structured manner, in addition to the publication of individual contributions.

This will allow you to work efficiently and save a lot of time and revision work, especially in the final stages.

It is recommended that figures, tables, formulae, etc. in the originals are clearly organised as individual folders and are correctly numbered and clearly labelled in the file name. For example, create a separate folder for original illustrations and a separate folder for original tables, etc.
It is also important to make permanent **backup copies** of the entire thesis to prevent data loss!

Defining your own format template for a dissertation includes:

- **Defining the document format** (e.g. paper format, margins, single or double sided, font, line spacing, 1st to maximum 4th order headings, spacing between text and headings, indentations)
- **Layout of lists** (table of contents, list of figures, list of tables, list of formulae, list of abbreviations, glossary, bibliography)
- **Standardised design of bulleted lists** (standardised indentation, only one, maximum two indentation characters)
- **Standardised layout of figures***
  In scientific texts, the term 'figure' is preferred. The term 'figure' includes illustrations, diagrams, graphics and photographs.
  (Font type and sizes, preferred shapes, colours used and their meaning, figure designation)
  Figures are usually given a figure number, a figure caption, relevant literature sources, do not forget the figure references if applicable)
- **Standardised design of tables** (e.g. table template, fonts and font size, table designation), tables are usually given headings, don't forget the table references!
- **Standardised design of formulas** (font, font size, formula number and explanation of all formula symbols with indication of the unit, if necessary also with reference to literature)
- **Standard formst of references and bibliography**
  (choose a common citation style, e.g. APA 7, and collect <u>all</u> necessary references in full).
  Wherever possible, collect the relevant pdf files in a separate folder so that you can quickly access this literature source again without having to search for it again.

The following recommendations apply to spelling and expression:

- For all non-native speakers, we recommend automatic checking with a word processor.
- The following applies to everyone: simple, clearly formulated sentences without any reinforcing words increase comprehensibility and make it easier to place commas.
- When expressing yourself, make sure that you use technical language and not 'corporate language' or 'colloquial language', e.g. do not use the term 'ant' but 'hand pallet truck'!
- Furthermore, one and the **same technical term** should always be used. You can refer to it in the introduction when you use the term for the first time, e.g: 'The Ishikawa diagram is also known as a fishbone diagram or cause-effect diagram. In the following, the term Ishikawa diagram is used exclusively in the dissertation.' In the following, the term 'Ishikawa diagram' will always be used in the dissertation. Terms that have different meanings in different contexts should be briefly defined in the text or in a glossary. (e.g. Kanban in logistics, Kanban in IT) to prevent misunderstandings and misinterpretations.
- The **labelling of figures, tables and formulae** should always reflect the content clearly and unambiguously. The aim should be to use short designations! To ensure clarity, identical designations should not be used.
- **Abbreviations** should be used sparingly. Nowadays, word-processors make it easy to replace an abbreviation originally used in writing with the full term. This significantly improves readability and at the same time increases comprehensibility! Abbreviations from the "Duden" dictionary do not belong in the list of abbreviations.
- When you create an **outline**, there must always be at least two subsections. Chapter 5, for example, is divided into 5.1. and 5.2. If there is only '5.1', then there is only chapter 5, without any further subdivision.

In summary, the authors' many years of practical experience have resulted in the tips in Table 2 for avoiding common formal errors.

Table 2: Checklist of typical formal errors in dissertations (author's research)

Aspect of form	Typical mistakes
Layout	• No standardised layout • Obvious impression of lack of accuracy and cleanliness • Numbering errors
Table of Contents	• Bullet points are not linguistically identical (sometimes verbs, sometimes nouns, sometimes short, sometimes long). • A bullet point has only one sub-point, i.e. there is only 3.1. and no 3.2.
List of figures	• Unclear figure captions • Figure caption does not reflect the content of the figure • Not properly indented
List of tables	• Table names not clear • Not all tables begin with capital letters
List of abbreviations	• Dictionary abbreviations included
References	• Missing references to figures, tables, formulae or literature
Figure design	• Inconsistent design (fonts, sizes, colours) • Poor legibility • Missing legends • Captions not always used • No clear explanation of figures
Table layout	• Inconsistent design (fonts, sizes, colours where appropriate) • Poor legibility • Missing legends • No table headings used • Unclear design
Formulas	• Formulas not numbered • Missing legend with explanation of the formula symbols and indication of the formula units • Formulas
Enumeration in the text	• Use of different bullet characters • Different indentation
Expression	• No use of standardised terms • Synonymous terms used • Colloquial language used • Operational expressions used • Nested sentences • Reinforcing words • Subjective opinion • No clear statement in the sentence
Spelling	• Incorrect comma placement
Bibliography	• Inconsistent style • Individual, missing information
Glossary	• Glossary or definitions are missing, although necessary

Continuation of Table 2

These notes can be used as a checklist for possible formal errors before submission of the thesis/manuscript.

5. Note 3: Procedure and some hints for identifying the state of knowledge and the research gap

Researching the state of knowledge, identifying research gaps and formulating research questions are crucial for the quality of the doctorate. (e.g. [8])
The research should be comprehensive, but at the same time efficient.

Recognised potential research gaps should be listed in a table to accompany the analysis process and roughly evaluated using an ABC classification according to the criteria of novelty and importance. A short verbal description is also helpful.

This combination of collection, evaluation and characterisation saves you from having to constantly rethink the facts.

The search should initially be somewhat broader in order to be narrowed down again as a result of the cognitive process.
The aim of this step is to subsequently select a research gap (or possibly several related gaps) for your own dissertation.

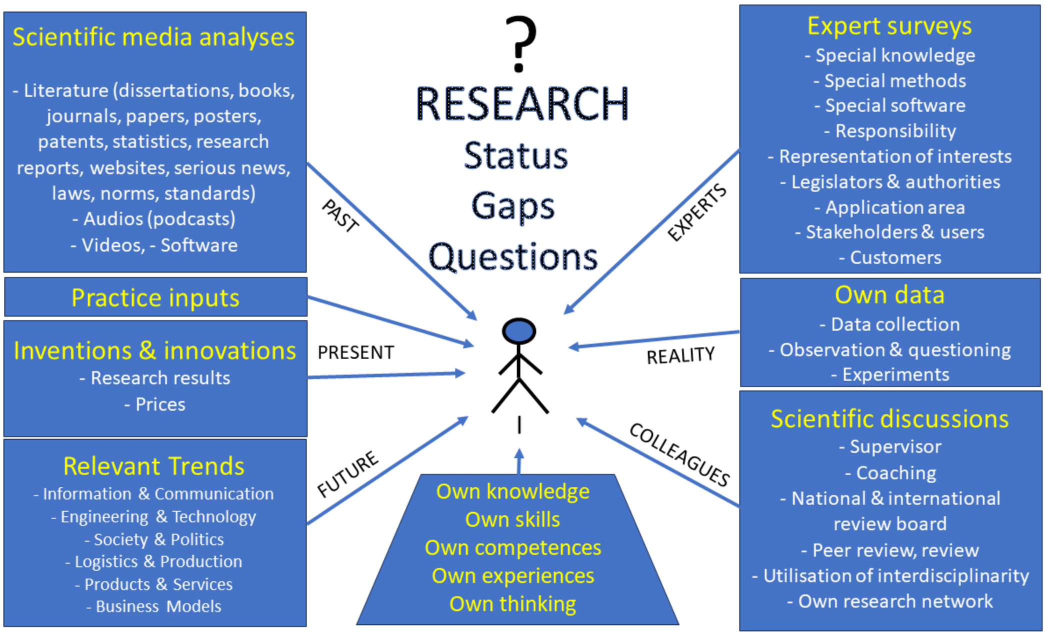

Figure 3: Holistic research to uncover the state of knowledge, identify a research gap(s) and formulate research questions

Ideally, this should be:

- in the A-range in terms of degree of novelty, i.e. new and at the same time
- in the A-range in terms of importance, i.e. very important.

In the search and identification of the research gap, several perspectives must be combined (see Figure 3 and the following list and explanations in Table 3):

(1) Past: Literature and media analysis:
The already published knowledge that is externalised and accessible through a scientific literature & media analysis. (see additional references at the end of the paper)

(2) Current expert knowledge (cf. Figure 3):
This expert knowledge is usually only available in an internalised form and can only be accessed via specific expert discussions & expert interviews. Experts can be identified, e.g. with regard to certain procedures:

- **Procedures** (e.g. Business reengineering experts),
- **Methods** (e.g. simulation experts),
- **Tools** (e.g. SPSS experts)
- **Expertise** (e.g. business insiders)
- **Industry experts**, application experience),
- **Responsibilities** (e.g. ministries, authorities),
- **Interest groups** (e.g. ADAC, ADFC)

(3) Specialist discourse and change of perspective: Conscious use of the interdisciplinary nature of logistics and supply chain management (cf. [9])

(4) Current status quo of the application area, current objectives, current contexts (e.g. laws, general environment, competition, etc.). As a rule, this involves analysing operational data and key figures, as well as making your own observations and notes. If necessary, the 'hard' data should be supplemented with 'soft' data.

(5) Future: Record and list trends and developments from publications, expert discussions, current daily news.

The recorded data, information and the researched knowledge gathered must always be critically examined! (e.g. truthfulness, up-to-dateness, etc., cf. the comments on data quality criteria in Table 4 - 'perceive' row).

The following Table 3 contains some advice on conducting scientific research.

Table 3: Notes on holistic, scientific research

Search focus	**Important notes on research**
Overall overview of the research	Draw up a table with the following information in it: • What need to be researched & • What types of research should be used?
The past: scientific literature & media analysis	• Where: Research locations: Internet + Scientific databases (e.g. Google scholar, Researchgate, Statista, IEEE, Scopus, Web of Science Core Collection, Emerald. SciELO, DOAJ) + Search engines (e.g. Google, Bing, MetaGer)+ Chatbots (AI) + Library databases + Publishers (e.g. Springerlink)
	• What: prompts, search terms and search strategies: 'playing' with search terms: e.g. abbreviations, synonyms and close terms, English terms, superordinate and subordinate terms, combinations of terms.
	• Classic term entry (e.g. *; ''; Boolean operators; exclusion of irrelevant knowledge areas, desired file type).
	• Restrictions - Temporal limitation - Language area - Application area • Use of different search strategies (broad search, deep search)
	• Examples of scientific approaches, e.g. Webster & Watson and many others.

First continuation of table 3

Search focus	• **Important notes on research**
	• Document the search clearly. It must be comprehensible! • 'View' at least the first 100 references, compile a bibliography
	• Try to map the structure of knowledge, try to identify "experts" and institutions, journals etc. that make comparisons and evaluations
	• Extract the most important knowledge, always 'clean' with the (multiple) literature references => choose the most appropriate form of presentation!
	• Use all media appropriately!
Experts	• Draw up a list of experts, depending on the context, your own company, universities and colleges, research institutes etc.
	• Fill in the expert profiles
	• Prepare interviews
	• Focus and establish appropriate contacts
	• Prepare documentation and evaluation
Experts Professional discourse and other perspectives	• Professional discourse with e.g. peers, other doctoral candidates, the supervisor, colleagues etc.
	• Discussing research with others, arguing professionally (use the team effect!)
	• Consciously adopt and obtain other perspectives (e.g. information technology, economics, environment, technology, social, maintenance, (cf. [9])
Analysis of the current situation	• If necessary, a separate analysis of the current situation in the company, in the process or in the environment is required

Second continuation of table 3

Search focus	• **Important notes on research**
Trends	• Research current trends, e.g: DHL, BVL, SCM, manufacturing trends
	• Think about the impact of trends and new developments on your own topic and record and consider your thoughts in writing

The knowledge gathered according to Table 3 should then be related to your own knowledge and experience.
Apply, include daily news
=> Supplement search results from (1) with own knowledge, categorise, develop own ideas etc., establish references.

The authors recommend preparing the research results in such a way that ideas and suggestions (possibly with references) are first collected and localised in a portfolio. See Figure 4 for an illustration.

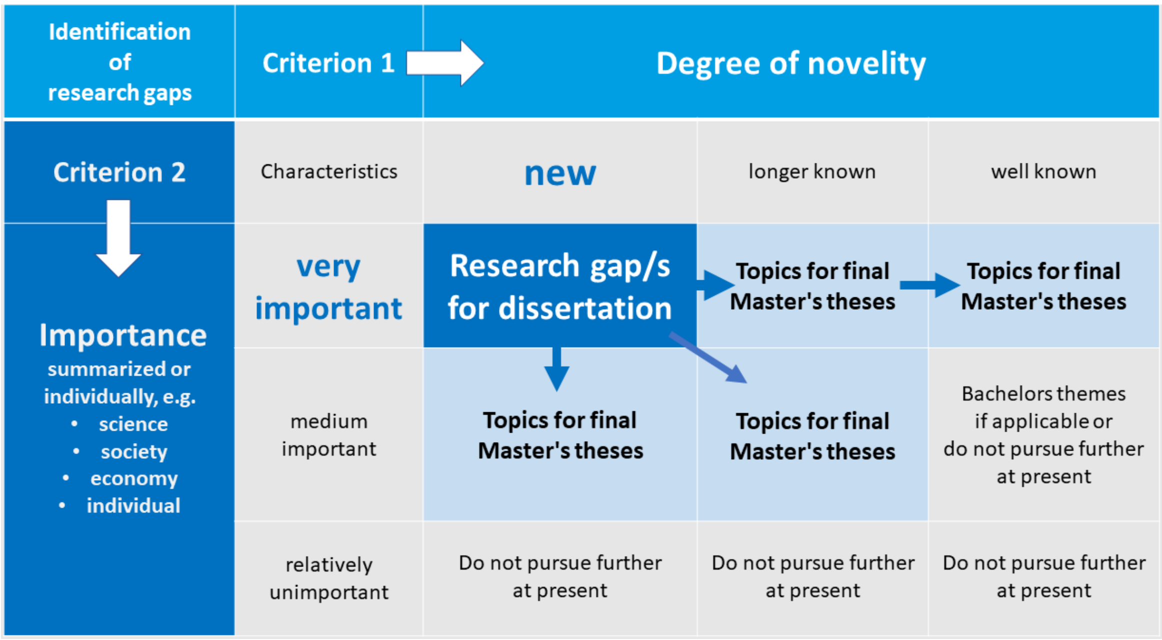

Figure 4: Portfolio for prioritising research topics and research questions

The two key criteria here are the degree of novelty and importance (relevance). The authors' recommendations for the other areas are shown in Figure 4.

The ideas for research gaps that fall into the 'A-A field' (area new & very important) are characterised in a table below. Importance can be demonstrated by verbal or quantified values (statistics, metricsm, arguments). The degree of novelty should be proven by reference to the research findings.

The topics of the secondary fields may play a role in rounding off Master's theses or Bachelor's theses.In order to increase the efficiency of the research process, the authors encourage students not only to find, substantiate and argue the importance of their own dissertation topic in a self-serving manner, but also to evaluate and develop the research area they have researched in a generally beneficial manner. In this way, a much greater contribution to research can be made through the use of accompanying, deliberately designed theses (Master's theses, Bachelor's theses and Master's project theses) than is possible and achievable through a single, focused dissertation.

In this sense, this perspective enables a broadening of the perspective in such a way that the dissertation not only demonstrates one's own ability to carry out independent, scientific work, but also develops strategic competences in the sense of research management in parallel.

6. Note 4: Good scientific practice for conducting research

Logistics as an applied research discipline comprises typical research activities that are used in a doctorate phase and dissertation.

These research activities are:

- Perceiving
- Informing
- Describing
- Inventing
- Analysing
- Modelling
- Planning
- Optimise
- Improve
- Explain
- Carry out / Execute
- Evaluate
- Reflect
- Recognise / Understand
- Decide
- Self-learning (is also an important component.)

Table 4 provides information on when these research activities are carried out correctly in terms of good scientific practice.

Table 4 can serve as a useful checklist and basis that can and must be adapted and expanded for your own dissertation.
If you look at each row in Table 4 below, you will see that the specific assessments in each table row can be generalised,
e.g. like this:

- Current overview knowledge researched and prepared?
- Objectives defined and prioritised qualitatively and quantitatively?
- Tasks defined and delimited?
- Targeted, well-founded selection of procedures and methods?
- Efficient way of working?
- Technically correct use of the methods (modification and improvement if necessary)?
- Comprehensible documentation of the path of knowledge?
- Reasoned, correct conclusions?
- Documentation of errors and mistakes?
- Holistic evaluation of the results?
- Generalisation of possible uses and initiation of appropriate communication channels for the dissemination of research results to other knowledge domains?
- Relevance: scientific, economic, societal, social, personal?
- Self-checking: Consistently scientific work?

Each row of the table can and must be completed with these questions in mind.

For the sake of clarity and simplicity, this has been omitted in this paper.

However, if these Tables 4 are to be re-used by universities, colleges and doctoral centres, these above-mentioned aspects should be added.

However, the focus points should remain clearly visible. This could be achieved by prioritisation or colour grading (e.g. black-grey).

Table 4: Quality-orientated execution of research activities:

Research activity	Methods Category	Evaluation
Perceive & inform	- Training the senses - Scientific literature analysis - Internet research & Chatbots (AI) - Data collection (technics) - Data collection (humans) - Experimentation	- Data quality criteria (including relevance, scope, representativeness, completeness, accuracy, consistency, unambiguity, comparability, authenticity, availability, comprehensibility, integrity, validity, traceability, data protection, scalability, etc.). (Cf. also [10]) - At least three perspectives: - **Past** (evaluation of publications, historical data), - **Present** (current news, expert knowledge, own (current) data collection, practical input) and - **Future** (trends and developments, visions) - Type and extent of data collection and / or data gathering - Correctness of the experiment (planning, structure, implementation, evaluation)
Describe	- Technical language - Formulas - Symbols - Key figures - Special description models	- Adequacy of terminology, including categorisation and hierarchy of terms as well as definition of terms - Appropriateness of the forms of presentation and their correct use - Completeness of the explanations of figures and formulae - Correctness of the illustrations - Correct and justified choice of the model
Invent	- Creativity techniques - TRIZ - Chatbots like ChatGPT	- Originality and potential significance of the new ideas - Proven own contribution - Effort versus potential benefits, risks, protection of inventions
Analyse	- Statistics - Stochastics - Classification - Algorithms - Pattern recognition	- Selection of the right analysis objectives and aspects (e.g. sustainability (economic, environmental, social), errors, flexibility, time, security, transparency, agility, scalability) - Correct prioritisation - Mathematical correctness - Adequate presentation, correct conclusions
Modeling	- Holistic logistics models - Customised logistics models: > Customer requirements & constraints > Business models > Object models > Process models > System models > Infrastructure models > Key figure systems and individual key figures - Drawings - Graph theory - Operational models - Structural models - Simulation models - Reliability theory - Visualisation - Animations - Digitisation	- Objectivity and quality of mapping - Sound justification for model selection - Assessment of model suitability - Correct use of the model - Use of appropriate key figures - Appropriate visualisation (VR, AR, 3D, 2D, digital twin)

First continuation of table 4:

Research activity	Methods Category	Evaluation
Plan	- Scenario technique - Forecasting methods - Estimation methods - Structural models - Process organisation - Calculation methods - Variant formation - Layout methods - Project management methods - Agile methods	- At least 3 scenarios considered? Best case, trend case, worst case - Calculation and estimation reasonable, correctly applied? - Reasonable selection and characterisation of the chosen structural model chosen (e.g. network, point, line, island, spine, matrix, ring) - Logical, functional, temporal, spatial - Reasoned choice and correct application of calculation methods - Reasonable creation of variants and evaluation based on the target variables - Evaluation of the overall solution
Optimize	- Inventory theory - Linear optimisation based on objective functions; often multi-criteria optimisation - Design of experiments (DoE)	- Correct task definition - Correct target functions and limits for non-involved target variables - Correct and efficient experimental design and execution - Holistic approach, seldom partial optimization
Improve	- Kaizen - Business Process Reengineering (BPR) - Lean practices - Standards - Benchmarking - Six Sigma - Reference solutions - Research work - Logistics 4.0	- Utilisation of all improvement approaches and conscious selection of relevant improvement methods - Evaluate the developed improvement solution - Define and, if possible, quantify of the results: Visions, strategies, trends, goals, models, procedures, reference solutions, prototypes, master plan for implementation, master plan for roll-out - Critical reflection on the solution - Development of tips for the broad use of the results

Explain	- Theorising
	- Formulate hypotheses
	- Define laws
	- Formulate rules
	- Designing case studies
	- Designing a sample solution
		- Correct application of:
		  - Empiricism,
		  - Logical thinking
		  - Induction, deduction
		- Language, concepts, expression
		- \`Rules' for rules (as commandments, short, understandable)
		- Classification methods, selection of representative types
		- Ensuring representativeness, generalising
		- Given, sought, procedure, results and evaluation

Execute	- Supply chain network models - Sourcing methods - PPS - Traffic flow theory - Organisation theory - Control loops - Loops, cycles - Project management	Correct implementation in: - SCM models: design, plan, execute, control, improve, optimise, etc. - Sourcing methods: single sourcing, dual sourcing, modular sourcing, global sourcing - Classic PPS (MRP II, JIT, JIS, priority rules) or agile PPS - Simulation - Consideration of errors and exceptional situations - Scheduling, availability control, progress control, defect control, agile organisation

Second continuation of table 4:

Research activity	Method Category	Evaluation
Evaluate	- Valuation - Methods - Assessment objectives	Selection of the most appropriate evaluation (validation, verification, quantification) - Consideration and weighting of traditional, current and future objectives: Sustainability (economic, environmental, social), flexibility, etc.
Reflect	- Self-reflection - Team-reflection - Academic feedback - Theory-practice-reflection	Selection and correct use of evaluation methods: - Hand formula, spiral of reflection, funneling, - Presentation, argumentation, discussion - Conversation, workshop, presentation, interpretation - Theory-practice reflection model
Self-learning, self-study, Practice inter-disciplinarity	- Internet, all forms of media - Global literature and news - Experts - Practical experience - Interdisciplinarity	Utilise all opportunities to learn: - Chatbots - Scientific literature and media analysis - Perception from the real world (What do I see? What do I hear?) - Scientific discussions and chats - Tests, reference solutions, limits & rules of use - Synergetic linking of different sciences for the research of logistics

7. Results and discussion

This paper summarises four important tips for doctoral students:

1. Advice on how to practice academic writing
2. Advice on an accurate form as part of the self-organisation of writing
3. Tips on identifying the state of knowledge and the research gap
4. Tips for self-evaluation of the correct performance of typical logistics research activities.

The information has been systematised and explained in Tables 1 to 4 as an aid to subsequent use. Tables 1 to 4 can also be used as checklists:

Table 1: For self-assessment of consistent scientific work
Table 2: For checking form and avoiding formal errors
Table 3: For holistic research and identification of research gaps
Table 4: For self-checking the scientific accuracy of research activities

The research findings in this paper are largely based on our own practical experience of supervising more than 100 international doctorates. The value lies in the comprehensiveness of its findings, its summary nature and its rigorous systematic approach. Although the evaluation has not yet been completed, the research results can be assessed according to the following criteria and using the following methods:

- **Sufficient completeness** (through expert interviews),
- **Unambiguity** (by interviewing international doctoral students),
- **Comprehensibility** (through interviews with doctoral students),
- **Applicability** (validation & usefulness): through post-application survey
- **Proper prioritisation**/selection through professional advice and scientific debate
- **Accuracy** (verification) (by expert consultation and scientific discussion).

The limitations of these research results lie in the knowledge and experience of the authors.

What are the next steps in the research work?

- Professional discussion & processing of the professional critique
- Completing the criteria and notes
- Application of the checklists in practice and their gradual improvement
- Realisation of a common online FAQ platform for knowledge transfer to all international doctoral students 24/7
- Make the paper available & publicise it in other countries
- (e.g. Austria, France, Italy, Slovakia, Hungary, Ukraine, Cuba)
- Sharing the paper with the BVL (German) & the ELA (German & English)

Topics for further work could include:
1. What is the recommended structure of a dissertation?
2. What have been the typical research topics and research questions of dissertations in the last five years?
3. How can the state of research be recorded efficiently? (interviews with experts, own data collection and experiments, media analyses)

8. References

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[2] Schenk, M.; Glistau, E.; Trojahn, S. (2018): The dissertation - way and aim. In: 11th International Doctoral Students Workshop on Logistics 2018 Magdeburg: Institut für Logistik und Materialflusstechnik an der Otto-von-Guericke-Universität Magdeburg; ISBN 978-3-944722-71-9, pp. 21-27.

[3] Promotionsordnung der Fakultäten des Ingenieurcampus der Otto-von-Guericke-Universität Magdeburg vom 12.06.2023. published 14.06.2023. Amtliche Bekanntmachung Nr. 41/2023 der OVGU (in German). Link: Amtliche Bekanntmachung Nr. 41/2023 - ID 20142 (ovgu.de). Access: 5. March 2024.

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[5] Technische Universität Berlin: Qualitätskriterien wissenschaftlicher Arbeiten (pdf) Chapter 3: Wissenschaftsethik Qualitätskriterien (2024): https://www.static.tu.berlin/fileadmin/www/10002431/PDF_Studium_Lehre/Qualitaetskriterien_wissenschaftliche_Arbeiten_.pdf Access: 5. March 2024.

[6] Hochschule Merseburg. Qualität von Promotionen. PFWE, 07.10.2022. (E-Mail, Doreén Pick: prorektorat.forschung@hs-merseburg.de).

[7] Behrendt, F.; Schmidtke, N.; Trojahn, S.: Meine Promotion. Austausch PromZ-Studierende im Themenfeld Produktion und Logistik (19.02.2024): Microsoft Teams.

[8] Delfmann, W.; Kersten, W.; Stölzle, W.; ten Hompel, M.; Schmidt, T. (2017): Logistik als Wissenschaftzentrale Forschungsfragen in Zeiten der vierten industriellen Revolution. Positionspapier des Wissenschaftlichen Beirats der Bundesvereinigung Logistik (BVL). https://www.bvl.de/positionspapier-logistik40 Access: 5. March 2024.

[9] Glistau, E.; Coello Machado, N.I.; Trojahn, S. (2023): Logistics thinking - methods and interdisciplinarity. In: Multidiszciplináris Tudományok – Miskolc: Miskolc University Press, Bd. 13, Heft 2, pp. 176 – 186.

[10] Datenschutz-Grundverordnung (DSGVO) (2018): Comment GDPR applies throughout the EU and sets out comprehensive rules on data protection, including data quality requirements: i.e. https://www.datenschutzstelle.li/datenschutz/themen-z/datenrichtigkeit-und-datenqualitaet Access: 5. March 2024.

Appendix: Supplementary literature recommendations

Systematic literature analysis (SLA)

→ Guidelines:

Kitchenham, B.; Charters, S. M. (2007): Guidelines for performing systematic literature reviews in software engineering. Technical Report. Ver. 2.3. EBSE Technical Report. School of Computer Science and Mathematics. Keele University.

→ Procedure of the SLA:

Moher, D. et al. (2010): Preferred reporting items for systematic reviews and meta analyses: the PRISMA statement. In International journal of surgery (London, England) 8, Nr 5: pp.336 341. doi: 10.1016/j.ijsu.2010.02.007.

Mongeon, P.; Paul-Hus, A. (2015): The journal coverage of Web of Science and Scopus: a comparative analysis, Scientometrics, vol. 106, no. 1. pp. 213–228.

→ Emphasising the particular suitability of Scopus and Sciencedirect for economics and engineering:

Duong, L. N. K.; Chong, J. (2020): Supply Chain Collaboration in the Presence of Disruptions: A Literature Review. International Journal of Production Research 58:3488–3507, doi: 10.1080/00207543.2020.1712491.

→ Exemplary application of the SLA:

Schmidtke, N.; Behrendt, F.; Gerpott, F.T.; & Wagner, M. (2022): Integration of New Business Models in Smart Logistics Zones. International Journal of Supply and Operations Management 9 (1) p. 19.

Antons, O., Arlinghaus, J. (2022): Distributing decision-making authority in manufacturing – review and roadmap for the factory of the future, International Journal of Production Research, 60, no. 13:
doi: 10.1080/00207543.2022.2057255 pp. 4342-4360.

Scientific work (all in German)

Qualifizierung der Graduate Academy der OVGU Magdeburg. www.grs.ovgu.de
Access: 5. April 2024.

Leitfaden für wissenschaftliches Arbeiten.
www.spw.ovgu.de
Access: 5. April 2024.

Hinweise zum wissenschaftlichen Arbeiten – Cultural Engineering www.cult-eng.ovgu.de
Access: 5. April 2024.

Leitfaden zur Erstellung wissenschaftlicher Beiträge und Abschlussarbeiten für Studierende der Berufs- und Wirtschaftspädagogik. www.wp.ovgu.de
Access: 5. April 2024.

Expert interview (all in German)

Gläser, J; Laudel, G. (2010): Experteninterviews und qualitative Inhaltsanalyse. 4. Edition. VS Verlag. Wiesbaden. ISBN 978-3531172385.

Mayring, P. (2002): Einführung in die qualitative Sozialforschung. Weinheim, Basel: Beltz Verlag, 2002. 3-407-3-407-25252-8.

Agile project management (all in German)

Neumann, M. (2023): Projekt Safari 2: Das Handbuch für agiles Projektmanagement. Campus Publisher books.google.com.
ISBN 978-3593516844

Helbling, T. (2023): Agile Projektmanagement - Methoden. Einfluss auf die Kaufabsicht in der Vorkaufphase und auf die Kundenzufriedenheit in der Nachkaufphase. kumulative Dissertation of the University Freiburg / Schweiz. sonar.ch.
doi10.51363/unifr.eth.2022.007

Timinger, H. (2024): Modernes Projektmanagement. Mit traditionellem, agilem und hybridem Vorgehen zum Erfolg. 2. Edition. Wiley.
ISBN: 978-3-527-84163-9

Trends

Hint: The following organizations publish trends on an ongoing basis.

Please research the current links yourself on the following websites:

→ Logistics
Bundesvereinigung für Logistik (BVL).
www.bvl-trends.de.
Access: 5 April 2024

DHL (Abkürzung der Gründer Dalsey, Hillblom &Lynn) Logistics Trend radar
www.dhl.com
Access: 5. April 2024.

→ Technical logistics
WGTL. Jährliche Fachkolloquien der WGTL
www.wgtl.de
Access: 5. April 2024.

→ Production & production technology
Wissenschaftliche Gesellschaft für Produktionstechnik (WGP)
www.wgp.de
Access: 5. April 2024.

→ Supply Chain Management
TU Wien (2024): 23 Supply Chain Management Trends im Überblick. www.tu wien.at/ace/news/news/supply-chain-management-trends
Access: 5. April 2024.

Selbstevaluierung der Dissertation: Leitfaden und Checklisten

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DOI: http://dx.doi.org/10.25673/116278

Abstrakt
Der Internationale Doktorandenworkshop für Logistik, Supply Chain und Produktionsmanagement bietet eine gute und langjährig erprobte Präsentations- und Reflexionsplattform, um die eigene Forschungsarbeit im Rahmen der Promotion sowohl im frühen Anfangsstadium als auch im Entstehungsprozess bis hin zur Vorbereitung des Abschlusses vorzustellen und mit internationalen Fachkolleginnen und Kollegen zu diskutieren. Neben einem Coaching und wertvollen Hinweisen sollen auch neue, internationale Kontakte geknüpft und eine Vernetzung z.B. zur Erarbeitung gemeinsamer Forschungsarbeiten und aufbauenden Publikationen initiiert werden.
Zur Ergänzung soll dieses Paper den Blick dafür schärfen, welche Qualitätskriterien bei der Bewertung der Dissertation und des gesamten Promotionsprozesses herangezogen werden. Damit soll vor der Evaluierung durch die Gutachter am Ende der Promotionsphase, eine Eigenevaluierung und damit eine gezielte, eigene Verbesserung durch den Doktoranden ermöglicht und angeregt werden. Dieses Paper qualifiziert und ergänzt die Publikationen [1] & [2] aus den Jahren 2011 und 2018.

1. Einführung und Motivation
Zunächst zwei kleine, einfache Begriffsklärungen:

- „Promotion“ ist der gesamte Prozess zur Erlangung eines Doktortitels, während
- „Dissertation“ die schriftliche Arbeit im Rahmen einer Promotion bezeichnet.

Wenn man mit einem Promotionsvorhaben beginnt, hat man zunächst unendlich viele Aufgaben vor sich. Eine strukturierte Arbeitsweise und die Fähigkeit zur Selbstorganisation helfen, auch bei Unterbrechungen, den Überblick zu bewahren und den Aufwand zu minimieren.

Dieses Paper vermittelt:

- die Evaluierungskriterien einer Promotion / Dissertation,
- die Prinzipien wissenschaftlicher Arbeit,
- Hinweise zur effizienten Selbstorganisation,
- verschiedene Formate einer Dissertation (klassische Monografie, kumulative Dissertation) und
- einen Gesamtüberblick auf einen strukturierten Promotionsprozess und relevante Forschungstätigkeiten.

2. Formen der Promotion / Dissertation
Grundsätzlich gibt es bei uns (Otto-von Guericke-Universität Magdeburg & Hochschulen in Sachsen-Anhalt / Deutschland) aktuell zwei unterschiedliche Formen der Dissertation, um in unseren Fachgebieten zu promovieren. [3], [4]:

Form A: Promotion mit einer klassischen Dissertation:

- Monografie mit ca. 120 Seiten im Hauptteil (plus Anlagen),
- zusätzlich Publikation und Diskussion in international anerkannten Konferenzen sowie Doktoranden-Workshops,
- optional Journal-Publikationen.

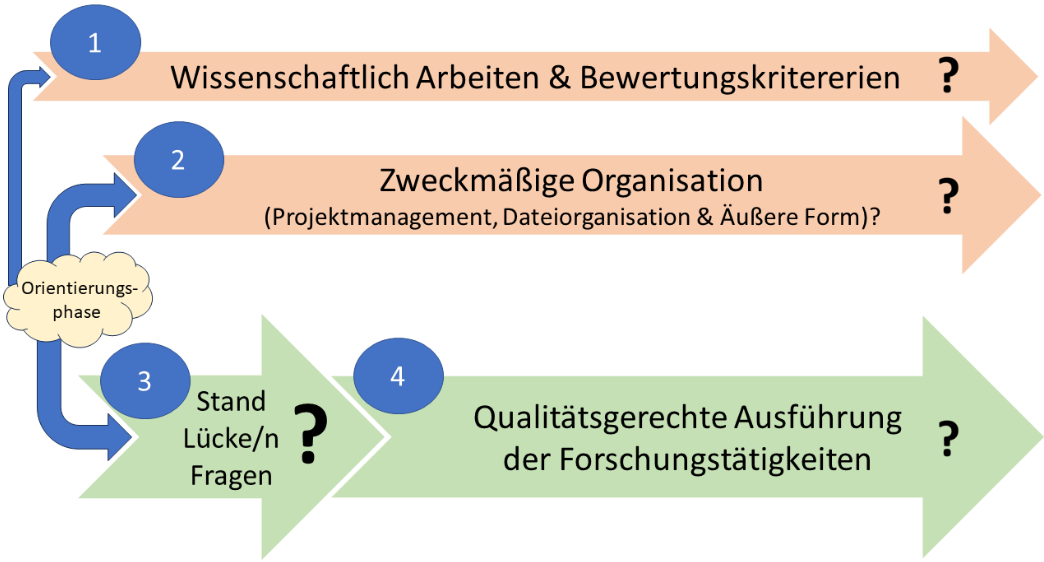

Abbildung 1: Inhaltliche Schwerpunktsetzung dieses Papers bezüglich der Dissertation

Form B: Promotion mit einer kumulativen Dissertation:

- mindestens 3 Paper in hoch gerankten, begutachteten (Peer review) Journalen
- Mantelschrift von ca. 40 Seiten

Beiden Formen A und B ist gemeinsam, dass hochwertiges, wissenschaftliches Arbeiten praktiziert wird und schriftliche Ausarbeitungen im Promotionsprozess anzufertigen sind. Nach nachgewiesener positiver Bewertung der schriftlichen Leistungen findet ein Kolloquium mit Vortrag und fachlicher Diskussion statt. Einzelheiten dazu und zur Gesamtbewertung siehe z.B. [3], [4].

Der Begleitprozess der Publikation ist von enormer Bedeutung, da dieser die Forschungslücke(n) und Lösungsmethoden iterativ veröffentlicht, um die Qualitätssicherung der Doktorarbeit abzusichern und um nicht am Ende eine Arbeit abzugeben, die in der Zwischenzeit z.B. durch Jemand anderen mit einer ähnlichen Methodik bearbeitet wurde.

Daraus ergeben sich für den Doktoranden im Allgemeinen folgende Fragen:

1. Was sind wichtige Kriterien für das wissenschaftliche Arbeiten? Wann arbeite ich anerkannt wissenschaftlich?
2. Welche Formfehler kann ich in den schriftlichen Ausarbeitungen vermeiden?
3. Wie identifiziere ich eine Forschungslücke?
4. Wann habe ich die einzelnen Forschungstätigkeiten qualitätsgerecht ausgeführt? Was wird dabei bewertet?

Im Abbildung 1 sind die Schwerpunkte dieses Papers als Zeitstahl dargestellt, um deren Einordnung und den Zusammenhang in den Rahmen des gesamten Dissertationsvorhabens zu verdeutlichen.

3. Hinweis 1: Allgemeine Kriterien für das wissenschaftliche Arbeiten

Eine kurze Definition zum wissenschaftlichen Arbeiten lautet: „Wissenschaftliches Arbeiten ist das Suchen nach gesicherten Erkenntnissen.“ [5]

An dieser Stelle soll zu diesem Thema keine breite wissenschaftliche Diskussion geführt werden. Dieses Paper beschränkt sich darauf, wichtige Hinweise und Denkanstöße zu geben. Jede Promotionsstelle formuliert zudem eigene Qualitätskriterien für die Promotion und Dissertation. Die Hochschule Merseburg (Deutschland) [6] gibt z.B. vor:

- Qualität während der Erstellung der Dissertation in allen Stufen des Forschungsprozesses (u.a. Themenfindung, Forschungslücke, Methodenauswahl und -durchführung)
- Relevanz des Themas
- Methode (deskriptive Statistiken, eigenständige Einarbeitung)
- Dauer der Promotion
- Ergebnisqualität
- Grad der Eigenständigkeit (v.a. bei kumulativen Dissertationen)
- Stichprobenart und -größe bei empirischen Untersuchungen
- Annahme auf renommierten Konferenzen (mit hoher Ablehnungsquote, bekannten Keynote-Speakern und durchgeführt von wissenschaftlichen Verbänden)

- Gute Bewertungen bei Einreichung und Bewertung sowie faktisch Annahme in hochrangigen Journals (bei kumulativen Dissertationen).

Basis dieser individuellen Qualitätsmaßstäbe sind dabei zunächst mit einer großen Allgemeingültigkeit die Qualitätskriterien für das wissenschaftliche Arbeiten. [5]
Tabelle 1 charakterisiert auf Grundlage von [5] zwölf wichtige Qualitätskriterien einer wissenschaftlichen Arbeit aus [5], die zusammenfassend in Abbildung 2 visualisiert werden.

Tabelle 1: Checkliste zu wichtigen, wissenschaftlichen Qualitätskriterien (Extrakt aus [5], vgl. dazu auch Abbildung 2)

Allgemeine ethische Kriterien:
Ehrlichkeit
• Keine Plagiate, Täuschungen, Daten-Manipulationen, Erfinden von Ergebnissen
Objektivität
• Unabhängig von persönlichen Vorlieben und Einstellungen, frei von politischen und wirtschaftlichen Einflüssen und Interessen • Seien Sie sachlich und neutral! • Wählen Sie unvoreingenommen die Quellen! • Zitieren Sie richtig und vollständig!
Fairness und Fair Play
• Kollegialität, gegenseitiger Respekt und die Anerkennung der Leistung von anderen, Teamarbeit, interdisziplinärer Austausch, weltweite Kooperationen • Offene Kommunikation
Verantwortung
• Selbstverantwortung, Verantwortung gegenüber dem Team, der Wissenschaft und den Folgen der neuen Erkenntnisse, • Messen der Tragweite der Forschungsarbeit
Anspruch an Neuheit und Wichtigkeit des Themas & der Ergebnisse:
Originalität
• Was ist neu? Wieviel ist neu? • Neues Konzept, neues Modell, neuer Lösungsweg, neue Methode, neu zu erschließendes Anwendungsgebiet? • Neues Wissen schaffen, Wissen verknüpfen, Querdenken? • Originalität und Qualität haben Vorrang vor Quantität!
Relevanz
• **Wissenschaftliche Relevanz:** Inhalte mit einem hohen Informationswert für die Grundlagenforschung, die Angewandte Grundlagenforschung und die Angewandte Forschung meines Gebietes oder ggf. anderer Gebiete • **Praxisrelevanz:** Lösen von Praxisproblemen

Fortsetzung der Tabelle 1:

• **Gesellschaftliche Relevanz:** Lösen von Problemen gesellschaftlicher Dimension (z.B. Energie, Klima) • **Eigene Relevanz:** Bedeutung bezüglich meiner Entwicklung und dem Aufbau von meinem, eigenem Spezialwissen
Sicherung der Nachvollziehbarkeit als umfassendes Qualitätskriterium, umfasst:
Validität
• Prüft, ob das gemessen (erforscht) wird, was gemessen (erforscht) werden soll: • Klar definierte und abgegrenzte Fragestellung bzw. Fragestellungen • Repräsentative Stichproben • Wie aussagekräftig sind die Ergebnisse?
Reliabilität
• Bei Wiederholung der Untersuchung muss man zu den gleichen Ergebnissen gelangen! • Eignung der Mess- /Untersuchungsmethode, • Ergebnisse stabil und zuverlässig?
Verständlichkeit
• Wissenschaftliche Arbeiten werden veröffentlicht, damit andere sich informieren und das neue Wissen prüfen und nutzen können. Dies erfordert: • Vollständigkeit, Systematischer Aufbau • Klare sprachliche Gestaltung = einfach, kurz, prägnant, gegliedert • Definition wichtiger und neuer Begriffe • Übersichtliches Layout • Geeignete Wahrnehmungshilfen (Überschriften, Aufzählungen, Abbildungen, Tabellen, Formeln) • Erläuterung von Abkürzungen, Symbolen, Formeln und Darstellungen
Logische Argumentation
• Argumente aufstellen • Argumente logisch verknüpfen • Schlussfolgerungen ziehen • Deduktive Argumente (der Schluss ergibt sich aus den Begründungen) • Induktive Argumente (man schließt von Einzelfallbeobachtungen auf das Ganze) • Prüfen: Reichen die Begründungen aus, um Schlüsse zu ziehen? • Habe ich Fehlschlüsse vermieden?
Überprüfbarkeit
• Etwas, was nicht überprüfbar ist, kann man nicht bestätigen oder widerlegen => • Quellen, Lösungswege, Beweise und Ergebnisse sind anschaulich offenzulegen und zu dokumentieren. • Mut zu Fehlern: Fehler und Irrtum sind Teil des Erkenntnisprozesses und des Fortschritts

Abbildung 2: Wissenschaftliche Qualitätskriterien

4. Hinweis 2: Projektmanagement und äußere Form der Schrift

Wichtig für den Erfolg der Dissertation ist auch die Effizienz der Bearbeitung.

Projektmanagement: Ein Promotionsvorhaben ist ein individuelles Forschungsprojekt und deshalb können und sollen alle aus dem Studium bekannten oder auch neu zu erschließenden Projektmanagementmethoden und -vorgehenweisen zum Einsatz kommen.
Diese umfassen sowohl den klassischen Vorrat an Methoden und Vorgehensweisen als auch die agilen Methoden und Vorgehensweisen.
Mit einem agilen Projektmanagement hält man z.B. den Planungsprozess offen und veränderbar, teilt die Arbeitspakete in: „geplant", „in Arbeit" oder „fertig" ein, definiert sich kurze Fristen (z.B. 4 Wochen), nach denen ein bestimmtes Ergebnis vorliegen soll und baut Evaluierungsschleifen zur Verbesserung dieses Ergebnisses ein.
Einzelne Universitäten, Hochschulen und Promotionszentren geben Hilfestellungen zum Projektmanagement. Ein Beispiel ist der Musterplan des Promotionszentrums der Hochschulen in Sachsen-Anhalt (H2, Anhalt, Harz und Merseburg) (vgl. [7]), der u.a. Arbeitsschritte, Arbeitsformen und Meilen-steine enthält und so eine zielorientierte, kontinuierliche Bearbeitung des Einzelnen in einem definierten Rahmen sichert.

Ein zweiter wichtiger Punkt betrifft die **Organisation des Schreibens** und umfasst das eigene Datenmanagement. Mit einer effizienten eigenen Schreiborganisation vermeidet man Datenverlust, unnötigen Umarbeitungsaufwand, unnötige Fehler und unnötige, unproduktive

Suchzeiten. Dabei ist insbesondere immer die Orientierung am angestrebten Ergebnis wichtig.

Dies rückt die Form der Dissertation mit einem systematischen Grundaufbau der Gestaltung des Layouts, der Definition der Struktur und der Verzeichnisse, der Abbildungen, Tabellen, Aufzählungen und Formeln, der sprachlichen Gestaltung u.a. in den Fokus.

Im Rahmen dieses Papers soll diese **Form der schriftlichen Arbeit** etwas ausführlicher diskutiert werden:
Bei den Publikationen auf Tagungen, in Zeitschriften und Büchern werden in der Regel Formatvorlagen vom Veranstalter oder Verlag gestellt, die einzuhalten sind.

Für die Dissertation gibt es in der Regel solche Vorgaben in Form von Formatvorlagen nicht. Deshalb sollen an dieser Stelle Empfehlungen für das Gesamtlayout der Dissertationsschrift und die Arbeit mit Aufzählungen, Abbildungen, Tabellen, Formeln und Literaturangaben sowie allen Verzeichnissen gegeben werden.

Es empfiehlt sich, gleich am Anfang der Dissertation eine individuelle, äußerlich ansprechende **Formatvorlage** zu definieren und gleich alle entstehenden Arbeitsergebnisse, zusätzlich zu den Veröffentlichungen einzelner Paper, im richtigen Format der Thesis bzw. Mantelschrift zu editieren und strukturiert abzulegen. Das ermöglicht eine effiziente Arbeitsweise und spart speziell in der Endphase viel Zeit und Umarbeitungsaufwand.

Es ist zu empfehlen, die Abbildungen, Tabellen, Formeln usw. in Originalen übersichtlich als einzelne Ordner und gleich im Dateinamen richtig zu benummern und klar zu bezeichnen. So entsteht z.B. ein separater Ordner für die Originalabbildungen sowie ein separater Ordner für die Originaltabellen etc.

Wichtig sind auch **permanente Sicherheitskopien** der gesamten Arbeit, um einem Datenverlust vorzubeugen!

Zur Definition einer eigenen Formatvorlage für eine Dissertationsschrift gehören:

- **Festlegen des Dokumentenformats** (u.a. Papierformat, Ränder, ein- oder zweiseitig, Schriftart, Zeilenabstand, Überschriften 1. bis maximal 4. Ordnung, jeweilige Abstände des Textes zur Überschrift, Einrückungen)
- **Gestaltung der Verzeichnisse** (Inhaltsverzeichnis, Abbildungsverzeichnis, Tabellenverzeichnis, Formelverzeichnis, Abkürzungsverzeichnis, Glossar, Literaturverzeichnis)
- **einheitliche Gestaltung von Aufzählungen** (normierte Einrückung, nur ein, maximal zwei Einrückungszeichen)
- **einheitliche Gestaltung von Abbildungen*** In wissenschaftlichen Texten wird bevorzugt der Begriff „Abbildung" verwendet. Der Begriff Abbildung schließt Illustrationen, Diagramme, Grafiken und Fotos ein. (Schriftart und -größen, bevorzugte Formen, verwendete Farben und deren Bedeutung, Abbildungsbezeichnung) Abbildungen erhalten in der Regel eine Abbildungsnummer, eine Abbildungs-unterschrift, relevante Literaturquellen, vergessen Sie auch nicht ggf. die Abbildungsverweise)
- **einheitliche Gestaltung von Tabellen** (Tabellenvorlage, Schriftarten und -größe, Tabellenbezeichnung), Tabellen erhalten in der Regel Überschriften, vergessen Sie auch nicht die Tabellenverweise!
- **einheitliche Gestaltung von Formeln** (Schriftart, Schriftgröße, Formelnummer sowie die Erklärung aller Formelzeichen mit Angabe der Einheit, ggf. auch mit Literaturverweis)
- **einheitliche Gestaltung von Literaturverweisen** und Literaturverzeichnis (Wählen Sie eine gebräuchliche Zitierart z.B. APA 7 und sammeln Sie vollständig <u>alle</u> notwendigen Literaturangaben.) Dort, wo es möglich ist, sammeln sie die relevanten pdf-Dateien in einem separaten Ordner, um bei Bedarf schnell und ohne erneutes Suchen wieder Zugriff zu dieser Literaturquelle zu erhalten.

Zu **Rechtschreibung und Ausdruck** gibt es folgende Empfehlungen:

- Für alle Nicht-Muttersprachler empfehlen wir die automatische Überprüfung mit einem textverarbeitenden Programm.
- Für alle gilt: **einfache, klar formulierte Sätze** <u>ohne</u> jegliche Verstärkungswörter erhöhen die Verständlichkeit und erleichtern die Komma-Setzung.
- Beim Ausdruck ist darauf zu achten, dass Fachsprache und keine „Unternehmens-sprache" und keine „Umgangssprache" verwendet werden, z.B. nicht den Begriff „Ameise", sondern „Handhubwagen" verwenden!
- Ferner sollte immer ein und derselbe **Fachterminus** verwendet werden. Man kann einleitend, wenn man den Begriff das erste Mal verwendet, darauf verweisen, z.B.: „Das Ishikawa Diagramm wird auch als Fischgrätendiagramm oder Ursache-Wirkungs-Diagramm bezeichnet. Nachfolgend wird in der Dissertationsschrift ausschließlich der Begriff Ishikawa-Diagramm verwendet." Danach verwendet man in der Dissertationsschrift immer den Begriff „Ishikawa-Diagramm". Begriffe, die in unterschiedlichen Kontexten unterschiedliche Bedeutung haben, sollten im Text oder in einem Glossar kurz definiert werden. (z.B. Kanban in der Logistik, Kanban in der Informatik), um Missverständnissen und Fehlinterpretationen vorzubeugen.
- Die **Bezeichnung von Abbildungen, Tabellen und Formeln** sollte immer klar und eindeutig den Inhalt widerspiegeln. Dabei sind <u>kurze</u> Bezeichnungen anzustreben! Gleiche Bezeichnungen dürfen zur Wahrung der Eindeutigkeit <u>nicht</u> vorkommen.
- Mit **Abkürzungen** sollte man sparsam umgehen. Durch die textverarbeitenden Programme kann man heute einfach eine zunächst beim Schreiben genutzte Abkürzung mit dem vollen Begriff ersetzen. Das erhöht deutlich die Lesbarkeit und erhöht gleichzeitig die Verständlichkeit! Abkürzungen aus dem Duden gehören nicht in das Abkürzungs-verzeichnis.
- Wenn man eine **Gliederung** erstellt, muss es immer mindestens zwei Unterpunkte geben: Kapitel 5 unterteilt sich z.B. in 5.1. und 5.2. Wenn es nur ein 5.1 gibt, bleibt es bei nur Kapitel 5, ohne eine weitere Untergliederung.

Zusammenfassend ergeben sich aus den jahrelangen, praktischen Erfahrungen der Autoren die in Tabelle 2 gesammelten Hinweise zur Vermeidung häufig auftretender Formfehler.

Tabelle 2: Checkliste typischer Formfehler bei Dissertationen (Eigenes Ergebnis)

Formaspekt	Typische Fehler
Layout	• Kein einheitliches Layout • Offensichtlicher Eindruck fehlender Präzision und Sauberkeit • Nummerierungsfehler
Inhalts-verzeichnis	• Keine sprachlich gleiche Bezeichnung der Gliederungspunkte (mal Verben, mal Substantive, mal kurz, mal lang) • Ein Gliederungspunkt hat nur einen Unterpunkt, d.h. es gibt nur 3.1. und kein 3.2.
Abbildungs-verzeichnis	• Abbildungsbezeichnungen nicht eindeutig • Abbildungsbezeichnung gibt nicht den Inhalt der Abbildung wider • Nicht sauber eingerückt
Tabellen-verzeichnis	• Tabellenbezeichnungen nicht eindeutig • Nicht alle Tabellen mit Großbuchstaben begonnen
Abkürzungs-verzeichnis	• Es sind Abkürzungen aus dem Duden enthalten
Verweise	• fehlende Verweise auf Abbildungen, Tabellen, Formeln oder Literatur
Abbildungs-gestaltung	• Keine einheitliche Gestaltung (Schriftart, Schriftgrößen, Farben) • Schlechte Lesbarkeit • Fehlende Legende • Nicht immer Abbildungsunterschriften verwendet • Keine klare Abbildungsaussage
Tabellen-gestaltung	• Keine einheitliche Gestaltung (Schriftart, Schriftgrößen, ggf. Farben) • Schlechte Lesbarkeit • Fehlende Legende • Nicht immer Tabellenüberschriften verwendet • Unübersichtliche Gestaltung
Formeln	• Formeln nicht benummert • Fehlende Legende mit Erläuterung der Formelzeichen und Angabe der Formeleinheiten

Fortsetzung der Tabelle 2:

Formaspekt	Typische Fehler
Aufzählung im Text	• Unterschiedliches Aufzählungszeichen benutzt • Unterschiedliche Einrückung
Ausdruck	• Keine einheitlichen Begriffe, sondern synonyme Bezeichnungen verwendet • Umgangssprache verwendet • Betriebliche Ausdrücke verwendet • Schachtelsätze • Verstärkungswörter • Subjektive Meinung • Keine klare Aussage im Satz
Recht-schreibung	• Kommasetzung fehlerhaft
Literatur-verzeichnis	• Kein einheitlicher Stil • Einzelne, fehlende Angaben
Glossar	• Glossar bzw. Definitionen fehlen, obwohl Notwendigkeit bestünde

Diese Hinweise können als Checkliste genutzt werden, um potenzielle Formfehler vor Abgabe der Thesis / Mantelschrift auszuschließen.

5. Hinweis 3: Vorgehensweise und einige Hinweise, um den Stand des Wissens und die Forschungslücke zu identifizieren

Die Recherche zum Stand des Wissens, die Identifikation der Forschungslücke/-n und das Aufstellen der Forschungsfragen entscheidet maßgeblich über die Qualität der Promotion. (z.B. [8]) Die Recherche sollte ganzheitlich, aber gleichzeitig auch effizient erfolgen.

Erkannte, potenzielle Forschungslücken sollten begleitend zum Analyseprozess tabellarisch gelistet und grob mit einer ABC-Klassifikation nach den Kriterien Neuheitsgrad und Wichtigkeit bewertet werden. Hilfreich ist auch eine kurze verbale Beschreibung. Diese Kombination aus Sammlung, Evaluation und Charakterisierung spart, dass man sich immer wieder neu in die Sachverhalte eindenken muss.

Die Suche sollte zunächst etwas breiter erfolgen, um danach im Ergebnis des Erkenntnisprozesses wieder streng fokussiert zu werden.
Ziel dieses Arbeitsschrittes ist es, dass man nachfolgend begründet eine Forschungslücke (oder ggf. auch mehrere zusammenhängende) für die eigene Dissertation auswählt.

Idealerweise sollte diese:

- im Bereich A bezogen auf den Neuheitsgrad, d.h. neu und gleichzeitig
- im Bereich A bezogen auf die Wichtigkeit, d.h. sehr wichtig, liegen.

Bei der Recherche und der Suche nach der Forschungslücke muss man mehrere Perspektiven vereinen (Vgl. Abbildung 3 und nachfolgende Aufzählung sowie die Erläuterungen in Tabelle 3):

(2) **Vergangenheit: Literatur- und Medienanalyse**: Das bereits publizierte Wissen, das externalisiert vorliegt und über eine wissenschaftliche Literatur- & Medienanalyse erschlossen werden kann. (siehe ergänzende Literaturhinweise am Ende des Papers)

(3) **Aktuelles Expertenwissen** (Vgl. dazu Abbildung 3): Dieses Expertenwissen liegt zumeist nur internalisiert vor und kann nur über spezielle Expertengespräche & Experteninterviews erschlossen werden. Experten können identifiziert werden z.B. bzgl. bestimmter:

- **Vorgehensweisen** (z.B. Business Reengineering Experten),
- **Methoden** (z.B. Simulationsexperten),
- **Tools** (z.B. SPSS-Experten)
- **Spezial-Wissen** (z.B. Unternehmensinsider, Branchenexperten, Anwendungserfahrung),
- **Zuständigkeiten** (z.B. Ministerien, Behörden),
- **Interessensvertretungen** (z.B. ADAC, ADFC)

(3) Fachlicher Diskurs und Perspektivwechsel: Bewusste Nutzung der Interdisziplinarität der Logistik und des Supply Chain Managements (Vgl. dazu [9])

(4) Aktueller Istzustand des Applikations-bereiches, aktuelle Zielstellungen, aktuelle Kontexte (z.B. Gesetze, allgemeines Umfeld, Konkurrenz etc.). Dazu sind in der Regel Betriebsdaten und Kennzahlen auszuwerten, eigene Beobachtungen und Erfassungen sind vorzunehmen. Ggf. sind die „harten“ Daten mit „weichen“ Daten aus b) zu komplettieren.

(5) Zukunft: Trends und Entwicklungen aus Publikationen, Expertengesprächen, aktuellen Tagesnachrichten aufnehmen und listen.

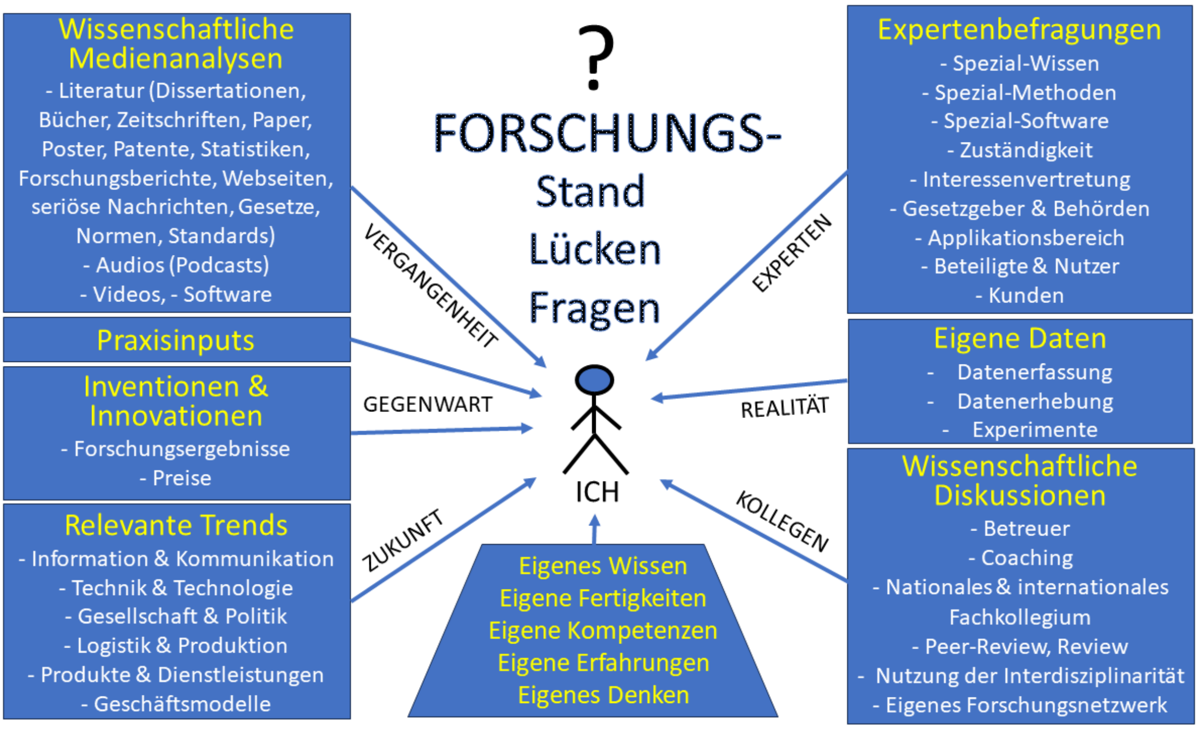

Abbildung 3: Ganzheitliche Recherche zum Aufdecken des Stands des Wissens, der Identifikation einer/mehrerer Forschungslücke/n und der Formulierung von Forschungsfragen

Die aufgenommenen Daten, Informationen und das recherchierte Wissen sind immer kritisch zu hinterfragen! (z.B. Wahrheitsgehalt, Aktualität etc., vgl. dazu die Ausführungen zu Qualitätskriterien von Daten in Tabelle 4, in der Zeile „wahrnehmen“)

Die folgende Tabelle 3 enthält Hinweise zur Durchführung der wissenschaftlichen Recherche.

Tabelle 3: Hinweise zur ganzheitlichen, wissenschaftlichen Recherche

Recherche-fokus	**Wichtige Hinweise zur Recherche**
Gesamt-überblick über die Recherche	Anfertigen einer Tabelle mit folgenden Angaben: • Was soll recherchiert werden & • Welche Recherchearten sollen genutzt werden?
Vergangen-heit: **Wissen-schaftliche Medien-analyse (Literatur, Audios, Videos)**	• Wo: Suchorte: Internet + Chat-Bots (KI) + Bibliotheksdatenbanken + Verlage (z.B. Springerlink) + Wissenschaftliche Datenbanken (z.B. Google scholar, Researchgate, Statista, IEEE, Scopus, Web of Science Core Collection, Emerald. SciELO, DOAJ) + Suchmaschinen (z.B. Google, Bing, MetaGer)
	• Was: Prompts, Suchbegriffe und Suchstrategien: mit Suchbegriffen „spielen“: z.B. Abkürzungen, Synonyme und nahe Begriffe, englische Begriffe, Begriffsüber- und -unterordnungen; Begriffskombinationen
	• Klassische Eingabe von Begriffen (z.B. *; „“; Boolesche Operatoren; Ausschluss irrelevanter Wissensgebiete, gewünschte Datei-Art
	• Begrenzungen, z.B. - Zeitliche Begrenzung - Sprachraum - Applikationsgebiet • unterschiedliche Suchstrategien anwenden (Breitensuche, Tiefensuche)
	• Beispiele für wissenschaftliche Vorgehensweisen z.B. Webster & Watson u.v.a.
	• Die Suche übersichtlich dokumentieren. Sie muss nachvollziehbar sein!
	• Mindestens die ersten 100 Hinweise „sichten“, Literaturliste aufstellen

1. Fortsetzung der Tabelle 3:

Recherche fokus-	**Wichtige Hinweise zur Recherche**
Fortsetzung Medienanalyse	• „Struktur des Wissens versuchen abzubilden, versuchen „Experten“ zu identifizieren und Institutionen, Zeitschriften etc. die Vergleiche und Bewertungen machen
	• Wichtigstes Wissen extrahieren, dabei immer mit den (mehreren) Literaturstellenarbeiten => Bestgeeignete Darstellungsform wählen!
	• Alle Medien geeignet nutzen!
Experten	• Expertenübersichtsliste anfertigen, je nach Kontext eigenes Unternehmen, Universitäten und Hochschulen, Forschungs-institute ec.
	• Expertensteckbriefe ausfüllen
	• Vorbereiten der Interviews
	• Fokussierung und geeignete Kontaktaufnahm,
	• Dokumentation und Auswertung vorbereiten
Fachlicher Diskurs und andere Perspektiven	• Fachlicher Diskurs mit z.B. Fachkollegen, anderen Doktoranden, dem Betreuer, Kollegen etc.
	• Forschungsarbeit mit anderen fachlich diskutieren, argumentieren (Teameffekt nutzen!)
	• Bewusst andere Perspektiven einnehmen und einholen (z.B. Informationstechnik, Wirtschaft, Umwelt, Technik, Ergonomie, Soziales, Instandhaltung, (Vgl. dazu [9])
Ist-Analyse	• Ggf. ist eine eigene Ist-Analyse im Unternehmen, im Prozess oder im Umfeld notwendig

2. Fortsetzung der Tabelle 3:

Recherche fokus	**Wichtige Hinweise zur Recherche**
Trends	• Aktuelle Trends recherchieren, z.B.: DHL, BVL, SCM, Produktionstrends
	• Auswirkungen der Trends und neuer Entwicklungen auf das eigene Thema durchdenken und Gedanken schriftlich festhalten und berücksichtigen

Das entsprechend der Tabelle 3 gesammelte Wissen ist nachfolgend mit dem eigenen Wissen, und eigenen Erfahrungen in Relation zu bringen. anwenden, Tagesnachrichten einbeziehen
=> Suchergebnisse aus (1) mit eigenem Wissen ergänzen, einordnen, eigene Ideen entwickeln etc., Bezüge herstellen.

Die Autoren empfehlen die Aufbereitung der Rechercheergebnisse derart, dass zunächst Ideen und Anregungen (ggf. mit Verweisen gesammelt) und in einem Portfolie verortet werden. Zur Verdeutlichung siehe Abbildung 4.

Dabei sind die beiden <u>entscheidenden</u> Kriterien Neuheitsgrad und Wichtigkeit (Relevanz).

Für die anderen Felder ergeben sich die in Abbildung 4 dargestellten Empfehlungen der Autoren.

Die im „**A-A-Feld**“ verorteten Ideen für Forschungslücken (Feld neu & sehr wichtig) sind nachfolgend in einer Tabelle zu charakterisieren.

Dabei kann die Wichtigkeit durch verbale oder quantifizierte Größen (Statistik, Kennzahlen) belegt werden.

Beim Neuheitsgrad sollte zum Nachweis der Bezug zu den Rechercheergebnissen erfolgen.

Die Themen der Nebenfelder können ggf. für abrundende Masterarbeiten oder auch Bachelorarbeiten eine Rolle spielen.

Die Autoren regen zur Steigerung der Effizienz des Forschungsprozesses an, nicht nur eigennützig das eigene Thema der Promotion zu finden, zu belegen und bzgl. der Wichtigkeit zu argumentieren, sondern allgemeinnützig den recherchierten Forschungsbereich aktuell zu bewerten und zu erschließen.

Das ermöglicht, mit begleitenden, bewusst gesetzten Abschlussarbeiten (Masterarbeiten, Bachelorarbeiten und Masterprojektarbeiten) einen wesentlich größeren Beitrag zur Forschung zu leisten als dies eine einzelne fokussierte Dissertation ermöglicht und leisten kann.

In dem Sinne ermöglicht diese Sichtweise eine Erweiterung des Blickwinkels derart, dass mit der Dissertation nicht nur die eigene Leistungsfähigkeit zur selbstständigen, wissenschaftlichen Arbeit nachgewiesen wird, sondern auch strategische Kompetenzen im Sinne eines Forschungsmanagements parallel entwickelt werden.

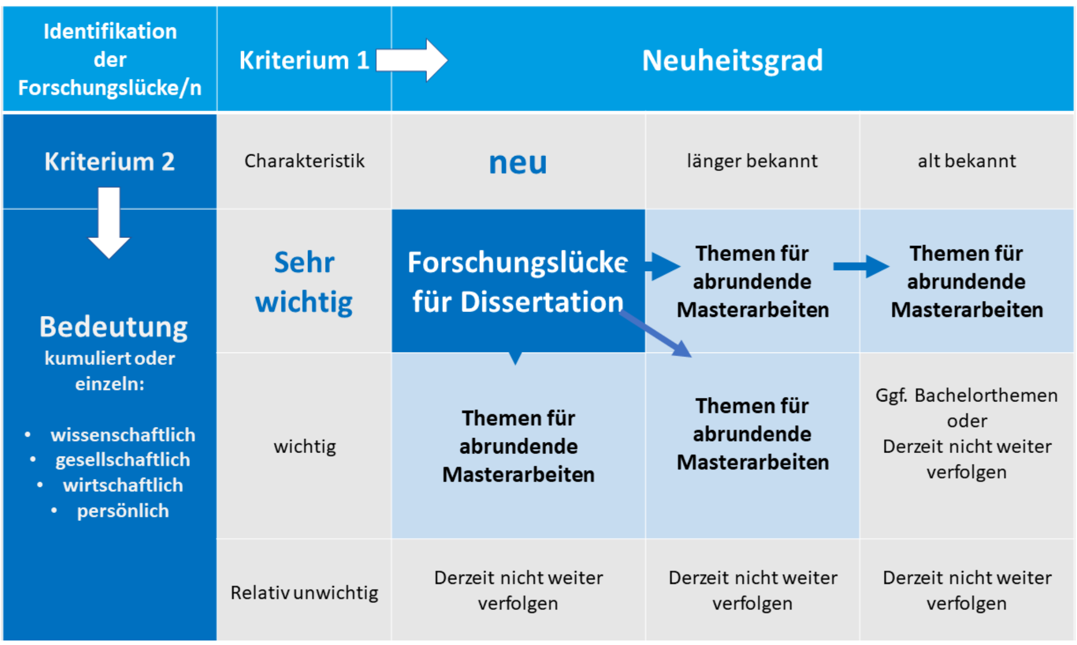

Abbildung 4: Portfolie zum Priorisieren von Forschungsthemen und Forschungsfragen

Die erkannten, zusätzlichen Forschungsthemen und Forschungsfragen sollen in der Promotion / Dissertation nicht ausgeführt, aber durch die Recherche gezielt initiiert werden.

Damit wird die Idee des Promotionskollegs, dass ein ertragreiches größeres Forschungsfeld fokussiert, auf alle Dissertationen übertragen.

6. Hinweis 4: Gute wissenschaftliche Praxis zur Durchführung der Forschungsarbeit

Die Logistik als angewandte Forschungsdisziplin umfasst typische Forschungstätigkeiten, die in einer Promotion/ Dissertation genutzt werden. Diese Forschungstätigkeiten sind:

- Wahrnehmen
- Informieren
- Beschreiben
- Erfinden
- Analysieren
- Modellieren
- Planen
- Optimieren
- Verbessern
- Erklären
- Durchführen / Ausführen
- Evaluaieren
- Reflektieren
- Erkennen / Verstehen
- Entscheiden
- Selbst lernen (Ist auch ein wichtiger Bestandteil.)

In Tabelle 4 werden Hinweise gegeben, wann diese Forschungstätigkeiten im Sinne einer guten wissenschaftlichen Praxis richtig ausgeführt werden.

Die Tabelle 4 kann als nützliche Checkliste und Basis dienen, die für die eigene Dissertation angepasst und erweitert werden kann und muss.

Wenn man sich die einzelnen Tabellenzeilen der folgenden Tabelle 4 näher ansieht, stellt man fest, dass sich die spezifischen Bewertungen jeder Tabellenzeile verallgemeinern lassen,
z.B. derart:

- Aktuelles Überblickswissen recherchiert, aufbereitet?
- Ziele qualitativ und quantitativ definiert sowie priorisiert?
- Aufgabenstellung fixiert und abgegrenzt?
- Gezielte, begründete Auswahl von Vorgehensweisen und Methoden?
- Effiziente Arbeitsweise?
- Fachlich richtige Nutzung der Methoden, (ggf. Modifikation und Verbesserung)?
- Nachvollziehbare Dokumentation des Erkenntnisweges?
- Begründete, richtige Schlussfolgerungen?
- Dokumentation von Fehlern und Irrtümern?
- Ganzheitliche Bewertung der Ergebnisse?
- Verallgemeinerung der Nutzungsmöglichkeiten und Initiierung geeigneter Kommunikationspfade zur Verbreitung der Forschungsergebnisse in andere Wissensbereiche?
- Relevanz: wissenschaftlich, wirtschaftlich, gesellschaftlich, sozial, persönlich?
- Self-check: Konsequent wissenschaftliches Arbeiten?

Unter diesen Fragestellungen können und müssen die einzelnen Tabellenzeilen vervollständigt werden.

Zur Wahrung der Übersichtlichkeit und damit auch einer angestrebten Einfachheit wurde im Rahmen dieses Papers darauf verzichtet.

Wenn diese Tabellen 4 aber an Universitäten, Hochschulen und Promotionszentren nachgenutzt werden, sollten diese o.g. Aspekte ergänzt werden.

Dabei sollten aber die Schwerpunkte deutlich ersichtlich bleiben. Dies könnte man mit einer Priorisierung oder farblichen Abstufung (z.B. schwarz-grau) erreichen.

Tabelle 4: Qualitätsgerechte Ausführung von Forschungstätigkeiten

Forschungs-tätigkeit	Methoden-kategorie	Evaluierung
Wahr-nehmen & Informieren	- Training der Sinne - Wissenschaftliche Literaturanalyse - Internetrecherche & Chatbots - Datenerfassung - Datenerhebung (Personen) - Experimente	- Qualitätskriterien der Daten (u.a. Relevanz, Umfang, Repräsentativität, Vollständigkeit, Genauigkeit, Konsistenz, Eindeutigkeit, Vergleichbarkeit, Authentizität, Verfügbarkeit, Verständlichkeit, Integrität, Validität, Nachvollziehbarkeit, Datenschutz, Skalierbarkeit (Vgl. dazu auch [10]) - Mindestens 3 Perspektiven: - **Vergangenheit** (Auswertung von Publikationen, Vergangenheitsdaten), - **Gegenwart** (Aktuelle Nachrichten, Wissen von Experten, eigene (aktuelle) Datenerfassung, Praxisinput) und - **Zukunft** (Trends und Entwicklungen, Visionen) - Art und Umfang der Datenerfassung und / oder -erhebung - Korrektheit des Versuchs (Planung, Aufbau, Durchführung, Auswertung)
Beschreiben	- Technische Sprache - Formeln - Symbole - Kennzahlen - Spezielle Beschreibungsmodelle	- Korrektheit der Fach-Begriffe inklusive Einordnung und Begriffshierarchie sowie Begriffsabgrenzung - Eignung der Darstellungsformen und deren fachgerechte Nutzung - Vollständigkeit der Erläuterungen von Abbildungern und Formeln - Richtigkeit der Abbildungen - Richtige und begründete Auswahl des Modells
Erfinden	- Kreativitätstechniken - TRIZ - Chatbots	- Originalität und potenzielle Bedeutung der neuen Ideen - Nachgewiesener Eigenanteil - Aufwand versus Nutzenpotenzial, Risiken, Schutz von Erfindungen
Analysieren	- Statistik - Stochastik - Klassenbildung - Algorithmen - Mustererkennung	- Auswahl der richtigen Analyseziele und -aspekte (z.B. Nachhaltigkeit (ökonomisch, ökologisch, sozial), Fehler, Flexibilität, Zeit, Sicherheit, Transparenz, Agilität, Skalierbarkeit) - Richtige Schwerpunktsetzung - Mathematische Korrektheit - Geeignete Darstellung, richtige Schlussfolgerungen
Modellieren	- Ganzheitliche Logistikmodelle - Individuelle Logistikmodelle: > Kundenanforderungen & -restriktionen > Geschäftsmodelle > Objektmodelle > Prozessmodelle > Systemmodelle > Infrastruktur-Modelle > Kennzahlsysteme und Einzel-Kennzahlen - Zeichnungen - Graphentheorie - Bedienmodelle - Strukturmodelle - Simulationsmodelle - Zuverlässigkeitstheorie - Visualisierung - Animationen - Digitalisierung	- Abbildungsziel und Abbildungsqualität - Stichhaltige Begründung der Auswahl des Modells - Bewertung der Eignung des Modells - Korrekte Nutzung des Modells - Geeignete Kennzahlen - Geeignete Visualisierung (VR, AR, 3D, 2D, Digitaler Zwilling)

1. Fortsetzung der Tabelle 4:

Forschungs-tätigkeit	**Methoden-kategorie**	**Evaluierung**
Planen	- Szenario-Technik - Prognosemethoden - Schätzmethoden - Strukturmodelle - Prozessorganization - Kalkulations-methoden - Variantenbildung - Layoutplanung - Projektmanagement - Agile Methoden	- Mindestens 3 Szenarien betrachtet? Bester Fall, Trendfall, Schlimmster Fall - Berechnung und Schätzung sinnvoll, richtig eingesetzt? - Begründete Auswahl und Charakterisierung des gewählten Strukturmodells (z. B. Netz, Punkt, Linie, Insel, Wirbelsäule (Spine), Matrix, Ring) - logisch, funktional, zeitlich, räumlich - Begründete Auswahl und richtige Anwendung der Kalkulationsmethoden - Begründete Variantenbildung und Evaluierung anhand der Zielgrößen - Bewertung der Gesamtlösung
Optimieren	- Bestandstheorie - Lineare Optimierung auf der Grundlage von Zielfunktionen; häufig multikriterielle Optimierung - Versuchsplanung (DoE)	- Richtige Aufgabenstellung - Richtige Zielfunktionen und Limits für nicht involvierte Zielgrößen - Ganzheitliche Bewertung, selten Einzeloptimierung - Richtige und effiziente Versuchsplanung und -durchführung
Verbessern	- Kaizen - Business Process Reengineering (BPR) - Lean-Praktiken - Standards - Benchmarking - Six-Sigma - Referenz-Lösungen - Forschungsarbeit - Logistik 4.0	- Nutzung aller Verbesserungsansätze und bewusste Auswahl relevanter Verbesserungsmethoden - Bewertung der erarbeiteten Verbesserungslösung - Definition und möglichst Quantifizierung der Ergebnisse: Visionen, Strategien, Trends, Ziele, Modelle, Verfahren, Referenzlösungen, Prototypen, Masterplan für die Umsetzung, Masterplan für den Roll-out - Kritische Reflexion der Lösung - Erarbeitung von Hinweisen für die breite Nutzung der Ergebnisse
Erklären	- Theoriebildung - Hypothesen formulieren - Gesetze definieren - Regeln formulieren - Entwurf von Fallstudien - Entwurf von Musterlösungen	Richtige Anwendung von: - Empirie, - Logistischem Denken - Induktion, Deduktion - Sprache, Begriffe, Ausdruck - “Regeln” für Regeln (als Gebote, kurz, verständlich) - Klassifikationsmethoden, Typenvertreterauswahl - Repräsentativität sichern, generalisieren - Gegeben, Gesucht, Verfahren, Ergebnisse und Bewertung

2. Fortsetzung der Tabelle 4:

Forschungs-tätigkeit	Methoden-kategorie	Evaluierung
Ausführen	- Netzwerk-Modelle der Lieferkette - Sourcing-Methoden - PPS - Verkehrsflusstheorie - Organisationstheorie - Regelkreise - Schleifen, Kreisläufe - Projektmanagement	Korrekte Umsetzung in: - SCM-Modelle: Entwerfen, Planen, Ausführen, Kontrollieren, Verbessern, Optimieren, etc. - Sourcing-Methoden: Single Sourcing, Dual Sourcing, Modular Sourcing, Global Sourcing - Klassische PPS (MRP II, JIT, JIS, Prioritätsregeln) oder agile PPS - Simulation - Berücksichtigung von Fehlern und Ausnahmesituationen - Disposition, Verfügbarkeitskontrolle, Fortschrittskontrolle, Fehlersteuerung, agile Organisation - Kanban, ConWIP, - Milkrun, Recycling-Schleifen - Klassisches und agiles Projektmanagement
Evaluieren	- Bewertungs-methoden - Bewertungsziele	- Auswahl der am besten geeigneten Bewertungsmethode (Validierung, Verifizierung, Quantifizierung - Berücksichtigung und Wichtung traditioneller, aktueller und zukünftiger Ziele: Nachhaltigkeit (ökonomisch, ökologisch, sozial), Flexibilität, und vieles mehr
Reflektieren	- Selbst Reflexion - Team Reflexion - Wissenschaftliches Feedback - Theorie-Praxis-Reflexion	Auswahl und richtige Anwendung von Evaluierungsmethoden: - Handformel, Reflexionsspirale, Trichterbildung, - Präsentation, Argumentation, Diskussion - Gespräch, Workshop, Präsentation, Interpretation - Vorgehensmodell der Theorie-Praxis-Reflexion
Erkennen	- Bewusstsein	- Metakognition (Nachdenken über das eigene logistische Denken und über den gesamten Problemlösungsprozess und die Ergebnisse)
Entscheiden	- Zielsystem - Entscheidungs-methoden	Richtige Anwendung von Entscheidungsmethoden und Zielmodellen: - SMART, Zielpyramide, Zielhierarchie, Zielgewichtung - Entscheidungsmethoden unter Sicherheit, Unsicherheit und unter Risiko, Spieltheorie, nutzen von Künstlicher Intelligenz
Selbst-lernen, Selbst-studium, Interdiszi-plinarität praktizieren	- Internet, alle Formen von Medien - Globale Literatur und News - Experten - Praktische Erfahrungen - Interdisziplinarität	Nutzen Sie alle Möglichkeiten des Lernens: - Chatbots - Wissenschaftliche Literatur- und Medienanalyse - Podcats und Videos - Wahrnehmung aus der realen Umwelt (Was sehe ich? Was höre ich?) - Wissenschaftliche Diskussionen und Chats - Tests, Referenzlösungen, Grenzen & Regeln der Anwendung - Synergetische Verknüpfung verschiedener Wissenschaften für die Logistikforschung

7. Ergebnisse und Diskussion

Im vorliegenden Paper wurden zusammenfassend vier wichtige Hinweise für Doktoranden gegeben:

1. Hinweise zum Praktizieren wissenschaftlichen Arbeitens
2. Hinweise zu einer akkuraten Form als Teil der Selbstorganisation des Schreibens
3. Hinweise zur Identifikation des Wissensstandes und der Forschungslücke

4. Hinweise zur Selbstevaluation der korrekten Ausführung von typischen Forschungstätigkeiten der Logistik

Als Hilfestellung zur Nachnutzung wurden die Hinweise systematisiert und in den Tabellen 1 bis 4 erläutert.

Die Tabellen 1 bis 4 können gleichzeitig als Checklisten genutzt werden:
Tabelle 1: Zur Selbstüberprüfung des konsequent wissenschaftlichen Arbeitens
Tabelle 2: Zum Check der Form und zur Vermeidung von Formfehlern
Tabelle 3: Zur ganzheitlichen Recherche und Aufdeckung von Forschungslücken.
Tabelle 4: Zur Selbstüberprüfung der wissenschaftlich exakten Ausführung von Forschungstätigkeiten

Die Forschungsergebnisse dieses Papers beruhen zu einem großen Teil auf eigenen, praktischen Erfahrungen bei der Begleitung von mehr als 100 internationalen Promotionen. Der Wert liegt in der Ganzheitlichkeit, der Verdichtung der Aussagen und der stringenten Systematik. Obwohl die Bewertung noch aussteht, können die Forschungsergebnisse anhand der folgenden Kriterien und mit den folgenden Methoden bewertet werden:

- **Ausreichende Vollständigkeit** (durch Expertenbefragung),
- **Eindeutigkeit** (durch Befragung internationaler Doktoranden),
- **Nachvollziehbarkeit** (durch Befragung von Doktoranden),
- **Anwendbarkeit** (Validierung & Nützlichkeit) (durch Befragung nach erfolgter Anwendung).
- **Korrekte Festlegung**/Auswahl der Prioritäten durch Expertenkonsultation und wissenschaftliche Diskussion,
- **Genauigkeit** (Verifizierung) (durch Expertenbefragung und wissenschaftliche Diskussion).

Die Grenzen dieser Forschungsergebnisse liegen in den Kenntnissen und Erfahrungen der Autoren.

Was sind die nächsten Schritte der Forschungsarbeit?

- Fachliche Diskussion & Aufarbeitung der fachlichen Kritik
- Vervollständigung der Kriterien und Hinweise
- Anwendung der Checklisten in der Praxis und ihre schrittweise Verbesserung
- Realisierung einer gemeinsamen Online-FAQ-Plattform zum Wissenstransfer an alle internationalen Doktoranden 24/7
- Bereitstellung des Papers & Bekanntmachung in anderen Ländern (z. B. Österreich, Frankreich, Italien, Slowakei, Ungarn, Ukraine, Kuba)
- Teilen des Papers mit der BVL (deutsch) & der ELA (deutsch & englisch)

Themen für weitere Arbeiten könnten sein:

- Welcher Aufbau der Dissertation wird empfohlen?
- Was waren typische Forschungsthemen und Forschungsfragen der letzten fünf Jahre von Dissertationen?
- Wie kann die Erfassung des Forschungsstandes effizient durchgeführt werden? (Expertenbefragung, eigene Datenerfassungen und Versuche, Medienanalyse)

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Trends

Hinweis: Die folgenden Organisationen veröffentlichen laufend Trends.

Bitte recherchieren Sie die aktuellen Links selbst auf den folgenden Webseiten:

→ Logistik

Bundesvereinigung für Logistik (BVL).
www.bvl-trends.de
Zugriff: 5. April 2024

DHL (Abkürzung der Gründer Dalsey, Hillblom &Lynn) Logistics Trend radar. www.dhl.com
Zugriff: 5. April 2024.

→ Technische Logistik

WGTL. Jährliche Fachkolloquien der WGTL
www.wgtl.de
Zugriff: 5. April 2024.

→ Produktion & Produktionstechnologie

Wissenschaftliche Gesellschaft für Produktionstechnik (WGP)
www.wgp.de
Zugriff: 5. April 2024.

→ Supply Chain Management

TU Wien (2024): 23 Supply Chain Management Trends im Überblick. www.tu_wien.at/ace/news/news/supply-chain-management-trends
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Analysing Vehicle Cost Dynamics: How CO_2 Pricing Drives Electrification in Road Transport

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Abstract
Globally, logistics activities contribute between 11% and 12% of emissions. In 2021, the EU27 transportation sector emitted 782 MtCO2e, with 21% from heavy goods vehicles. This paper analyses the effects of environmental policies on road freight transport costs. Therefore the BGL cost calculation scheme was used and sharped in order to calculate sustainable total cost of ownership (STCO), which includes compensation cost for CO2 emissions and break even points for Battery electrical vehicles (BEV). It suggests that a price of >= €291 per ton CO2 with toll rates from 2023 or €96 with toll reforms including a CO2 component could justify transitioning to BEVs provided TCO remains below €225,000. The results gain transparency for practitioners and academics to identify break even points in transport cost calculation as well as show policy makers financial effect of environmental measures.

1. Introduction
The latest IPCC report underscores the significant impact of global warming and the urgency of transitioning to a green economy [11]. In 2021, the EU27 domestic transportation sector emitted 782 MtCO2e, with 21% attributed to heavy goods vehicles and approximately 5% of all EU27 emissions are from HGVs [7]. Globally, logistics activities contribute between 11% and 12% of emissions [21]. To incentivize freight companies to reduce CO2 emissions, governments are increasingly relying on market-based environmental policies. One of these measures is the introduction of a CO2 component in the truck toll and the associated exemption of BEV trucks. Of the approximately 800,000 trucks on German roads, only 400 are currently electrically powered, which corresponds to a share of 0.05%. In the coming years, however, this proportion is to be increased. In the realm of battery electric vehicles (BEVs), two primary types exist: battery trucks, which rely solely on their internal batteries for power, and overhead line trucks, where energy is continuously supplied to the truck via an overhead power line along the road [12]. Logistics service providers (LSP) now have the challenge of making an economic decision for themselves as to when it makes sense to switch to a BEV truck. The following research question arises from this problem:

> **RQ: What level must a national CO2 price reach to ensure the economic viability of battery-electric (BEV) trucks over internal combustion engine (ICEV) trucks?**

To answer this question, the lead author continues his investigations and draws on the results already calculated in the last IDWL paper [18]. These results are compared with new values for a BEV truck and a variance analysis is carried out. The author thus continues to show which results can be calculated with his TCO model based on VDI standard 3633 and supports this in his dissertation project. The study is divided into five chapters. Chapter 2 identifies the interactions of environmental policy measures on the individual cost units and provides an overview of various BEV truck types. Chapter 3 presents the main results of the variant analysis. Chapter 4 identifies the limitations and further research opportunities.

2. Methods or experimental part

Various TCO calculations were carried out to perform this calculation. Goeckeler et al 2023 calculated TCO costs based on tolls, energy costs, energy infrastructure costs, administrative costs, purchasing costs and other costs [10]. Rosenberg et al 2023 compare different technologies and their applications and costs [22]. Bongrad et al 2023 also calculates the economics of BEV trucks [5]. Joehrens et al 2022 also calculate different cost levels for different powertrain technologies depending on annual mileage [14]. Together with Andersson, Joehrens also discussed different TCO cost levels in different countries [1]. The basis for this paper was the BGL cost model [3]. Current legal framework conditions as well as the technical and economic environment of a BEV trucks were considered.

2.1. CO2 Truck toll and national CO2 Price

Since December 2023, toll charges in Germany have increased by more than 80%. This primarily stems from the introduction of a novel toll rate component, valuing CO2 emissions at €200 per ton of CO2 [23]. Consequently, toll charges now comprise components including noise pollution, air pollution, infrastructure, and CO2 emissions. Both heavy goods vehicles (HGVs) are classified as Euro 6, with the battery electric vehicle (BEV) HGV assigned CO2 class 5 and the diesel HGV assigned CO2 class 1.

Presently, BEVs enjoy exemption from the CO2 toll charges. However, commencing 2026, they too will become subject to tolls, albeit to a limited extent [2]. Nevertheless, they will accrue savings on a portion of the noise pollution costs, 75% of the infrastructure costs, and 100% of the CO2 emission costs. Consequently, commencing 2026, BEVs will incur 0.2 cents for noise pollution costs, 2.3 cents for air pollution costs, and 25% of the 19 cents for infrastructure costs [4].

In addition, BEV trucks are also exempt from motor vehicle tax. This exemption initially applies until the end of the year 2030 or for a maximum of ten years after purchase [19]. Normally, the tax for trailers pulled by an electrically powered vehicle is reduced by 50%.

The global adoption of carbon pricing mechanisms has witnessed a progressive rise, with CO2e pricing schemes encompassing an increasing proportion of greenhouse gas emissions. In 2020, these schemes covered 15.1% of global emissions, escalating to 21.7% by 2021 [27] . This surge is chiefly attributable to the implementation of diverse carbon pricing mechanisms worldwide, including the Chinese Emissions Trading Scheme, the BEHG in Germany, an ETS in the UK, and CO2e taxes in Luxembourg and the Netherlands [17].

Concurrently, the EU has fortified its decarbonization endeavours via initiatives like the European Green Deal, which aims to achieve a 95% reduction in greenhouse gas emissions by 2050, aligning with the Paris climate targets. Notably, the EU has instituted the EU-ETS, a certificate trading system targeting major emitters, particularly in the energy sector. However, the transportation sector, expected to witness burgeoning demand and emissions, remains excluded from the EU-ETS. Efforts have been underway to explore the integration of logistics service providers into carbon pricing mechanisms to mitigate emissions [16].

In Germany, a synthesis of the Pigou tax and certificate trading scheme culminated in the establishment of a national emissions trading system under the BEHG. This system features a fixed price for the initial five years, incrementally rising from €25 per ton of CO2e in 2021 to €55 by 2025 [6]. The EU intends to incorporate the transportation sector into the EU-ETS by 2026 (ETS2); however, the specific mechanisms for offsetting emissions, whether via downstream or upstream principles, remain ambiguous. This transition could significantly impact national freight forwarders, particularly in terms of cost implications. Furthermore, with only a limited number of countries currently implementing carbon pricing mechanisms, carriers may exploit strategic tour calculation methods to minimize fuel costs. Concurrently, discussions persist regarding additional political instruments, such as the modification of truck tolls or the fortification of fleet regulations, to align with national climate laws [20].

These unfolding developments necessitate adjustments in the transport cost calculation schemes of national carriers.

2.2. System analysis BEV truck

There are two main types of BEV. One is the battery truck, and the other is the overhead line truck. In the case of the overhead line truck, the truck is constantly supplied with energy via a power line above the road. The first trials have already been carried out in the Frankfurt area and near Hamburg. Here, a single-lane road was equipped with overhead lines over a length of 5 km. The advantage of such a system is that the battery does not add weight to the truck, and the truck can carry the same or even more payload than an ICEV truck. A major disadvantage, apart from the high infrastructure costs, is that the cables are in the way during a potential air rescue and can only be attached to the left or right outer

side, as the cables need to be supported every 10 metres to prevent sagging. This not only limits the number of trucks that can use such a cable, but also prevents individual trucks from overtaking on another lane. A traffic jam or accident on the overhead line in question would mean that all the trucks behind would have to wait. Because of these drawbacks, the current literature tends to focus on pure battery electric trucks or hybrid models with internal combustion engines, which cannot run long time without overline electricity.
A battery electric truck is operated in the same way as a battery electric car, with permanently installed or replaceable batteries on board. As technology has progressed, different battery sizes with different ranges have become available. In the case of a battery-powered truck, the conflicting objectives are that a larger battery, usually a larger number of individual batteries, not only increases the purchase cost, but also the total weight, which results in a lower available payload, a larger tyre footprint and thus higher power consumption. Currently, BEVs can travel more than 500 kilometres without stopping to recharge [13]. They can carry payloads of up to 18 tonnes and need only 45 minutes to recharge their batteries for another trip of a similar distance. Despite these advances, there is still a considerable gap to close with ICEVs, which can achieve ranges between 600 and 1000 km on a 15-minute charge. To compensate for the competitive disadvantage of low payload due to the additional weight of the battery, the EU discuss at the moment to increase for battery-powered trucks the gross vehicle weight from 42 to 44 tonnes [15].

The purchase price of a BEV is currently three times higher than that of an ICEV. The decision to purchase BEVs depends heavily on government subsidies, which can subsidise up to 80% of the additional costs for electric drive systems (as of October 2023). All new commercial vehicles in EC vehicle classes N1, N2 and N3 that have an electric drive and no conventional drive were subsidised until last year [4]. BEV trucks fall into the EC commercial vehicle category N3 and would be procured as new vehicles so that they remain eligible for subsidies. Due to the reduction in the fiscal budget, funding has been suspended in 2024 until further notice [26]. Table 1 summarizes all the relevant subsidies.
The higher acquisition costs of BEVs compared to ICEVs are mainly due to the currently high manufacturing costs. It is expected that these costs will fall over time, both due to falling battery prices and due to efficiency improvements in the production facilities based on experience and learning effects, which will lead to more costeffective manufacturing processes. Future economies of scale should also help to reduce the production costs of BEVs in the coming years. By 2030, BEVs are expected to have an overall cost advantage over ICEVs in all weight classes.

Table 1: Relevant subsidies and laws

Description	**Time**	**Source**
Act on national certificate trading for fuel emissions (Fuel Emissions Trading Act - BEHG).	Since 2021 – today (currently discussed if it would be integrated in a EU-ETS2 in 2027).	[9]
Act on the levying of distance-related charges for the use of federal motorways and federal roads (Federal Trunk Road Toll Act - BFStrMG).	Since 2011. Updated frequently. Last update December 2023. Introduction of CO2 Component	[2]
Announcement of the directive on the promotion of light and heavy commercial vehicles with alternative, climate-friendly drive systems and associated refueling and charging infrastructure for electrically powered commercial vehicles (pure battery electric vehicles, externally chargeable hybrid electric vehicles and fuel cell vehicles).	Since 2021. Suspended since 2024	[4]

To illustrate the effect of CO2 pricing and subsidies, two trucks were compared with real costs in a case study.

2.3. Data acquisition

There are different figures in the literature for the price of a BEV truck and different future scenarios. However, all prices are currently higher than for an ICEV. A price of €381,600 for a Volvo FH 42 Electric was obtained from an internal dealer quote [25]. The government subsidy results in an actual purchase cost of €174,120. In addition to the purchase cost of a BEV truck, the cost of installing charging points and any route adjustments must also be considered. After deducting the subsidy, these amount to €31,052 for the installation of a

charging point at the ramp, €4,000 for underground engineering and €1,907 for the engineering office. All cost items could be allocated to several BEVs, as the infrastructure may not be used by just one BEV. However, to simplify the calculation, a TCO in the first year of €200,000 was assumed, in line with a study by PWC [8].
The results of the Kindsgrab et al. 2023 study were used to calculate the ICEV truck costs. Annual TCO of €172,834.35 were calculated based on various public databases [18]. A potential CO2 price, indicating a break-even point, can now be calculated using the available data.

3. Results and Discussion

To determine this CO2 price, the CO2-independent cost types must first be deducted from the TCO price of a BEV truck of €200,000 (see figure 1). At 40.8%, driver costs and other fixed costs form the largest value in the TCO calculation. At €41,406.25, driver costs account for the largest share. The proportionate administrative costs of €15,000 and other fixed costs such as repairs, vehicle tax, cleaning and imputed interest make up the smaller part at €20,134.10. After deducting these costs, €118,459.65 remains. If the variable costs, such as tire costs or depreciation costs, are deducted, €103,507.65 remains. Depending on the toll rate to be applied, this results in a diesel budget of €76,907.65 for a EURO VI under the old toll regulation (2023) and a budget of €54,787.65 under the new regulation (Dec. 2023) with a toll rate of 34.8 cents per km. With these diesel budgets, the potential CO2 price can now be calculated using the formulas as follows:

$$CP = \left(\left(\frac{Db}{Jkm/100} \times dk\right) - dp\right) \div \frac{Cf}{1000} \quad (1)$$

With:

CP	CO2 price [€/t]
Db	diesel budget [€]
Jkm	Annual mileage [km]
dk	Diesel consumption [l/100]
dp	Diesel price [€/l]
cf	CO2 consumption [kg CO2/ L Diesel]

As shown in the figure 1 this results in a CO2 price of €70.38 for the old toll rule and a negative price of -€125.44 for the new toll rule. This means that under the old toll rule, a BEV truck would be financially better off from a CO2 price of €70.38, which would lead to a diesel price of €195 per 100 litres of diesel (initial value €170). According to the new toll rule, only a subsidization of the diesel price through a negative CO2 price could generate the cost advantage for the ICEV truck.
With the help of a variance analysis and this formular, various tipping points of the solution can now be determined. Following the same logic, these values can also be converted into a CO2 price per tonne using the tank-to-wheel (TTW) value of 2.67 kg per litre of diesel, for example, in order to evaluate the steering effect of potential CO2 price paths in.

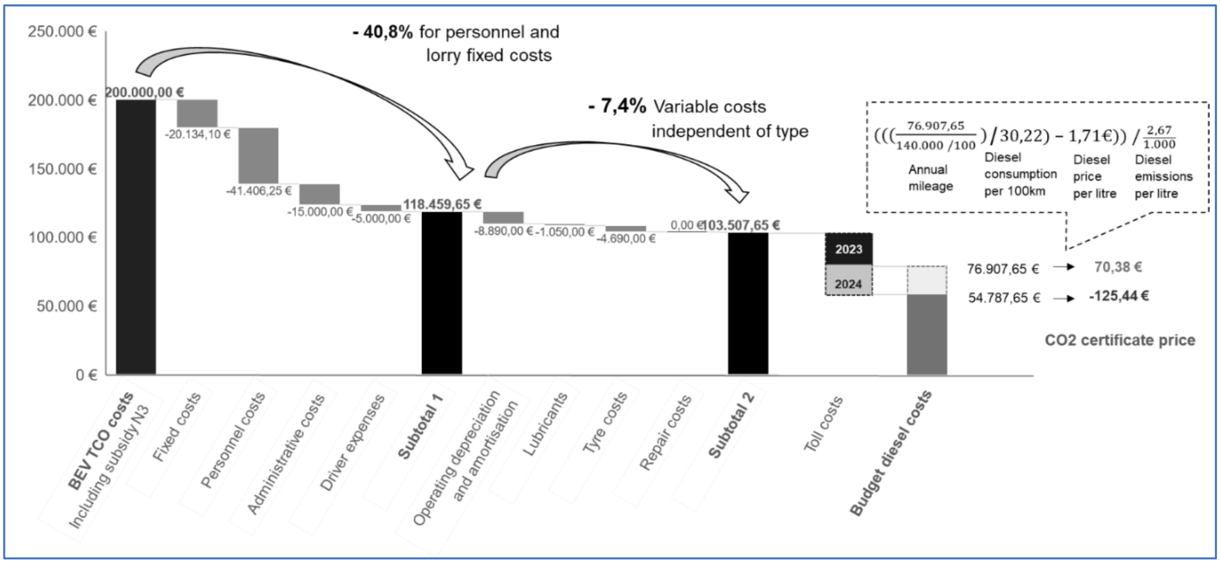

Figure 1: Illustration of Diesel budget.

3.1. Different level of diesel price

First, an analysis can determine the diesel price per litre at which different TCO costs for a BEV truck become more economically viable compared to the purchase of a EURO VI ICEV truck. The results are presented according to toll regulations (see Table 2). Notably, under the previous toll regulations without a CO2 component, a BEV would only become economically viable at a TCO value of less than €200,000. At a TCO value of €250,000, the diesel price would need to be nearly doubled for the BEV to be economically sensible. These values are revised downwards under the new market regulations. For example, a TCO value of €225,000 at a diesel price of €1.89 per litre is no longer unrealistic. Furthermore, with a TCO value of €180,000, as forecasted by PWC for the year 2030, the diesel price could be halved, and the BEV would still be more economically viable. This transition underscores the impact of regulatory changes and market evolution on the economic feasibility of BEV trucks, indicating a significant potential for cost savings and environmental benefits as market conditions evolve.

3.2. Different level of CO2 prices

Under the old toll system, a BEV truck became economically viable with a TCO value of less than €180,000, as this would have effectively resulted in a notional negative CO2 price. In contrast, under the new toll system, BEV trucks remain economically viable even with a TCO value exceeding €200,000. This demonstrates the impact of updated toll regulations on the economic feasibility of BEVs compared to traditional internal combustion engine vehicles. Looking ahead to 2026, when the national CO2 trading system is expected to integrate into the European Emissions Trading System (EU-ETS2), the economic case for BEV trucks strengthens further. At a projected CO2 price of €100 per tonne, a BEV truck would present a more economically advantageous option than a new EURO VI truck. This shift highlights the increasing financial incentives for adopting BEVs as regulatory frameworks and market conditions evolve, potentially leading to significant cost savings and environmental benefits for fleet operators.

3.3. Cost advantages for BEV truck

The results indicate a significant dependency on TCO values. For a BEV with a TCO value of €250,000, the cost advantage of ICEVs diminishes notably as diesel prices rise (see Table 3). At a diesel price of €1.60 per litre, the ICEV has a cost advantage of €0.88 per litre. This advantage gradually decreases with higher diesel prices, becoming negative beyond €1.90 per litre, which signifies that a BEV becomes more cost-effective at this point. As diesel prices increase, the economic benefit shifts more markedly towards BEVs. For instance, at a diesel price of €2.00 per litre, the cost advantage of an ICEV over a BEV with a TCO of €250,000 drops to €0.48 per litre. This trend is more pronounced at higher diesel prices, reflecting increased savings with BEVs. For BEVs with lower TCO values, such as €180,000, economic advantages manifest at even lower diesel prices.

Table 2: Variance analysis of different BEV costs, toll rates and CO2 prices

Diesel price per litre for break-even		**TCO BEV**				
		250.000,00 €	**225.000,00 €**	**200.000,00 €**	**180.000,00 €**	**150.000,00 €**
Toll rate	**without CO2 Component**	3,00 €	2,41 €	1,82 €	1,35 €	0,64 €
	with CO2 Component	2,48 €	1,89 €	1,29 €	0,82 €	0,11 €

1,71 €	Current diesel price

CO2 price for break-even per litre of diesel		**TCO BEV**				
		250.000,00 €	**225.000,00 €**	**200.000,00 €**	**180.000,00 €**	**150.000,00 €**
Toll rate	**without CO2 Component**	513,00 €	291,69 €	70,38 €	-106,67 €	-372,25 €
	with CO2 Component	317,18 €	95,87 €	-125,44 €	-302,49 €	-568,07 €

30,00 €	Current CO2 price (2023), 45€ pro tonne CO2e in 2024

At a diesel price of €1.60 per litre, the BEV with a TCO of €180,000 already exhibits a cost advantage of €0.31 per litre. This advantage expands as diesel prices rise, underscoring the economic feasibility of BEVs in scenarios with reduced TCO. Negative cost advantages, indicated by negative values, reveal scenarios where BEVs have a lower cost per litre of diesel compared to ICEVs. For example, at a diesel price of €2.00 per litre and a TCO of €150,000 for the BEV, the cost advantage is -€1.89, indicating significant savings for BEVs. The toll rate of €34.80 significantly impacts the overall cost dynamics, making BEVs more competitive under the new toll regulations that account for CO2 emissions. This regulatory shift further enhances the economic attractiveness of BEVs over ICEVs.

Table 3: Cost Advance BEV Truck per litre Diesel in the new toll system

Cost advantage of ICEV over BEV per litre of diesel with toll rate *		**TCO BEV**				
		250.000,00 €	**225.000,00 €**	**200.000,00 €**	**180.000,00 €**	**150.000,00 €**
Diesel price	**1,60 €**	0,88 €	0,29 €	-0,31 €	-0,78 €	-1,49 €
	1,65 €	0,83 €	0,24 €	-0,36 €	-0,83 €	-1,54 €
	1,70 €	0,78 €	0,19 €	-0,41 €	-0,88 €	-1,59 €
	1,75 €	0,73 €	0,14 €	-0,46 €	-0,93 €	-1,64 €
	1,80 €	0,68 €	0,09 €	-0,51 €	-0,98 €	-1,69 €
	1,85 €	0,63 €	0,04 €	-0,56 €	-1,03 €	-1,74 €
	1,90 €	0,58 €	-0,01 €	-0,61 €	-1,08 €	-1,79 €
	1,95 €	0,53 €	-0,06 €	-0,66 €	-1,13 €	-1,84 €
	2,00 €	0,48 €	-0,11 €	-0,71 €	-1,18 €	-1,89 €
	2,05 €	0,43 €	-0,16 €	-0,76 €	-1,23 €	-1,94 €
	2,10 €	0,38 €	-0,21 €	-0,81 €	-1,28 €	-1,99 €
	2,15 €	0,33 €	-0,26 €	-0,86 €	-1,33 €	-2,04 €
	2,20 €	0,28 €	-0,31 €	-0,91 €	-1,38 €	-2,09 €
	2,25 €	0,23 €	-0,36 €	-0,96 €	-1,43 €	-2,14 €
	2,30 €	0,18 €	-0,41 €	-1,01 €	-1,48 €	-2,19 €
	2,35 €	0,13 €	-0,46 €	-1,06 €	-1,53 €	-2,24 €
	2,40 €	0,08 €	-0,51 €	-1,11 €	-1,58 €	-2,29 €
	2,45 €	0,03 €	-0,56 €	-1,16 €	-1,63 €	-2,34 €
	2,50 €	-0,02 €	-0,61 €	-1,21 €	-1,68 €	-2,39 €
	2,55 €	-0,07 €	-0,66 €	-1,26 €	-1,73 €	-2,44 €
	2,60 €	-0,12 €	-0,71 €	-1,31 €	-1,78 €	-2,49 €
	2,65 €	-0,17 €	-0,76 €	-1,36 €	-1,83 €	-2,54 €
	2,70 €	-0,22 €	-0,81 €	-1,41 €	-1,88 €	-2,59 €
	2,75 €	-0,27 €	-0,86 €	-1,46 €	-1,93 €	-2,64 €
	2,80 €	-0,32 €	-0,91 €	-1,51 €	-1,98 €	-2,69 €
	2,85 €	-0,37 €	-0,96 €	-1,56 €	-2,03 €	-2,74 €
	2,90 €	-0,42 €	-1,01 €	-1,61 €	-2,08 €	-2,79 €
	2,95 €	-0,47 €	-1,06 €	-1,66 €	-2,13 €	-2,84 €
	3,00 €	- 0,52 €	-1,11 €	-1,71 €	-2,18 €	-2,89 €
			34,80 €	Toll rate		

4. Limitations and Conclusion

In order to reduce complexity and due to the lack of data, assumptions are made to calculate the results of this paper. Therefore have some limitations. Nevertheless, some conclusions can be drawn from it.

4.1. Limitation

The findings of this computation are partially derived from publicly available data that has been standardized and harmonized for the analysis. Diligence has been exercised to ensure the generalizability of the calculations; however, variations in TCO between BEVs and ICEVs may arise due to company-specific data, potentially leading to divergent break-even points. Nonetheless, the results align with existing literature indicating that, in numerous instances, BEV trucks are already economically advantageous relative to ICEV trucks within the prevailing regulatory environment, inclusive of subsidies and toll exemptions. Any alterations to these regulatory frameworks would necessitate corresponding adjustments to the break-even analysis.

Moreover, beyond the economic assessment of TCO expenses, the logistical viability within the individual customer's network must also be considered. Presently, BEVs exhibit constrained range capabilities, and access to charging infrastructure, either at public stations or at customer loading bays, may not always be feasible, necessitating meticulous route planning for BEV utilization.

Lastly, ensuring the market availability of BEVs is imperative. Currently, extended waiting periods exceeding a year are not uncommon.

4.2. Conclusion and further search

In conclusion, the results demonstrate the economic viability of BEVs over ICEVs under various diesel prices and TCO scenarios. As diesel prices rise, BEVs become increasingly cost-effective, particularly when supported by favourable toll regulations incorporating CO2 pricing. Fleet operators should consider these factors when evaluating the transition to BEVs, as long-term cost benefits and regulatory incentives are likely to improve the overall economic and environmental performance of their vehicle fleets. Furthermore, the paper aims to assess the effectiveness and efficiency of environmental policies in the logistics sector and to uncover potential challenges associated with their implementation. It seeks to foster discussions on integrating environmentally friendly practices into the business models of logistics companies and identifying best practices for sustainable logistics. Additionally, it endeavours to raise awareness about the necessity of a green transformation within the logistics industry and to incentivize innovation and investment in ecofriendly technologies and practices. Lastly, the paper aims to expedite the transition to a lowcarbon economy and enhance the long-term competitiveness of logistics companies and gain further transparency for the financial implication of CO2 pricing [24].

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Automation of VSM with a focus on customers and suppliers

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Abstract
Value Stream Management is a methodology for mapping and analyzing actual value streams as well as designing target ones. The end-to-end (E2E) consideration of a value stream from a company's perspective including the manufacturing process as value-adding transformation, the supplier as supply or source and the customer as demand or sink of the value stream reveals a holistic overview of the entire supply chain. This overview facilitates a structured elimination of wastes according to the principles of lean management. Value Stream Management is a widely applied and field-tested approach, whose fundamental principles are still valid, but facing challenges in the context of an increasing digitalized and volatile environment. Several recent publications refer to this disadvantage and provide approaches, to enhance or improve the methodology by the integration of data. Though, all of these reviewed studies are limited to investigation of the manufacturing process, whereby the customer and supplier perspectives are largely not considered in detail. Target of the paper at hand is the review of the key performance indicator (KPI) in terms of the domains of customer and supplier within the Value Stream Management framework, the identification of potential data sources in regard to business application systems and the design of a modular framework, enabling the automation of the Value Stream Mapping (VSM) in various process and system landscapes with special emphasis on the value stream's source and sink.

1. Introduction
Value Stream Management is based on the principles and methods of lean management. The approach is widely applied by different companies and supports a structured mapping, analyzing, designing and implementing measures for improving value streams. Following these activities, four phases are distinguished in the VSM framework. These are Value Stream Mapping (VSM) for capturing the value stream, Value Stream Analysis (VSA) for analyzing the value stream in terms of waste and inefficiencies, Value Stream Design (VSD) for designing an optimized target value stream, and Value Stream Planning (VSP) for planning and implementing improvement measures with the aim of approaching or achieving the target value stream through multiple iterations.

In this context, a value stream is defined as an end-to-end supply chain, described from a company's perspective. The essential core of the methodology is formed by the Value Stream Map, which is a graphical model, visualizing the manufacturing process, the related dependencies to suppliers as inputs and customers as outputs and the specific business process control referring to order handling with focus on production planning and scheduling. In the model all relevant material and information flows are taken into account. Customer as well as supplier can represent both, internal as well as external stakeholders. Based on the map, wastes in the process, e.g. waiting times and further non-value-adding activities according to the seven wastes of lean management (transportation, inventory, motion, waiting, over-processing, overproduction and defects) are identified and eliminated by designing a target value stream. [1], [2] Such a value stream map is schematically depicted in Figure 1 [3].

Based on a systematic literature review according to [4] covering the years 2021 to 2024 in the databases GoogleScholar and ResearchGate, the following findings are revealed. In volatile environments, Value Stream Management exhibits various weaknesses, the elimination of which is the subject of numerous studies, such as [5], [6], [7], [8]. Various approaches providing concepts for the utilization of digital technologies and techniques are discussed for this purpose, summed up in the next section.

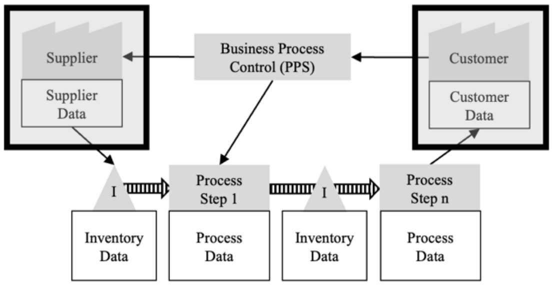

Figure 1: Supplier and Customer Information in the Context of a Value Stream Map

Companies face changing market conditions, leading to decreasing lot sizes, shorter innovation and product cycles, wider variety as well as increasing competition. Especially in dynamic environments, the procedure has several disadvantages, which are subject of recent research, as detailly investigated in [9], [10]. The future viability of Value Stream Management against the background of increasing digitization and digitalization as well as derived improvement potentials are investigated in several publications, e.g. [5], [6]. Different approaches are provided, aiming at the purposeful combination of the conventional Value Stream Management procedure and the application of data-based technologies to reduce the manual efforts and get more flexible. Beside the consideration of single technologies, e.g. RFID [13], [14], sensor networks [15], Industrial Internet of Things (IIoT) [16], Digital Shadows [17] and Digital Twins [7], cyber-physical systems (CPS) [18], [19] and industry 4.0 technologies in general [20], [21], universal frameworks, combining the application of a technology mix, e.g. [8], [22] are available. Furthermore, the utilization of data derived from business application systems as enterprise resource planning (ERP), warehouse management systems (WMS), manufacturing execution systems (MES), supply chain management systems (SCM) and similar ones is taken into account [23]. In differentiation to the conventional approach, the proposed procedures are named as dynamic Value Stream Management, smart Value Stream Management as well as VSM 4.0, considering the increased degree of digitalization [16], [21], [24].

Furthermore, findings reveal, all reviewed studies are limited to the manufacturing process, covering production- as well as logistics-related activities. An explicit consideration of the two domains of supplier and customer is missing, as visualized by the grey boxes in Figure 1. The supplier is the essential input of the manufacturing process and represents the supply, also mentioned as source of the production with input materials, e.g. raw materials, which are transformed into the final product or finished good during the manufacturing process. According to the lean principles, a production should follow the pull principle and is controlled by the actual demand, also mentioned as sink of the supply chain. For this reason, the output of the value stream is dependent from the customer's requirement. Even, if the demand for final products fluctuates, also the output of a levelled production is related to the demand per period to avoid resource-binding inventory, defined as waste in accordance with the lean management principles. In summary, the recent research focus lies on considering the manufacturing process within the framework of Value Stream Management, with suppliers and customers being treated as given parameters, lacking an explicit investigation. This leads to the central research question:

How can business data be utilized to automate the mapping procedure concerning the domains of supplier as the source and customer as the sink of the supply chain in the value stream map?

The aim of this paper is to examine this research question and to propose a possible solution approach. The methodology outlined in the following section forms the basis for this.

2. Applied Methodology

The applied methodology is divided into four steps and follows the procedure model, visualized in Figure 2.

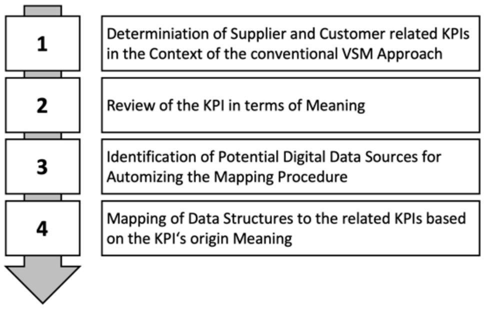

Figure 2: Applied Procedure

In the first step, the conventional Value Stream Management approach is reviewed with focus on the two domains of supplier and customer. Aim of the first step is the general determination of all supplier- and customer-related information, contained in the Value Stream Map. In the second step, the findings are structured and analyzed in terms of meaning, utilization and significance of the determined KPIs. Based on the refined and demarcated indicators, potential digital data sources, e.g. business application systems like ERP, enabling an automized derivation of the required information content from business application systems, are identified in the third step. The concrete business objects, e.g. customer order, purchase order and similar ones are deduced from the related digital data sources. Finally, the data structures of the business objects are mapped to the KPIs. In cases, a direct mapping of KPI and data structure is not feasible, calculation rules are redefined under the consideration of the KPI's origin meaning. In the fourth step a modular mapping framework is proposed, providing different ways of deriving the supplier and customer KPIs from available business information. By the modularity of the framework various company-specific process and systems landscapes are considered, which makes it universal in use.

The validation of the proposed approach is conducted on the basis of an SAP S4/HANA test environment, which covers the functions of common ERP systems and is provided by Magdeburg-Stendal University of Applied Sciences, Germany. Therefore, all figures depicting the graphical user interface are based on the testing environment, with the relevant data fields labeled.

2.1. Investigation of Customers in the Context of Value Stream Management

The customer is defined as demand of the value stream and highly impacts the manufacturing process and its efficiency. In accordance to Lean Management the manufacturing process should be controlled by the pull-principle. This means, the production is not based on forecasts, plannings and expected quantities, but only on actual customer demands. By this management principle, costs due to stock management, required for the materials, made to stock, as well as production lead times can be reduced. The value stream related indicators are mentioned according to [1], [2] in the following listing:

Customer (group)
A specific key customer or a selection of customers, grouped by the same conditions, e.g. ordering similar products, which can be grouped by a product family, defines the sink of the supply chain and impacts the required output of the manufacturing process according to the pull-principle of Lean Management.

Product / product family (output of the value stream)
The indicator product / product family is defined as the final product or material of the value stream.

Customer takt time
The customer takt time is the most important indicator to evaluate the effectivity of the value stream. The customer takt time [time/pcs.] is an indicator, which correlates with the reciprocal of the production rate from a sales point of view. The cycles time of each activity must be less than or equal to the customer tact to satisfy the demand with the given capacities. To calculate this key indicator, the following indicators are necessitated according to [1], [2], [23]:

- Factory days (according to factory calendar) in a specific period
- Daily working time
- Required quantity (annual sales volume) per period

Delivery time
The delivery time is affected by the logistical processing in the area of shipping and – if it is not stock material – the lead time of the manufacturing processing.

Delivery reliability
The delivery reliability is a performance indicator referring to the ability to consistently deliver products according to the agreed-upon specifications, schedules, and terms. It indicates the reliability or consistency of fulfilling delivery commitments without delays or errors.

Potential Data Sources
In general, the key indicators are directly connected to the domain of sales, but partially depend on the characteristics of the manufacturing process, e.g. available working time. As in the context of the supplier dimension, the ERP system is the central enterprise system, containing most of the required information. Additional data sources are customer relationship management (CRM) systems and sales platforms or order management systems (OMS) for information regarding customer, product as well as demand. But also supply chain management (SCM) systems are suitable data sources for determining (historical and future) sales volumes.

Mapping of Data Structures to KPIs
Products or product families define the value stream that is being examined more closely. This allows the demand causer, such as customer orders and consequently the underlying customers, to be identified.

The customer takt time is defined as the available time, in which an amount of one piece must be produced to match the customer demand. Therefore, its calculated as ratio of capacity's

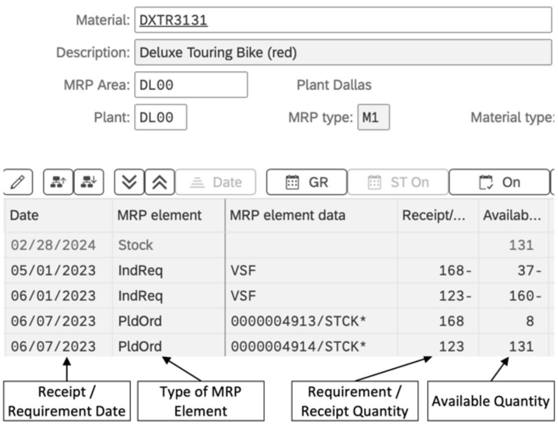

Figure 3: Determination of Sales Volume based on the Stock/Requirements List for one final Product

availability [time] per period and the customer demand [pcs.] per period. In the context of ERP systems, various MRP elements are differentiated, such as customer order, independent requirement, planned order, production order and further ones. The term MRP refers to the ERP-internal planning functionalities based on material requirements planning (MRP I) and manufacturing resource planning (MRP II). The selection of the relevant MRP-elements and the sum of all quantities in a specific period leads to the required quantity. For instance, a material-plant-specific stock/requirement list is shown in Figure 3, combining receipts and requirements including the related quantity and the date in one overview.
By the indicators daily working time and factory days, the average capacity availability is calculated, which is in addition to the annual sales volume

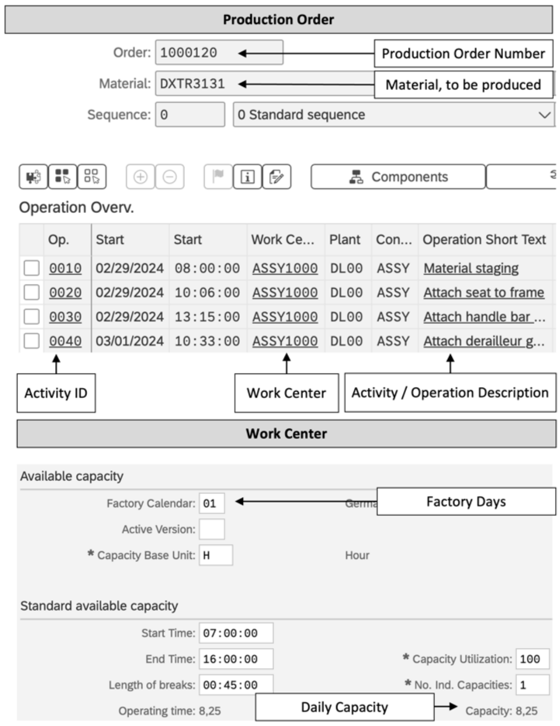

Figure 4: Determination of Availability based on Production Order and Work Center Parameters

required for calculating the customer takt time. These indicators are work center specific. The relevant work centers for producing the final product are determined by the material-related routing (master data object) and the concrete production order (transactional data object), as shown in Figure 4.
If all resources underly the same shift schedule and are not utilized by further production processes, the available capacity of the work center (production resources) is calculated by the related master data as product of factory days and daily working time. If the work centers' capacities are based on different shifts, but the same working days, the customer takt time can be calculated on a daily basis. Regarding work centers, which are part of further value streams or the full capacity is shared for the production of different products a proportional split of the capacity is necessary. Are more detailed consideration of capacities can be found in [23].

The actual delivery time is based on the stock level for unrestricted use. Customer orders are supplied from stock as long as stock is available. The information regarding the stock levels is available in ERP-systems, as shown in Figure 5, but also warehouse management system (WMS), directly connected to the ERP-system.

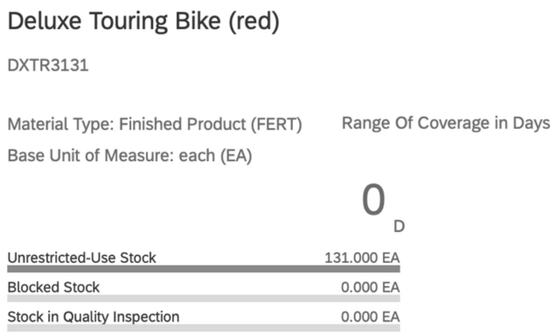

Figure 5: Product-related Stock Level

If no stock is available, the missing product must be externally ordered (in case of procurement type F) or internally produced (in case of procurement type E). Based on the MRP run, a backward scheduling is applied to determine the start of production of the final product based on the requirement date. If the calculated start date is in the past, a forward scheduling is applied. For procured material the replenishment time is explicitly maintained. From a sales' perspective handling times for packaging and shipping are available. On the basis of this data, the delivery time for stock material is calculated as sum of all handling activities in the area of shipping. For non-stock material the delivery time is extended by the replenishment time or production lead time as well as the times for logistical handling, e.g. inbound processing.

The delivery reliability is a performance indicator, derived from the planned delivery dates and the actual delivery dates. Therefore, the determination of this indicator is formula-based and requires historical data.

In addition to the mentioned business application systems, superior systems like DW and BI potentially provides the required information.

2.2. Investigation of Suppliers in the Context of Value Stream Management

The supplier in the Value Stream Map represents the source of the supply chain and ensures the supply of the manufacturing process. The value stream related indicators are mentioned according to [1], [2] in the following listing:

Supplier's name
The supplier´s name the identifier for the supplier, which provides the required components or raw materials to the company.

Materials (input components of the value stream)
The material or components are the input factors for the value stream.

Lead time for replenishment
The lead time for replenishment is the duration between two deliveries, e.g. controlled by delivery schedules, or in case of individual shipments the time between ordering and goods receipt.

Error rate/quantity reliability/delivery reliability
The reliability of the supplier is expressed by the three indicators, referring to volume (quality and quantity) as well as time.

Whereas the first three indicators are related to general master data information in the context of procurement, the last three ones are defined as relative indicators, describing the supplier's performance/reliability by relative indicators, which are calculated from the ratio of past-orientated transactional data and a reference value. The error rate (good, waste, repair) and quantity reliability (deviations as under- and over-delivery) relates to volume and the delivery reliability (punctual delivery) to time.

Due to the high complexity of the bill of material (BOM) structure of several products in practice, it is not economically feasible, to cover all materials by the conventional approach. Therefore, the investigation is limited to the most important or critical one(s).

Potential Data Sources
All indicators are directly connected to the domain of supplier. Therefore, potential digital data sources are business application systems, covering the operational procurement process, e.g. ERP as central enterprise system, but also domain-specific systems like supplier relationship management (SRM) systems and procurement platforms. Quality-related figures in terms of supplier assessment are available in quality management (QM) systems, covering supplier management functions. Data warehouses (DW) in combination with analytic tools and process mining enables further options of the automation of gathering the specific supplier information. The determination of the mentioned indicators based on ERP-data is described in the following section.

Mapping of Data Structures to KPIs
The production order is the central data object of the manufacturing process and defines, inter alia, the material and quantity, to be produced, the way of production (routing/activity lists with resources), as mentioned in the former section, and the input components based on the bill of material (BOM). In accordance to the base quantity, the required components and related quantities are calculated by the system. Furthermore, the listing of materials in the component overview shows the material allocation to the activity/operation in the manufacturing process, ensuring, that the materials are supplied in the area of production at that time, the material is actually needed, as shown in Figure 6.

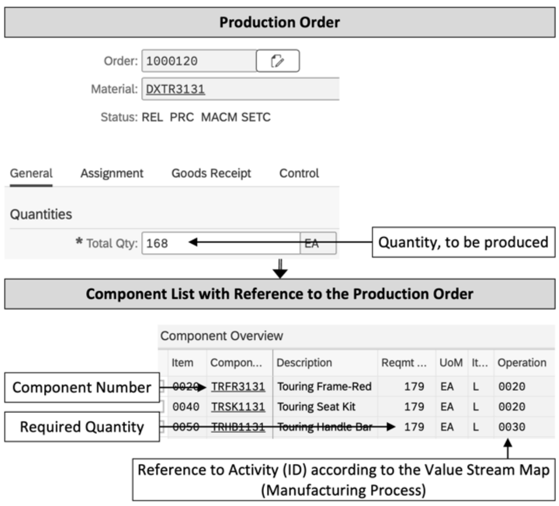

Figure 6: Determination of Input Materials of the Value Stream

By a drill-down to the plant-specific material master data, different views on the material are available, such as basic data, MRP, accounting, costing, storage location stock and further ones. In the area of MRP, the procurement type defines the material as in-house production (E) or external procurement (F) as shown in Figure 7.

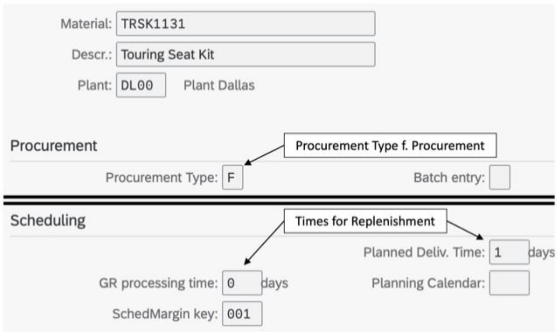

Figure 7: Determination of Source of Supply and Replenishment Time

For in-house production materials, the mentioned consideration enables the identification of interdependencies between the investigated value stream and adjacent ones, forming a system of value streams. The value stream, consuming a component corresponds with the role of a customer in regard to the value stream supplying the required component. This leads to interactions between these ones and rise the complexity to a level, the conventional methodology based on an analog model cannot manage.

Based on the externally procured material number, the available supplier or - in case of dual-/multiple-sourcing - suppliers can be derived. In SAP most of the information is contained in the purchasing info record, which is a source of information in regard to the procurement process, illustrated in Figure 8. Essential information, e.g. pricing and conditions and lead time can be directly derived and utilized for enriching the supplier information in the Value Stream Map. Furthermore, basic vendor evaluation reports are available and enable the rolling calculation of KPIs based on a specific period, e.g. one year. More detailed evaluations, which are not covered by the standard reports, can be processed by the targeted combination of data warehouses, business intelligence (BI) tools (business analytics) and process mining.

3. Results and Discussion

The paper at hand aims at the provision of a framework for automizing the mapping process of the conventional Value Stream Management procedure, limited to the consideration of the two domains of supplier and customer.

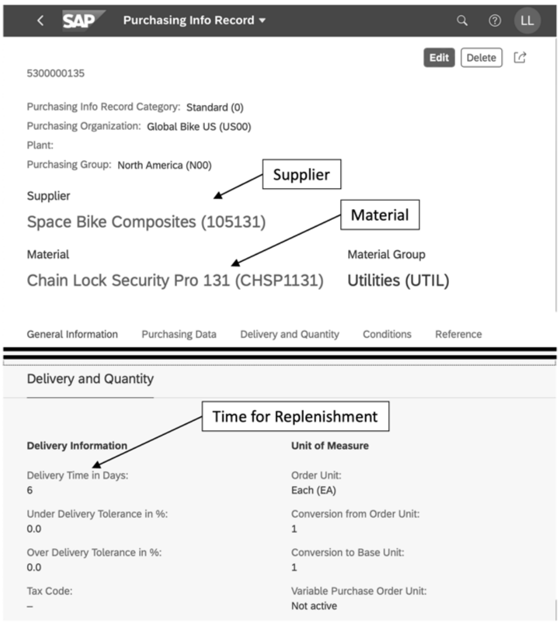

Figure 8: Determination of Supplier based on Purchasing Info Record

The starting point of this investigation is the determination of relevant supplier as well as customer indicators according to the conventional approach. The review of each indicator in terms of meaning and significance is the information baseline, for the identification of potential data sources. In the areas of the different data sources, e.g. ERP, WMS, MES and further ones, related data objects are determined to map the digital data to the appropriate Value Stream Management indicators.

The naming of data objects for the automated derivation of Value Stream Management indicators, as well as the identification of various data sources for these data objects, ensures modularity of the mapping framework. This supports universal usage in heterogeneous process and system landscapes. The fundamental feasibility is demonstrated through validation in an S/4HANA training environment, provided by the Magdeburg-Stendal University of Applied Sciences.

4. Limitations and Conclusion

Value Stream Management is still a valid and widely used approach to optimize value streams. As pointed out in various studies, the conventional procedure has some improvement potentials to ensure its economical application in highly dynamic environments. Recent studies provide approaches for the combination of the conventional methodology and modern information and communication technologies. The focus of this consideration is mainly limited to the manufacturing process. By the paper at hand an approach is discussed to enhance digitalization of

VSM by covering the two domains of supplier and customer.

As detailly described in the previous sections, the mapping Value Stream Management indicators in the domains of customers and suppliers in its origin meaning to data objects, hosted by different types of business application systems is generally feasible. Different data sources are discussed and included in the consideration.

The present study provides a solid foundation, yet it also exhibits limitations that offer potential for further investigation:

As emphasized, the validation of the mapping framework is restricted to the consideration of an S/4HANA training environment. In the next step, the validation is to be extended to other application systems.

The study at hand focuses on external suppliers. The topic of intra-company customer-supplier relationships, which lead to interactions between value streams, mentioned in section 2.2 under the term "system of value streams" and visualized in Figure 9; however, a more in-depth examination is lacking. The digital representation of value streams, as well as the application of simulation models, opens up options in this context that go beyond the possibilities of the conventional approach. In addition to the aforementioned customer-supplier-relationships, also the consideration of shared resources, utilized in more than one value stream, offer investigation potentials, taking into account the tendency towards more flexible production configurations.

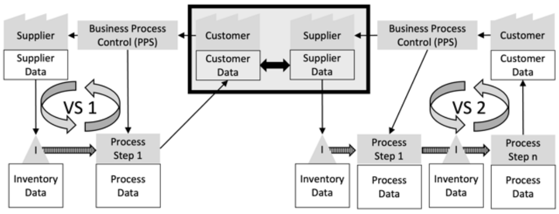

Figure 9: System of Value Streams

Value Stream Management 4.0 follows the approach to create a digital representation of a Value Stream Map as a data-based model, continuously enriched by operational data. Such a digital model opens new opportunities in regard to the utilization of techniques in the field of data sciences. But a detailed analysis of the concrete potentials in terms of VSM and the residual phases is missing and requires further investigations – not only in the domains of supplier and customer, but also in the domain of the manufacturing process.

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VSM 4.0: Application Potentials of Data Science

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Abstract
Value Stream Management (VSM) is a business methodology that focuses on optimizing the flow of materials and information across an organization and beyond to deliver maximum value to customers. It originated from lean manufacturing principles but has been adapted and applied in various domains, such as logistics and administration. To address some weaknesses of the conventional methodology and utilize the potential of increasing digitalization in supply chains in general and companies in particular, various studies explored the targeted application of modern technologies. A common approach in recent studies is to use a digital representation of the value stream, which is dynamically adjusted through continuous processing of operational business data. As reasoned by several studies, the application of data-driven techniques on current data and historical data in the areas of VSM offers several benefits and opens new opportunities in production and logistics management, such as real-time monitoring, early warning-system, enhanced decision-making, predictive analytics, discrete simulation and further ones. Combining VSM with Data Science techniques presents a synergy for organizations aiming to enhance efficiency and maximize value delivery. VSM provides a structured approach to visualizing and optimizing value streams, while Data Science techniques provide the means to gather and analyze big amounts of business data for improving and decision-making. By the present paper, the combined application of VSM and Data Science is investigated, aiming at the provision of an operation framework, which links the various elements of both domains.

1. Introduction
The digitalization of VSM, mentioned as Smart VSM, VSM 4.0, and Dynamic VSM, is made a research subject in several studies, taking different perspectives on the methodology and improvement approaches into account, as shown by [1]. In this context, data is described as an essential key driver for the digital transformation of companies, especially regarding value-adding processes. In addition, the management of data is a potential source of modern waste in terms of information logistics [2]. Both aspects are considered in terms of the future viability of VSM [3], [4]. In various studies data-processing techniques, such as data mining [5], [6], process mining [7], [8], data-based decision-making [9], [10] real-time data processing and data analytics in general [11] and further ones are introduced and critically discussed in terms of application fields. Therefore, the huge amount of business data is utilized for an automated mapping [4], [12] of the actual value stream, waste identification and elimination [13], [14], simulations of measures and target value streams for process improvement [15], [16] and further fields of application. All these data-driven techniques are implicitly related to the research area of Data Sciences. Most studies are limited to the consideration of solutions, combining single aspects of VSM, such as mapping and analyzing with individual data tools, such as machine learning (ML) and data-based decision-making. But for now in research, the merge of VSM and Data Science in its entirety, linking the phases of VSM, concretely from the mapping of the value stream over analyzing, designing to implementing (sometimes also monitoring) with the phases of Data Science projects.

This is the result of a systematic literature review according to PRISMA [17]. Based on an initial review of studies in the database Google Scholar (https://scholar.google.de/), by the search string (“value stream mapping” OR "value stream management”) AND “data science” 528 records, published between 2020 and 2024 are identified. Applying the inclusion criteria English or German, availability and relevant content, the number of records is reduced to 34 ones. The expression "VSM" is explicitly not included, due to different meanings of the abbreviation, such as "vector space method" and its implicit inclusion in the terms "value stream management" and "value stream mapping".

Data Science, a vast field of research, necessitates a more structured approach to project and process management to facilitate its integration with VSM. Data Mining, also known as Knowledge Discovery, describes the entire process from specifying to understanding a data related problem over analyzing it (e.g. for hidden patterns) to gain insights and find solution approaches.
It is pointed out, there is no sharp and clear definition and common understanding of the terminology. In this context, the analysis phase centered around modeling data to address future challenges (for example, predicting future trends based on historical patterns), is also referred to as "Data Mining". From a procedural perspective, the Data Mining process represents a specific methodology to be employed for Data Science applications [18], [19]. The CRoss Industry Standard Process for Data Mining (CRISP-DM) offers a standardized methodology for navigating through Data Science projects, ranging from the initial understanding of the problem or business context to the deployment of an effective model [19], [20]. Therefore, the framework CRISP-DM underlies the research, presented in the paper at hand.

The result of the literature review leads to two central research questions, which are investigated in the framework of the study at hand.

- **RQ1**: How to merge VSM and Data Science by mapping the phases of VSM with the CRISP-DM?
- **RQ2**: How to utilize data processing techniques and tools in the framework of Data Science in combination with the VSM procedure?

2. Methods

As stated in the literature review, some Data Science related techniques were already proposed to apply in the different VSM activities as the amount of data to process during VSM rises. But there is no holistic framework bringing together VSM and the Data Science stack. The paper at hand aims at closing this gap. For VSM, the actions that need to be taken in the four phases are explained in 2.1. To address the requirements for integrating big data into a tangible application, it is essential to delineate a structured approach that encompasses the necessary steps and considerations for effective implementation. To do that, the CRISP-DM was chosen and is explained in 2.2. The two approaches from the domains are then mapped in 2.3. To provide an operational framework, a selection of technologies and algorithms to incorporate Data Science in VSM is provided in 2.4.

2.1. VSM Procedure

VSM represents a holistic management approach to mapping, analyzing, and designing end-to-end value chains from suppliers to customers. It deals with eliminating waste according to Lean Management principles, aiming at the minimization of the overall lead time. Conventionally, this methodology relies on manual tools such as paper, pencil, and stopwatch [21], making it static in volatile environments, as reasoned by [22]. Recent research focuses on digitalizing VSM to overcome several disadvantages and take advantage of the increasing amount of business data. Therefore, in this section the procedure is described based on a four-phase model with reference to data-driven approaches, such as [3], [23], [24].

Phase 1: Value Stream Mapping
Value Stream Mapping refers to recording the actual value stream [21]. In addition to capturing the information and material flows in logical sequence, VSM-specific metrics are recorded, which are then consolidated in their entirety in a value stream map. Referring to a digital model of the value stream map, data from business application systems, such as enterprise resource planning (ERP) and manufacturing execution system (MES) as well as from machines and plants is utilized for deriving the status quo.

Phase 2: Value Stream Analysis
Value Stream Analysis, which depending on the literature considered can also include the phase of Value Stream Mapping, e.g. [21], describes a process of examining and evaluating the value stream's efficiency based on wastes such as overproduction, waiting time, unnecessary transportation, excess inventory, defects, and similar ones [21]. By the gathered metrics, the overall performance is measured, whereas root cause analyses are conducted on the identified wastes.

Phase 3: Value Stream Design
In the third phase, a target value stream is designed, eliminating the weaknesses and wastes, identified in the previous phase. In this context, tools and principles of Lean Management are applied, such as a leveled utilization of all

resources, reduction of stocks, optimization of setup processes by SMED (Single Minute Exchange of Die), flow orientation, customer-centric and further ones [21].

Phase 4: Value Stream Planning
Value Stream Planning refers to the iterative implementation of measures to achieve the target value stream and gradually reduce waste while increasing efficiency. [25], [26], [27].

2.2. CRISP-DM

This work aims at providing an operational framework that support the implementation of Data Science technologies and models in the context of VSM. The CRISP-DM is a common cycle to follow when implementing a data related model for a certain task. Although it is not new, Data Science is currently gaining a lot of publicity, but there is still no standard approach or model fixed in a German DIN norm. The German Federal Ministry for Economic Affairs and Climate Action supports the non-profit organization DIN with shaping this. They published the second edition of a “Normungsroadmap KI” - a road map to a potential DIN norm for Artificial Intelligence (AI) in 2022 [28].

The CRISP-DM represents a comprehensive methodology applicable to data mining projects. It serves as a structured framework designed to guide the execution of the development of applications leveraging (big) data for specific objectives within a corporate environment. This methodology has six distinct phases and incorporates options for iterative adjustments for refinement [20]. The procedure model is shown in Figure 1 and elucidated in this section.

Phase 1: Business Understanding
At the start of a Data Mining project, there is the need for general business understanding. The project team needs to determine the general business objectives. When the group is an internal team, ideally these are known by the team. But, especially when an external service provider is involved, the objective should be stated to all stakeholders in the project team. In addition to that, the current situation of the company should be assessed. For example, the available resources as well as potential risks the company is facing should be identified. Subsequently, the objectives of Data Mining, which the organization aims to achieve through the application of Data Science Technologies, must be clearly defined to facilitate the measurement of their success. Concluding this initial phase, the formulation of a preliminary project plan, is requisite [20].

Phase 2: Data Understanding
Central to Data Understanding is the acquisition of data. Ideally, an organization already engages in pertinent data collection (e.g., via Internet of Things (IoT) sensor technology) and storage with a database management system. To ascertain if the data is relevant, its information and value needs to be evaluated. The data needs to be described to get a common sense of what it contains and what not. This involves a high-level description that contains certain characteristics of the data such as the volume, its format properties, the number of data points, source and further features. Subsequent analysis possibly unveils first hidden information of the data, such as dominant market segments for specific product groups. In this phase, data quality is evaluated. Criteria for the quality of the data are for example the amount of data or number of missing values. It can also unveil features that are missing in the data at this point. The CRISP-DM model gives an option to circle back to the Business Understanding phase, as understanding the data of a company is closely related to understanding the company itself [20].

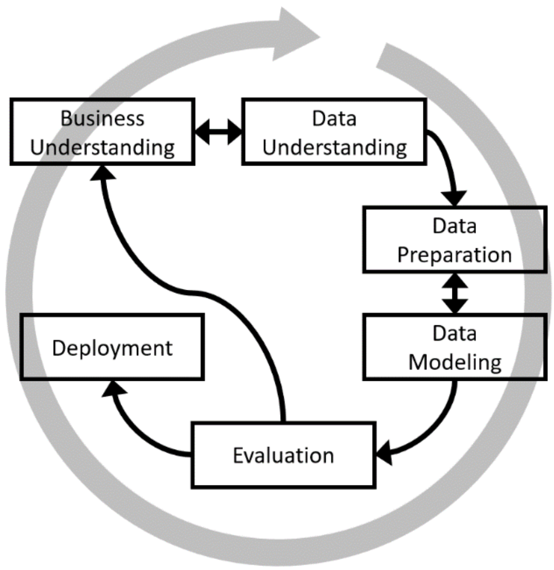

Figure 1: Circular phase model of CRISP-DM [20]

Phase 3: Data Preparation
With this step, the data that is relevant to the data mining objectives must be identified, selected, and subsequently prepared for the modeling phase. Preparation entails data preprocessing, which involves cleaning the data and convert it into a suitable format for modeling. This entails the identification and resolution of redundant attributes, inconsistencies, and outliers. Redundant attributes can be handled by removing duplicated ones, which at the same time achieves data reduction. Reducing the dimension of the data to the information that is relevant without loosing important information is an essential aim of

preprocessing as well. Furthermore, detecting and handling outliers and missing values are crucial for the applicability of the data in Machine Learning models. Another common preprocessing step is to normalize the data to enhance comparability of different features of the data [18], [20].

Phase 4: Modeling
Several models can be considered to solve a problem or execute a certain task. For example, classification tasks might leverage a Decision Tree model or a Neural Network architecture. To find the most suitable model, ideally more than one model is implemented. By benchmarking their performance, the superior model can be identified and deployed. Commonly, model evaluation involves comparing metrics such as error rates or accuracy. The Modeling and Data Preparation phases are interconnected in a cyclic process. Should the model be unable to process data in the preprocessed format, a step backwards to the Data Preparation phase becomes necessary. This iterative process may require multiple cycles to achieve optimal compatibility between the data format and the model's requirements [18], [20].

Phase 5: Evaluation
The assessment of the model must also incorporate an analysis of its contribution to the overarching (business) objectives intended by the initiative. To evaluate the impact of the model on the business objectives, it needs to be implemented and tested. Should the model fail to meet the project objectives, an investigation into the causative factors is needed. During the Evaluation phase, a comprehensive review of the entire process—from the initial phase through to the modeling phase—is conducted to ensure that all critical aspects have been accounted for in the project. If the model does not support the business objectives, the process circles back and starts over in the Business Understanding phase [20].

Phase 6: Deployment
If the model successfully passed the Evaluation phase, it can be deployed to be used for its task in the company. The deployment of an ML model itself is a project that needs to take into account many aspects. Therefore, a deployment plan is needed. Additionally, the model's validity must be regularly assessed. Here, online and offline models can be differentiated. The majority are offline models, trained once using data that is current at that time. Should the data evolve, these models do not automatically adapt unless they are retrained or further trained with new data. Conversely, online models are continuously updated with emerging data, ensuring they remain current and avoid obsolescence [29]. To make the process transparent and understandable for all stakeholders, a documentation is created [20].

2.3. Phase Mapping of VSM and CRISP-DM

From the description of VSM and CRISP-DM that this paper aims to merge, it can already be deducted that they share similarities. Data related technologies support VSM already, but for now there is no structured consideration of how to imply Data Science approaches in VSM, considering it as a holistic Data Mining Project [1], [14], [30]. In the following section, a mapping of the VSM-related phase model and the CRISP-DM phase model is conducted.

The Value Stream Mapping phase encompasses the Business and Data Understanding stages of CRISP-DM, through documenting and analyzing the current Value Stream. This process involves data collection and analysis to refine the Value Stream Map. Value Stream Analysis aligns with CRISP-DM's Data Understanding, Preparation, and Modeling phases, facilitating optimization strategies for Value Stream Design. The Design phase aims to enhance the Value Stream by minimizing waste and reducing lead times, necessitating evaluation to confirm improvements. This is reflected by a part of the Evaluation phase in the CRISP-DM. Subsequently, these optimizations are implemented during the Value Stream Planning phase, paralleling CRISP-DM's Deployment phase, to actualize the refined Value Stream.

2.4. Design of an operational Framework

The design of the operational framework refers to the assignment of VSM phases and CRISP-DM phases, as well as allocating adequate tools of Data Sciences to support the VSM methodology in a data-based manner. The generic structure of the framework is depicted in Figure 2, whereas each procedure including the specific phases represents the horizontal and vertical axes, forming a matrix. The framework aims to emphasize the view on digital VSM as a Data Science initiative. Consequently, this section provides a framework of tools explicitly related to Data Science to cover all phases of VSM.

As the operational framework represents a generic structure, the proposed measures within the matrix represent a selection of best practices, from which the user utilizes the ones, which fulfill the specific requirements and optimally fit to the given data environment.

Value Stream Mapping involves digitally documenting the current value stream, utilizing digital tools such as sensors, ID technologies (e.g., radio-frequency identification (RFID), barcode), and tracking devices as previously mentioned in [1]. The data recording takes place. The creation of a digitized Value Stream Map is facilitated by employing a digital twin or a dedicated dashboard. The second phase in VSM, Value Stream Analysis, aligns with CRISP-DM's Data Understanding, Preparation, and Modeling phases, embodying VSM's most comprehensive task. It contains different steps from the collection of the data to building models. Initially, consolidating data, possibly via database management systems, is crucial for further analysis [31]. To further understand the data, it needs to be analyzed by describing and exploring it. This can be supported by data visualization (e.g. with histograms, scatter- and box plots). Process mining helps as well to consolidate and understand all the process related data. Existing dashboards may aid in data exploration, revealing potential data insufficiencies. In cases of scarce data - complex or costly to gather - special models are employed to extract insights from limited data points [32], [33].

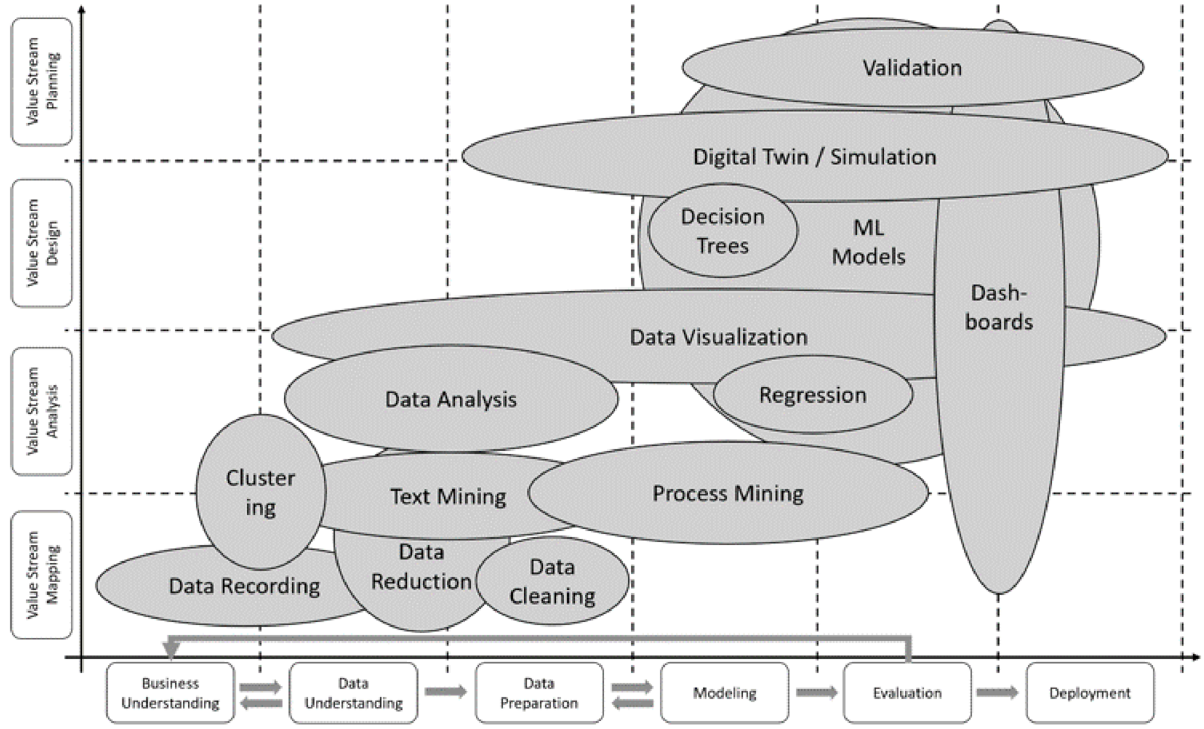

Figure 2: Mapping of the CRISP-DM phases and the VSM phases with exemplary measures

If unstructured data, such as feedback of employees and customers, need to be considered, we need to apply tools to get more structured information from the data, e.g. text mining, natural language processing (NLP) or clustering [34], [35], [36]. These activities occur in the Data Preparation and Understanding phase and extend into the modeling phase as well (e.g. when clustering algorithms are used). The Data Preparation phase covers data cleaning (e.g. noise reduction, handling missing data and outliers), data reduction and data construction (e.g. feature engineering and dimension reduction) [37], [38], [39]. The prepared data is formatted for model testing. Depending on the data and the goal that wants to be achieved, different ML models are of use, e.g. decision trees or a regression. In this Value Stream Analysis phase, ML models help to identify waste causes, predict future bottlenecks, and pinpoint inefficiencies, informing the Value Stream Design phase to craft a more efficient Value Stream.

In the Value Stream Design phase which also intersects with the Modeling phase of the CRISP-DM cycle ML models are used to optimize the Value Stream, e.g. supported by simulations and reinforcement learning with the digital twin [40]. What model can be beneficial to support reducing wastes and therefore optimize the Value Stream is depending on the problem and the data that is available. Therefore, expertise and experienced Data Scientist are needed [19]. The Evaluation phase, involving iterative interactions with the Modeling phase, intersects with both the Value Stream Design and Planning phases. This is reasoned by the iterative implementation of improvement measures of the Value Stream Planning phase as a real life validation of the model. This last phase of the VSM process is mapped with the Deployment phase of the CRISP-DM, where the evaluated model is deployed to be used in VSM.

3. Results and Discussion

This work offers an operational framework that can be used to utilize the full potential of the Value Stream related data and available Data Science applications in the context of VSM. The provided mapping of the phases of CRISP-DM and VSM proves the view on a data-based VSM as a Data Mining project. Data Mining enables the knowledge gaining from available business data in VSM to its full potential. As VSM, CRISP-DM is based on iterations and represents a continuous approach, which leads to a steady improvement of data quality and knowledge gaining with each cycle. To map the phases, the concrete tasks in each phase of the two procedures are reviewed and linked to each other. The operational framework then added tools that can be used in a real world scenario to optimize the data-driven VSM approach.

A main advantage of implementing Data Science applications in VSM is that it enables the possibility for real-time adjustments in the Value Stream. For example, once implemented in a digital twin of the Value Stream which is connected with the real Value Stream via digitization and digitalization technologies (sensors, RFID, barcodes etc.) it can be analyzed and adjusted agile in real-time. Another advantage is that the main KPIs can be observed in real-time as well, offering opportunity for close management. Using ML models that predict potential bottlenecks and identify inefficiencies can further lead to optimized use of resources like workforce, machines and materials. This can also be done by predicting the future demand. Furthermore, Data Science opens opportunities to evaluate the increasing amount of available business data in the area of production and logistics.

The provided framework supports the utilization of data within the VSM methodology. It provides an orientation to merge VSM with the Data Mining process.

4. Limitations and Conclusion

This work offers a holistic view on the VSM and Data Science process. This is resulting from the observed similarities in both procedures and the need of VSM to become more digital and data driven to foster optimizations in a more structured manner compared to the conventional approach. Data Science is a generic term for a lot of models applications and a big research field, a more concrete and process oriented view on it was demanded. The CRISP-DM offers this as a process standard for Data Science projects.

The tools and methodologies pertinent to Data Science disciplines this paper suggest to use extends beyond those exemplarily named within this work. The complexity and effectiveness of these tasks are significantly influenced by the specific use cases to which they are applied, suggesting that a universal approach may not be feasible. Moreover, the application of data-related technologies within a company's infrastructure is primarily contingent upon its existing system landscape. Consequently, the scope of this work does not cover data quality and quantity considerations, though they play a crucial role in the success of Data Mining projects. The process of data collection itself presents another layer of complexity, heavily influenced by the nature of the product and the industry involved. The intricacy of acquiring relevant and high-quality data varies significantly across different sectors, impacting the feasibility and efficiency of data-driven initiatives. Furthermore, it is critical to note that the pursuit of digitization should align with and serve the overarching objectives of an organization, rather than being pursued reasoned by itself. This work adopts a generalist approach and, therefore, does not delve into how VSM and related digital transformation efforts can be tailored to support specific business goals such as enhanced transparency, documentation, and continuous improvement.

In summary, while this study provides valuable insights and suggestions for employing Data Science applications in the domain of VSM, it acknowledges the limitations posed by the complexity of these tasks, the dependency on the organizational context, and the nuances of data quality and acquisition. Future research could benefit from exploring these dimensions in greater detail, focusing on tailored solutions that align technological advances with specific business objectives and industry requirements.

Partially, the considered tools and its utilization are already investigated in terms of VSM by various studies, as mentioned in the previous section. By the provided framework, an overview of Data Science tools to be utilized in the framework VSM is given, based on the view of VSM as a Data Mining process. In the next step, the interplay between the different tools with focus on synergies requires a deeper investigation as well as its validation in operational environments.

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Examining solar potential within electrical material flow

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Abstract

This paper highlights the challenges of integrating renewable energy into electricity distribution networks, focusing on modeling and optimizing electrical energy flows from sources such as nuclear, thermal, renewable, and geothermal to various consumers, including industrial, residential, commercial, and electric transportation sectors. It addresses a critical knowledge gap in managing the complexity of energy distribution with diverse sources and variable consumption patterns. The research aims to develop a comprehensive model that ensures voltage stability across grid levels and optimizes the allocation of energy from sources, including solar panels, over time intervals. The proposed model uses time constraint matrices and graph theory to represent energy flows between sources and consumers, and defines variables and constraints to maintain grid stability amidst demand fluctuations. The intended results include a detailed energy distribution framework with a clear implementation methodology designed for practical use by grid operators, policy makers, and researchers. By providing a structured approach to the integration of renewable energy, the results will support the development of more resilient and efficient electricity distribution networks, define the problem, and outline future research steps.

1. Introduction

Global energy consumption has been steadily increasing due to the growing world population, rapid industrialization, and technological advances. Research on solar energy adoption offers a multidimensional scope and warrants exploration from multiple perspectives, including political, economic, management, behavioral, policy, and innovation aspects s[1]. This surge in energy consumption has significant environmental implications, leading to increased carbon emissions and depletion of natural resources. In response, European countries have made efforts to transition to more sustainable energy sources, such as solar and wind power. Hungary, as one of the largest energy consumers in Europe, has been working to diversify its energy mix and increase the use of renewable energy sources.

This shift toward clean energy technologies has been supported by policy initiatives and investments in the development of renewable energy infrastructure. In addition, mathematical models involving matrices have become essential tools for analyzing complex systems and solving equations in various fields of research and industry. These models are used to study and predict energy consumption patterns, optimize energy production, and improve the efficiency of energy distribution systems.

As the global demand for energy continues to grow, it is critical for countries to prioritize the development and adoption of sustainable energy solutions. This includes investing in renewable energy sources, improving energy efficiency, and promoting the use of clean technologies. By doing so, we can reduce the environmental impact of our energy consumption and ensure the availability of natural resources for future generations.

The flow of materials, logistics, and electrical power are critical components of modern industrial and commercial operations. The efficient movement of raw materials, components, and finished products is essential to the smooth functioning of supply chains and manufacturing processes. Logistics involves coordinating these movements and managing storage, transportation, and distribution activities. Meanwhile, electrical

energy is a fundamental requirement for powering machinery, equipment, and lighting systems in various industrial and commercial environments. Together, these three elements play a vital role in supporting the operations of businesses and industries worldwide.
After analyzing the bibliography of the Scopus database found with the keywords optimization, material flow, and energy flow, it was observed that more than 800 papers have been published from 1970 to the present. It is interesting to note that 433 of these papers have been published since 2018, indicating a significant increase in interest in these topics in recent years. This increase in scientific production reflects the growing importance given to the optimization of material and energy flows in various fields, such as engineering, logistics, and environmental management.
Analyzing the bibliography with the keywords: network, material flow, energy flow and mathematical model in Scopus, a total of 51 papers were found, of which 39 are articles, 9 are conference papers, 3 are reviews and 1 is a conference review. As of 2018, the design of low-carbon supply chain networks has started to develop, indicating that this research topic has not been widely explored for a considerable period of time, despite the increasing emphasis on the development of a low-carbon economy [2]. This indicates that there is great potential for future research and development in this area, especially in the application of mathematical models to optimize energy flow in industrial and commercial networks.
Below is a table of bibliographic references of different scientific fields used to solve material flow problems, as well as a reference to material flow in the special case of energy:

Table 1: Scientific field used to solve for Material and Energy Flows

Scientific field	References
Literature review	[1], [3]
Circular economy	[4], [5], [6], [7], [8]
Algorithms	[9], [10], [11], [12], [13], [14]
Simulation	[15], [16], [17]
Variables	[18], [19], [20], [21], [22], [23]
Material (energy) flow	[24], [25], [26]

In the present research work, different aspects related to material and energy flows are addressed, focusing on the Hungarian context. First, an analysis of the background and the first model used to understand the relationship between material flows and energy are presented. Subsequently, the energy situation in Hungary will be specifically examined, highlighting the challenges and opportunities facing the country. In addition, a mathematical matrix model is developed to analyze the relationship between electricity consumption and generation. Different matrices and graphs will be analyzed to better understand the dynamics of electricity demand and supply in a given system. Finally, the results obtained will be discussed and possible future research directions in this area will be proposed.
A brief state of the art report including literature review, research gaps and research questions will be formulated.

2. Methods or experimental part

The procedure developed is the result of the bibliographic analysis carried out, since it includes in a rational way what has been proposed by the different authors with respect to the flow of materials and the different models studied. Figure 1 shows the procedure for improving the model.

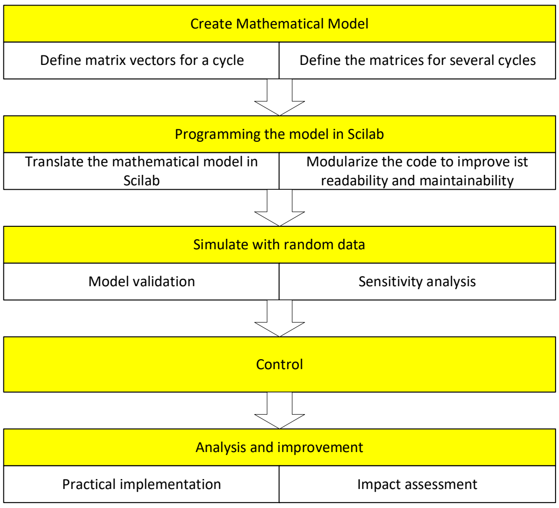

Figure 1: Methodology

2.1 Create Mathematical Model

A mathematical model based on matrices is proposed. Matrices are fundamental tools in various scientific disciplines and allow for the representation and solution of a wide range of problems. In this context, the chosen approach involves the development of a matrix system that captures the interactions and relationships between the relevant variables of the problem at hand [27]. This model would provide a framework for exploring and evaluating potential approaches. In addition, the flexibility and adaptability of the matrices would allow the model to be adapted to the specific needs of the problem and the constraints of the environment. The proposed model is:
Where n_f is the final number of elements for all the matrices in the model.

Where each element P_i represents the energy production of category i for one cycle.

$$P_{\mathrm{i}} = \begin{matrix} & 1 \\ 1 & p_{1,1} \\ 2 & p_{2,1} \\ 3 & p_{3,1} \\ \vdots & \cdots \\ i & p_{i,1} \\ \vdots & \cdots \\ n_f & p_{n_f,1} \end{matrix} \qquad (1)$$

Let be a matrix $cost_{p_i}$ of size $n\ x\ m$, where n represents the cost of the product for one cycle.

$$cost_{p_i} = \begin{matrix} & 1 \\ 1 & mp_{1,1} \\ 2 & mp_{2,1} \\ 3 & mp_{3,1} \\ \vdots & \cdots \\ i & mp_{i,1} \\ \vdots & \cdots \\ n_f & mp_{n_f,1} \end{matrix} \qquad (2)$$

The matrix $t, inicial_{p_i}$ would represent the initial time for one cycle:

$$t, inicial_{p_i} = \begin{matrix} & 1 \\ 1 & np_{1,1} \\ 2 & np_{2,1} \\ 3 & np_{3,1} \\ \vdots & \cdots \\ i & np_{i,1} \\ \vdots & \cdots \\ n_f & np_{n_f,1} \end{matrix} \qquad (3)$$

The matrix $t, final_{p_i}$ would represent the final time for one cycle:

$$t, final_{p_i} = \begin{matrix} & 1 \\ 1 & tkp_{1,1} \\ 2 & tkp_{2,1} \\ 3 & tkp_{3,1} \\ \vdots & \cdots \\ i & tkp_{i,1} \\ \vdots & \cdots \\ n_f & tkp_{n_f,1} \end{matrix} \qquad (4)$$

Where each element C_i represents the energy production of the category i for one cycle

$$C_{\mathrm{i}} = \begin{matrix} & 1 \\ 1 & f_{1,1} \\ 2 & f_{2,1} \\ 3 & f_{3,1} \\ \vdots & \cdots \\ i & f_{i,1} \\ \vdots & \cdots \\ n_f & f_{n_f,1} \end{matrix} \qquad (5)$$

Let be a matrix $cost_{c_i}$ of size $n\ x\ m$, where n represents the cost for product for one cycle.

$$cost_{c_i} = \begin{matrix} & 1 \\ 1 & mf_{1,1} \\ 2 & mf_{2,1} \\ 3 & mf_{3,1} \\ \vdots & \cdots \\ i & mf_{i,1} \\ \vdots & \cdots \\ n_f & mf_{n_f,1} \end{matrix} \qquad (6)$$

The matrix $t, inicial_{c_i}$ would represent the initial time for one cycle:

$$t, inicial_{c_i} = \begin{matrix} & 1 \\ 1 & nf_{1,1} \\ 2 & nf_{2,1} \\ 3 & nf_{3,1} \\ \vdots & \cdots \\ i & nf_{i,1} \\ \vdots & \cdots \\ n_f & nf_{n_f,1} \end{matrix} \qquad (7)$$

The matrix $t, final_{c_i}$ would represent the final time for one cycle:

$$t, final_{c_i} = \begin{matrix} & 1 \\ 1 & tkf_{1,1} \\ 2 & tkf_{2,1} \\ 3 & tkf_{3,1} \\ \vdots & \cdots \\ i & tkf_{i,1} \\ \vdots & \cdots \\ n_f & tkf_{n_f,1} \end{matrix} \qquad (8)$$

Where each element P_{i^*,j^*} represents the energy production of category i^* at bar j^*

$$P_{i^*,j^*} = \begin{matrix} & 1 & 2 & 3 & j & n_f \\ 1 & p_{1,1} & p_{1,2} & p_{1,3} & p_{1,j} & p_{1,n_f} \\ 2 & p_{2,1} & p_{2,2} & p_{2,3} & p_{2,j} & p_{2,n_f} \\ 3 & p_{3,1} & p_{3,2} & p_{3,3} & p_{3,j} & p_{3,n_f} \\ \vdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ i & p_{i,1} & p_{i,2} & p_{i,3} & p_{i,j} & p_{i,n_f} \\ \vdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ n_f & p_{n_f,1} & p_{n_f,2} & p_{n_f,3} & p_{n_f,j} & p_{n_f,n_f} \end{matrix} \qquad (9)$$

The matrix $COST_{p_{i,j}}$ of size $n_p\ x\ \mathrm{n}_{\mathrm{cycle}}$, where n represents the cost of one product in j. cycle in time.

$$COST_{p_{i,j}} = \begin{matrix} & 1 & 2 & 3 & j & n_f \\ 1 & cost_{p_{1,1}} & cost_{p_{1,2}} & cost_{p_{1,3}} & cost_{p_{1,j}} & cost_{p_{1,n_f}} \\ 2 & cost_{p_{2,1}} & cost_{p_{2,2}} & cost_{p_{2,3}} & cost_{p_{2,j}} & cost_{p_{2,n_f}} \\ 3 & cost_{p_{3,1}} & cost_{p_{3,2}} & cost_{p_{3,3}} & cost_{p_{3,j}} & cost_{p_{3,n_f}} \\ \vdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ i & cost_{p_{i,1}} & cost_{p_{i,2}} & cost_{p_{i,3}} & cost_{p_{i,j}} & cost_{p_{i,n_f}} \\ \vdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ n_f & cost_{p_{n_f,1}} & cost_{p_{n_f,2}} & cost_{p_{n_f,3}} & cost_{p_{n_f,j}} & cost_{p_{n_f,n_f}} \end{matrix} \qquad (10)$$

The matrix $INT_{p_{i,j}}$ would represent the i intensity for the source for j cycle:

$$INT_{p_{i,j}} = \begin{matrix} & 1 & 2 & 3 & j & n_f \\ 1 & int_{p_{1,1}} & int_{p_{1,2}} & int_{p_{1,3}} & int_{p_{1,j}} & int_{p_{1,n_f}} \\ 2 & int_{p_{2,1}} & int_{p_{2,2}} & int_{p_{2,3}} & int_{p_{2,j}} & int_{p_{2,n_f}} \\ 3 & int_{p_{3,1}} & int_{p_{3,2}} & int_{p_{3,3}} & int_{p_{3,j}} & int_{p_{3,n_f}} \\ \vdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ i & int_{p_{i,1}} & int_{p_{i,2}} & int_{p_{i,3}} & int_{p_{i,j}} & int_{p_{i,n_f}} \\ \vdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ n_f & int_{p_{n_f,1}} & int_{p_{n_f,2}} & int_{p_{n_f,3}} & int_{p_{n_f,j}} & int_{p_{n_f,n_f}} \end{matrix} \qquad (11)$$

The matrix $tInicial_{p_{i,j}}$ would represent the initial time i for the source for j cycle:

$$tInicial_{p_{i,j}} = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ \vdots \\ i \\ \vdots \\ n_f \end{array} \begin{array}{c} \begin{array}{ccccc} 1 & 2 & 3 & j & n_f \end{array} \\ \begin{bmatrix} t_{i,p_{1,1}} & t_{i,p_{1,2}} & t_{i,p_{1,3}} & t_{i,p_{1,j}} & t_{i,p_{1,n_f}} \\ t_{i,p_{2,1}} & t_{i,p_{2,2}} & t_{i,p_{2,3}} & t_{i,p_{2,j}} & t_{i,p_{2,n_f}} \\ t_{i,p_{3,1}} & t_{i,p_{3,2}} & t_{i,p_{3,3}} & t_{i,p_{3,j}} & t_{i,p_{3,n_f}} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ t_{i,p_{i,1}} & t_{i,p_{i,2}} & t_{i,p_{i,3}} & t_{i,p_{i,j}} & t_{i,p_{i,n_f}} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ t_{i,p_{n_f,1}} & t_{i,p_{n_f,2}} & t_{i,p_{n_f,3}} & t_{i,p_{n_f,j}} & t_{i,p_{n_f,n_f}} \end{bmatrix} \end{array} \quad (12)$$

The matrix $tFinal_{p_{i,j}}$ would represent the final time i for the source for j cycle:

$$tFinal_{p_{i,j}} = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ \vdots \\ i \\ \vdots \\ n_f \end{array} \begin{array}{c} \begin{array}{ccccc} 1 & 2 & 3 & j & n_f \end{array} \\ \begin{bmatrix} t_{f,p_{1,1}} & t_{f,p_{1,2}} & t_{f,p_{1,3}} & t_{f,p_{1,j}} & t_{f,p_{1,n_f}} \\ t_{f,p_{2,1}} & t_{f,p_{2,2}} & t_{f,p_{2,3}} & t_{f,p_{2,j}} & t_{f,p_{2,n_f}} \\ t_{f,p_{3,1}} & t_{f,p_{3,2}} & t_{f,p_{3,3}} & t_{f,p_{3,j}} & t_{f,p_{3,n_f}} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ t_{f,p_{i,1}} & t_{f,p_{i,2}} & t_{f,p_{i,3}} & t_{f,p_{i,j}} & t_{f,p_{i,n_f}} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ t_{f,p_{n_f,1}} & t_{f,p_{n_f,2}} & t_{f,p_{n_f,3}} & t_{f,p_{n_f,j}} & t_{f,p_{n_f,n_f}} \end{bmatrix} \end{array} \quad (13)$$

Where each element C_{i^*,j^*} represents the energy consumption of category i^* at bar j^*

$$C_{i^*,j^*} = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ \vdots \\ i \\ \vdots \\ n_f \end{array} \begin{array}{c} \begin{array}{ccccc} 1 & 2 & 3 & j & n_f \end{array} \\ \begin{bmatrix} c_{1,1} & c_{1,2} & c_{1,3} & c_{1,j} & c_{1,n_f} \\ c_{2,1} & c_{2,2} & c_{2,3} & c_{2,j} & c_{2,n_f} \\ c_{3,1} & c_{3,2} & c_{3,3} & c_{3,j} & c_{3,n_f} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ c_{i,1} & c_{i,2} & c_{i,3} & c_{i,j} & c_{i,n_f} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ c_{n_f,1} & c_{n_f,2} & c_{n_f,3} & c_{n_f,j} & c_{n_f,n_f} \end{bmatrix} \end{array} \quad (14)$$

The matrix $\mathrm{COST}_{c_{i,j}}$ of size $n_p \; x \; \mathrm{n_{cycle}}$, where n represents the cost of one product in j. cycle in time.

$$\mathrm{COST}_{c_{i,j}} = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ \vdots \\ i \\ \vdots \\ n_f \end{array} \begin{array}{c} \begin{array}{ccccc} 1 & 2 & 3 & j & n_f \end{array} \\ \begin{bmatrix} cost_{c_{1,1}} & cost_{c_{1,2}} & cost_{c_{1,3}} & cost_{c_{1,j}} & cost_{c_{1,n_f}} \\ cost_{c_{2,1}} & cost_{c_{2,2}} & cost_{c_{2,3}} & cost_{c_{2,j}} & cost_{c_{2,n_f}} \\ cost_{c_{3,1}} & cost_{c_{3,2}} & cost_{c_{3,3}} & cost_{c_{3,j}} & cost_{c_{3,n_f}} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ cost_{c_{i,1}} & cost_{c_{i,2}} & cost_{c_{i,3}} & cost_{c_{i,j}} & cost_{c_{i,n_f}} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ cost_{c_{n_f,1}} & cost_{c_{n_f,2}} & cost_{c_{n_f,3}} & cost_{c_{n_f,j}} & cost_{c_{n_f,n_f}} \end{bmatrix} \end{array} \quad (15)$$

The matrix $INT_{c_{i,j}}$ would represent the i intensity for the source for j cycle:

$$INT_{c_{i,j}} = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ \vdots \\ i \\ \vdots \\ n_f \end{array} \begin{array}{c} \begin{array}{ccccc} 1 & 2 & 3 & j & n_f \end{array} \\ \begin{bmatrix} int_{c_{1,1}} & int_{c_{1,2}} & int_{c_{1,3}} & int_{c_{1,j}} & int_{c_{1,n_f}} \\ int_{c_{2,1}} & int_{c_{2,2}} & int_{c_{2,3}} & int_{c_{2,j}} & int_{c_{2,n_f}} \\ int_{c_{3,1}} & int_{c_{3,2}} & int_{c_{3,3}} & int_{c_{3,j}} & int_{c_{3,n_f}} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ int_{c_{i,1}} & int_{c_{i,2}} & int_{c_{i,3}} & int_{c_{i,j}} & int_{c_{i,n_f}} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ int_{c_{n_f,1}} & int_{c_{n_f,2}} & int_{c_{n_f,3}} & int_{c_{n_f,j}} & int_{c_{n_f,n_f}} \end{bmatrix} \end{array} \quad (16)$$

The matrix $tInitial_{c_{i,j}}$ would represent the initial time i for the source for j cycle:

$$tInitial_{c_{i,j}} = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ \vdots \\ i \\ \vdots \\ n_f \end{array} \begin{array}{c} \begin{array}{ccccc} 1 & 2 & 3 & j & n_f \end{array} \\ \begin{bmatrix} t_{i,c_{1,1}} & t_{i,c_{1,2}} & t_{i,c_{1,3}} & t_{i,c_{1,j}} & t_{i,c_{1,n_f}} \\ t_{i,c_{2,1}} & t_{i,c_{2,2}} & t_{i,c_{2,3}} & t_{i,c_{2,j}} & t_{i,c_{2,n_f}} \\ t_{i,c_{3,1}} & t_{i,c_{3,2}} & t_{i,c_{3,3}} & t_{i,c_{3,j}} & t_{i,c_{3,n_f}} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ t_{i,c_{i,1}} & t_{i,c_{i,2}} & t_{i,c_{i,3}} & t_{i,c_{i,j}} & t_{i,c_{i,n_f}} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ t_{i,c_{n_f,1}} & t_{i,c_{n_f,2}} & t_{i,c_{n_f,3}} & t_{i,c_{n_f,j}} & t_{i,c_{n_f,n_f}} \end{bmatrix} \end{array} \quad (17)$$

The matrix $tFinal_{c_{i,j}}$ would represent the final time i for the source for j cycle:

$$tFinal_{c_{i,j}} = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ \vdots \\ i \\ \vdots \\ n_f \end{array} \begin{array}{c} \begin{array}{ccccc} 1 & 2 & 3 & j & n_f \end{array} \\ \begin{bmatrix} t_{f,c_{1,1}} & t_{f,c_{1,2}} & t_{f,c_{1,3}} & t_{f,c_{1,j}} & t_{f,c_{1,n_f}} \\ t_{f,c_{2,1}} & t_{f,c_{2,2}} & t_{f,c_{2,3}} & t_{f,c_{2,j}} & t_{f,c_{2,n_f}} \\ t_{f,c_{3,1}} & t_{f,c_{3,2}} & t_{f,c_{3,3}} & t_{f,c_{3,j}} & t_{f,c_{3,n_f}} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ t_{f,c_{i,1}} & t_{f,c_{i,2}} & t_{f,c_{i,3}} & t_{f,c_{i,j}} & t_{f,c_{i,n_f}} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ t_{f,c_{n_f,1}} & t_{f,c_{n_f,2}} & t_{f,c_{n_f,3}} & t_{f,c_{n_f,j}} & t_{f,c_{n_f,n_f}} \end{bmatrix} \end{array} \quad (18)$$

2.1. The model in Scilab

Using Scilab for data modeling and analysis provides a robust and versatile platform for researchers and professionals in various scientific and technical fields. With its wide range of functions and numerical computing capabilities, Scilab becomes an invaluable tool for creating and analyzing complex mathematical models. This latest model developed in Scilab takes advantage of these features in a realistic approach to simulate and analyze a variety of scenarios. In addition, Scilab's visualization capabilities, such as the creation of bar graphs for the generated matrices, facilitate the interpretation and understanding of the results obtained. These features make Scilab a powerful tool for research and data analysis in scientific and technical environments. The code to represent the mathematical model is:

```
function generate_random_matrix(n, m):
  // Generate a random matrix between 0 and 100 as integers
  matrix = new matrix of size n x m
  for each row i in the matrix:
    for each column j in the matrix:
      matrix[i][j] = round(random_number() * 100)
  return matrix

// Size of the matrices
n_ = 3 // Number of producers
m = 3 // Cycles
// Generate all matrices from the model
P = generate_random_matrix(n_, m)
C = generate_random_matrix(n_, m)
COST_p = generate_random_matrix(n_, m)
```

```
T_INITIAL_p = generate_random_matrix(n_, m)
T_FINAL_p = generate_random_matrix(n_, m)
COST_c = generate_random_matrix(n_, m)
T_INITIAL_c = generate_random_matrix(n_, m)
T_FINAL_c = generate_random_matrix(n_, m)
INT_p = generate_random_matrix(n_, m)
INT_c = generate_random_matrix(n_, m)
// Show all generated matrices
print 'Matrix P:'
print P
print 'Matrix C:'
print C
print 'Matrix COST_p:'
print COST_p
print 'Matrix T_INITIAL_p:'
print T_INITIAL_p
print 'Matrix T_FINAL_p:'
print T_FINAL_p
print 'Matrix COST_c:'
print COST_c
print 'Matrix T_INITIAL_c:'
print T_INITIAL_c
print 'Matrix T_FINAL_c:'
print T_FINAL_c
print 'Matrix INT_p:'
print INT_p
print 'Matrix INT_c:'
print INT_c
// Create bar chart for matrix P
create_chart(P, 'Matrix P')
// Create bar chart for matrix C
create_chart(C, 'Matrix C')
```

The approach used to develop the methods in the code is a procedural approach. The code defines a function to generate random matrices and then calls this function to generate the matrices needed for the model. It also includes visualization steps to create bar graphs for the P and C matrices. Alternative methodological approaches that exist could include object-oriented programming paradigms where classes and objects are used to encapsulate data and methods related to the matrices. In addition, functional programming approaches could be used, where functions are treated as first-class priorities and operations are performed by function composition and higher-order functions. These approaches could provide different perspectives on how to structure and manipulate data and operations within the program.

3. Results and Discussion

In the context of this study, a computational approach using the Scilab programming language is used for data generation and analysis. The following code in Scilab is used to enter the results obtained under the appropriate heading. The `generate_random_matrix' function is used to generate random matrices of predefined dimensions representing different parameters of the model. The generated matrices are then displayed with relevant information such as associated costs, start and end times, and other relevant variables. In addition, bar charts are presented to better visualize the data contained in the P and C matrices in relation to the categories and the corresponding energy. This computational approach provides a solid basis for detailed analysis of the results and their interpretation. Presentation and interpretation of results, presentation of limitations and generality of results.

3.1. Errors encountered

The difficulties and errors encountered with the AI-generated codes were as follows:

1. Random matrix generation error: An error indicated that a scalar was expected as an input argument to the `rand' function, but a matrix was provided instead. This was due to improper use of the `rand' function. The workaround was to correct the `rand` function call to properly generate random matrices.
2. Visualization of matrices in the console: Initially, the generated matrices were not displayed in the console, making it difficult to verify the results. The solution was to add the `disp` function to display the generated matrices in the console.

These solutions successfully addressed the identified problems and improved the readability and usefulness of the generated code.

3.2. Improvements

The code provided had several bugs and areas for improvement. Below is a detailed comparison between the original code and the suggested improvements:

The bugs and improvements in the provided code:

3. Matrix definition: The matrices `P' and `C' were not defined correctly and their dimensions did not match the provided model.
4. Random matrix generation: Matrices `P' and `C' were incorrectly generated using `rand(n, m) * 100', resulting in an error due to incorrect argument size. This has been fixed by removing the multiplication by 100.
5. Matrix visualization: Generated matrices were not displayed in the console for verification, making code debugging difficult. The `disp` function has been added to display them.

The bugs and improvements in the proposed code:

1. Matrix definition: The dimensions of the matrices ` COST_p', ` INT_p', ` T_INITIAL_p' and ` T_FINAL_p' were set correctly according to the provided model.

2. Random matrix generation: Random matrices were correctly generated with the `rand(np, ncycle)` function.
3. Construction of matrices according to the model: The matrices ` COST_p', ` INT_p', ` T_INITIAL_p' and ` T_FINAL_p' were constructed correctly according to the given model in the `for' loop.
4. Matrix visualization: The `disp' function was used to display the generated matrices in the console.
5. Data plotting: A section has been added to plot the data of each matrix column by column for better visualization.

3.3. Example to verify and validate my methodology

The following is a simple example of different energy producing sources and their consumers, based on the data provided and the answer obtained in the Scilab software. The number is randomly generated. In the next research step, the method for determining the numbers will be created.

Matrix P:

$$P = \begin{bmatrix} 65 & 75 & 85 \\ 99 & 41 & 6 \\ 5 & 61 & 83 \end{bmatrix} \quad (19)$$

Matrix C:

$$C = \begin{bmatrix} 93 & 82 & 12 \\ 57 & 6 & 73 \\ 57 & 56 & 27 \end{bmatrix} \quad (20)$$

Matrix COST_p:

$$COST_p = \begin{bmatrix} 55 & 0 & 26 \\ 99 & 59 & 63 \\ 74 & 31 & 12 \end{bmatrix} \quad (21)$$

Matrix T_INITIAL_p:

$$T\_INITIAL\_p = \begin{bmatrix} 61 & 3 & 24 \\ 68 & 52 & 51 \\ 33 & 39 & 42 \end{bmatrix} \quad (22)$$

Matrix T_FINAL_p:

$$T\_FINAL\_p = \begin{bmatrix} 29 & 35 & 29 \\ 9 & 71 & 65 \\ 62 & 52 & 9 \end{bmatrix} \quad (23)$$

Matrix INT_p:

$$INT\_p = \begin{bmatrix} 45 & 24 & 51 \\ 72 & 43 & 52 \\ 90 & 97 & 56 \end{bmatrix} \quad (24)$$

Matrix T_INITIAL_c:

$$T\_INITIAL\_c = \begin{bmatrix} 56 & 79 & 43 \\ 47 & 98 & 25 \\ 78 & 82 & 92 \end{bmatrix} \quad (25)$$

Matrix T_FINAL_c:

$$T\_FINAL\_c = \begin{bmatrix} 10 & 4 & 61 \\ 47 & 52 & 19 \\ 40 & 83 & 2 \end{bmatrix} \quad (26)$$

Matrix COST_c:

$$COST\_c = \begin{bmatrix} 84 & 1 & 75 \\ 7 & 19 & 94 \\ 85 & 49 & 21 \end{bmatrix} \quad (27)$$

Matrix INT_c:

$$INT\_c = \begin{bmatrix} 58 & 91 & 26 \\ 26 & 81 & 41 \\ 44 & 81 & 36 \end{bmatrix} \quad (28)$$

These matrices likely represent a system where energy is produced and consumed by different entities, and the values within these matrices are used to model and analyze different aspects of this energy system, such as costs, time, and intensities. The matrices provide a rich dataset for further analysis using the Scilab software.

4. Limitations and Conclusion

Conclusions:

The presented model provides a comprehensive representation of energy producing sources and their consumers, accompanied by various associated parameters, including costs, production, consumption times, and interruptions. By using the matrices provided, one can gain deeper insights into the dynamics of energy production and consumption within a given system. In addition:

- The suggested AI code improves the clarity and accuracy of the provided model implementation.
- Bugs in the original code have been fixed and improvements have been made to allow better visualization of the generated data.
- A dedicated section for plotting the data of each matrix has been included, which improves the understanding of the results.

Limitations:

Despite its utility, the model has certain limitations that require attention to strengthen its applicability. Notable limitations include:

- The simplicity of the model may overlook nuances inherent in real-world energy systems.
- External factors such as demand fluctuations or environmental changes are not considered.
- Variability in the accuracy of the data provided could affect the validity of the model.

Possible Future Research:

To refine the model and optimize its practical utility, future research could explore the following avenues:

- Integration of additional variables and parameters to more accurately reflect the complexity of energy systems.

- Validate the model against authentic data sets, coupled with comparative analyses against alternative methodologies to assess effectiveness and accuracy.
- Explore the applicability of the model in different contexts and sectors, ranging from energy management in buildings and industrial facilities to power distribution networks.

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Resilient production control by linking preventive maintenance strategies

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Abstract

The manufacturing industry, particularly in the area of customized single and small series production of complex products, is facing considerable challenges in the course of Industry 4.0. These include unplanned events and production interruptions, increasing customer individuality, and a high number of variants. The difficulties in managing short-term production and maintenance decisions in complex and dynamic environments are critical. Traditional, non-coordinated maintenance measures based on manual tools are quickly reaching their limits here. This often leads to reduced availability of production resources and a waste of resources due to unused time slots. The following concept aims to integrate preventive maintenance strategies into the production control of single and small series production. A major result of this integration is the provision of decision recommendations for planners within the operational planning horizon using a Job Shop Scheduling model. Decision support should make it possible to react effectively to unplanned events and thus make efficient use of unused time slots. The aim is to create resilient processes and generate a solid planning result.

1. Introduction

The manufacturing industry, particularly in the area of single and small batch production of complex products, is confronted with significant challenges in the context of Industry 4.0 [1], [2], [3], [4]. These include unplanned events and production interruptions, increasing customer individuality, and a high number of variants [5], [6], [7]. Short-term maintenance and production decisions, which are often inadequate and inefficient in complex and dynamic environments, are particularly difficult [4], [8]. Examples of unplanned events include new incoming orders, order cancellations, random machine breakdowns, changes to due dates, and material shortages [5], [9].

Uncoordinated maintenance measures that are not synchronized with production planning and control (PPC) and are based on manual tools quickly reach their limits [10], [11]. Unplanned events in the operational planning horizon (typically covering days to weeks) often result in wasted resources due to unused time slots in the production schedule on the one hand, and lower availability or the same utilization of production resources on the other hand [4], [5].

In current practice, maintenance is often viewed as a separation from production control, particularly in the operational planning horizon [1]. This separation often leads to inefficient decisions that are mainly based on traditional and manual methods [5], [7]. Existing algorithms and models developed for stable production conditions, e.g. in mass production, are often inadequate for the dynamic requirements of single and small batch production [7], [12]. Traditional reactive and rigid maintenance, e.g. based on fixed time intervals without the possibility of dynamic adjustments, increases these problems and leads to further interruptions, longer throughput times, and thus to rising costs [4], [5], [7].

The positive effects of maintenance planning can be seen on the one hand in the reduction of costs, and on the other hand, with optimal use, the speed of product delivery to the customer, product quality, and reliability can also be improved. An optimal maintenance strategy can therefore have a significant impact in many respects [3], [6], [13]. Predictive maintenance is a branch of preventive maintenance that can forecast failures by analyzing condition data [14], [15]. In customized single and small series production of complex products, this approach is not always suitable [16]. The production conditions here are so specific and variable that a standardized prediction of maintenance requirements is often not possible. The focus is therefore on preventive maintenance strategies, which are more useful for the conditions of single and small batch production [3], [17]. The closer linking of preventive maintenance strategies with production control should lead to more resilient processes as well as increasing planning reliability in the event of unplanned events. The aim is to sustainably increase the responsiveness and efficiency of production through these adjustments [3], [4], [16].

The application of dynamic maintenance measures offers considerable potential for reducing machine failures and maintenance costs [5], [12], [13]. Existing planning models often do not take sufficient account of the effects of maintenance measures and the resources required for them on production capacity and the specific requirements of single and small-batch production in complex production environments [5], [7], [18].

Therefore, there is a need for a concept that enables the areas to be linked and supports dynamic planning [9] in this environment to overcome the abovementioned challenges and increase efficiency. Such a concept would close the gap between maintenance planning and production control and promote a flexible approach.

The concept is relevant for production and maintenance planners in the area under consideration, as they can react more quickly to unplanned events within the operational planning horizon. By advancing maintenance measures into unused time slots caused by unplanned events, preventive maintenance strategies can be implemented and these time slots can be used effectively, either through targeted maintenance measures or by rescheduling production orders. This helps to reduce the waste of resources, especially personnel. Other restrictions, such as delivery times and machines, are not only considered, but positively influenced, especially critical machines with higher failure rates. The model is intended to assist/support the planner with decision recommendations in the operational planning horizon in order to optimize their planning processes. This can increase the flexibility and efficiency of production in the long term. The planner is also relieved because they no longer have to search for solutions manually.

1.1. Research gap

The introduction explains the challenges of current maintenance and production planning and highlights the need to integrate preventive maintenance strategies into production control, especially in the focus area. The dissertation aims to improve the area under review by developing a concept. In order to illustrate the area under review, it is visualized as a morphological box (see Figure 1). This visualization serves as a structured tool to present the relevant parameters and their possible characteristics comprehensively and concisely. The research gaps identified are briefly presented below, always against the background of the specific area under review.

The selection of characteristics and their characteristics in the morphological box was made according to the area under review of the concept in order to briefly capture the essential aspects of the production system. The characteristics cover the areas of production, including product type, production structure, production orders, quantity, variety of variants, production process, production stages, type of manufacturing, form of manufacturing, flexibility, productivity, planning horizon, machine load, machine type, machine inventory, and operator qualification. This selection makes it easier to view the production environment and creates a basis for the development and optimization of production processes. Each of the criteria was selected based on its relevance. For example, the product type influences the requirements for flexibility and productivity, while the production structure is decisive for the complexity of the production processes. The selection of specific characteristics such as "make-to-order" for production orders and "low" for quantity reflects the focus on customer-specific, low-volume production, which places specific demands on flexibility and planning. The terms in the morphology box are based on the sources [14], [19], [20], [21] and [22].

1.1.1. Research gap (Linking production control and preventive maintenance in the area under review)

In production environments, as shown in Figure 1, there is a challenge for specially developed maintenance strategies that can be effectively integrated into operational production control. This is confirmed by the literature research for the area under review and has not yet been systematically investigated [23], [24]. The production environment is characterized by a high degree of complexity and variability, and each order can have individual requirements in terms of materials, processes, and personnel skills.

Existing manufacturing approaches often do not have the flexibility and adaptability to respond to unplanned events. Maintenance strategies based on regular maintenance intervals are not sufficient for dynamic production requirements [5]. There is

	Characteristic	Characteristic value					
Product	Product	Piece goods		Liquid bulk		Bulk goods	
Product	Product type	Customized product		Prototype		Standard product	
Product	Product structure	Multicomponent with complex structure		Multicomponent with simple structure		Minor components structure	
Product	Types of production orders	Make-to-Order		Assemble-to-Order	Make-to-Stock	Engineer-to-Order	
Product	Quantity	Low		Medium		High	
Product	Variety of variants	Low		Medium		High	
Production process	Production process	Continuous			Discontinuous		
Production process	Production stages	Single-stage		Two-stage		Multi-stage	
Production process	Type of manufacturing	Nonrepetitve production		Single and small batch production		Series production	Mass production
Production process	Form of manufacturing	Matrix production	Job shop production	Flow line production		Batch production	Cellular production
Production process	Flexibility	Low		Medium		High	
Production process	Productivity	Low		Medium		High	
Production process	Planning horizon	Operational		Tactical		Strategic	
Production resources	Machine load	Continuous		Low	High	Variable	
Production resources	Type of machinery	Specialized or custom machines		Simple machines		Highly complex universal machines	
Production resources	Machine inventory	Homogeneous			Heterogeneous		
Production resources	Operator qualification	Inexperienced or untrained operators		Semi-skilled operators		Skilled operators	

Figure 1: Area under review, own representation of the morphology [14], [19], [20], [21], [22].

therefore a need to adapt preventive maintenance strategies and develop a concept so that they can be proactively embedded in production control and integrated into a decision support system. This should promote more resilient processes and enable a solid planning result for the operational planning horizon [6].

1.1.2. Research gap (Resilient and priority-based maintenance)

Another issue is the risk assessment, prioritization, and effective integration of maintenance measures into production control, especially in the case of unplanned events, which often create unused time slots in the production schedule. There is a need for a systematic approach with recommendations to decide which maintenance work can be brought forward for specific machines, how these measures can be efficiently integrated into the time slots that arise, and how the decision should be made based on urgency, available resources, and the time required.

1.1.3. Research gap (Predictive Maintenance)

The area under review, which is characterized by constantly changing production parameters and a heterogeneous machine park, proves to be critical for predictive maintenance. These strategies, often developed and tested under idealized laboratory conditions, reach their limits in dynamic production contexts. Their effectiveness and direct transferability to real production conditions can therefore only be implemented to a limited extent. For this reason, it is necessary to adapt existing preventive maintenance approaches to the complexity and dynamics of the production environment to meet these requirements [14].

1.2. Research theses

The central research theses of this dissertation result from the identified research gaps. They aim to identify the solutions that address the above research gaps. The theses address the subsequent implementation of the methods to close the research gaps.

1. The concept developed enables decision support for planners by linking both areas. Potential for improvement in single and small series production of complex products is exploited, especially in the case of unplanned events in the operational planning horizon.
2. Adapting methods from stable production types such as mass production requires applicable strategies for single and small batch production of complex products due to the process differences. While these stable production types are based on standardized production processes with constant workflows, low variability of product specifications, and predictable demand, single and small batch production requires flexibility and adaptability. Productivity in this area can be increased through the targeted selection of methods to meet production requirements.

3. Predictive maintenance does offer the possibility of reducing costs and minimizing downtimes. However, in production environments with variable parameters and the manufacture of complex, customer-specific products, it reaches its limits due to the high implementation costs and strong data dependency, which is why it is not recommended for these use cases.
4. The risk assessment and prioritization of important maintenance measures and their targeted integration into production control can reduce the downtime of systems by combining various preventive maintenance strategies using different selection criteria. These measures increase production efficiency, especially in the event of unplanned events in the operational time horizon.
5. Implementing the concept of decision support networking maintenance and production control has the potential to increase the resilience and reliability of complex production systems by creating an improved and solid planning basis with a uniform database. This allows unplanned events to be dealt with more quickly and unused time slots to be used more effectively while minimizing process time.

1.3. Novelty and state of research

In this section, the current state of research is presented based on the systematic literature review method (see section 2.1). The results of the literature review and the presentation of the novelty also make it clear where the present work differs from the literature and where there is a need for additions.

Research Approaches and SLR

The topic of general production planning and control (PPC) and maintenance has received a lot of attention in research in recent decades [1]. The challenge of linking production and maintenance in particular has been the focus of numerous studies. Various algorithms, heuristics, and models have been developed to analyze and optimize the dependencies between PPC and maintenance [2], [25].

Against the background of increasing demands on the availability of technical systems, systematic approaches to robustness assessment have been developed in the field of maintenance [26], [27]. These methods provide a basis for the selection of maintenance strategies and the specific use of maintenance resources, depending on factors such as system structure, type of use, and changes in condition. In most scientific papers, however, only one maintenance strategy, such as predictive maintenance, is addressed [27].

The scientific papers only focus on one maintenance strategy. In the literature, maintenance is divided into two categories (see Figure 2), each of which is further divided:

- reactive maintenance
- preventive maintenance

Preventive maintenance includes measures such as preventive and regular maintenance and planned repairs. Reactive maintenance, on the other hand, deals with unexpected breakdowns and emergencies [15]. In planned maintenance, maintenance activities are often seen as time constraints that must be considered in any production plan to ensure trouble-free production [16].

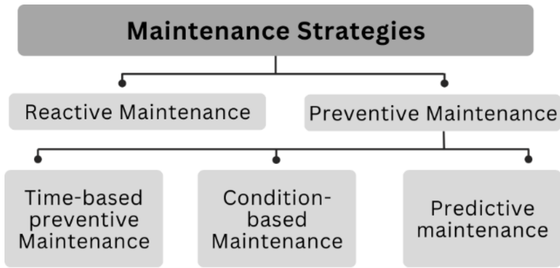

Figure 2: Maintenance Strategies [14], [15].

The high potential of data-driven maintenance, known as predictive maintenance, is often discussed, particularly in the context of Industry 4.0. Predictive maintenance, a sub-area of preventive maintenance, draws on historical data and, where necessary, maintenance-relevant data collected in real time. Comprehensive data collection is required for a significant evaluation and analysis of this data, often using artificial intelligence (AI), for example. These data volumes must be collected by the machines continuously and over longer periods. [14], [15], [16].

The systematic literature search shows that many studies have examined the interface between production planning and maintenance. Studies such as [28] and [29] provide an overview of the targets of production planning, such as lead times and production costs. In order to increase system availability, avoid system failures, and reduce maintenance costs, [30] and [31] provide an overview of various maintenance strategies. While [32] proposes a method to determine optimal production, replacement/repair, and preventive maintenance strategies, [33] argues that preventive maintenance can reduce failure frequency and develop corresponding production and maintenance strategies based on inventory levels. In contrast, the papers [34] and [35] deal with the impact of production schedules on equipment wear, especially in systems with one machine producing one type of product and serving a random demand over a limited period.

The conclusion from the literature review makes it clear that production planning models tend to assume constant availability and maximum performance of the systems, while the effects of maintenance activities on production capacity are often ignored in maintenance models and there is no explicit consideration of production requirements [10], [18]. These differences mean that unplanned maintenance, triggered by unplanned faults, can have a significant impact on production. The integration of a combination of maintenance strategies into production is therefore essential to ensure the operational readiness of the machines and to stabilize the production processes. The integration of production and maintenance processes corresponds to the real requirements of production environments and is an essential element to maximize process resilience. The development and implementation of resilient processes that take into account both production and maintenance schedules are therefore crucial [10].

In a follow-up SLR, it was found that many models already exist in the literature. These models deal with the integration of maintenance measures into production planning and are closely linked to solution approaches from the field of mathematical optimization. A brief excerpt from the SLR is presented below.

Considering machine downtime and regular maintenance, [17] and [36] consider production scheduling, with the former focusing on job stop and the latter on single machine scheduling problems. In [37], these considerations are extended to flexible job stop with integrated maintenance and transportation planning, although further research is seen to be needed for resource constraints and search strategies. The simultaneous optimization of production and maintenance planning is investigated in [38] and [13], where the former uses genetic algorithms and the latter a heuristic solution without considering dynamic events. In [39], a dynamic control algorithm for optimizing production planning is presented, which, however, can lead to increased maintenance costs. A dynamic planning strategy for machine failures is proposed by [40] but may be limited by the complexity of the algorithm configuration.

Some of the publications focus on minimizing lead times, which leads to an increase in capacity and flexibility requirements [7], while others focus on preventive maintenance strategies in (partially) automated production systems.

Research into single and small batch production, which requires a high degree of flexibility and adaptability, nevertheless remains limited. This type of production, characterized by its specific requirements and the possibility of operational optimization, is particularly underrepresented in the literature [19], [20].

1.4. Novelty of the work

The novelty of this work lies in the development of a concept that increases the resilience of complex production systems by integrating preventive maintenance strategies into production control. In contrast to existing studies, which often assume a static production environment and constant machine availability [6], the work has a particular focus on unplanned events and production downtimes and their short-term use. By making decision recommendations for planners such as maintenance and production planners, especially about unpredictable events, this work differs from previous approaches that do not fully incorporate the dynamic aspects of production and maintenance. A usable algorithm aims to increase efficiency in an operational planning horizon and thus provides, in the best case, real-time support for planners [5]. This work thus contributes to a new planning approach that places a special focus on maintenance and emphasizes the practical relevance and applicability in dynamic production environments.

2. Methods

The next section presents the methods used in the paper. The methods are used to close the research gaps and to verify the research theses.

2.1. Systematic Literature Review

The systematic literature review was used to evaluate existing publications. This method was chosen because it enables an analysis of existing research and thus leads to research gaps being identified and closed [41]. As a result, an understanding of current research in the field of production planning and control with a particular focus on maintenance in the area under review should be gained. The searches are based on a combined search chain consisting of key terms and their synonyms, including:

- "Production planning and control"
- "Individual and small batch production"
- "Maintenance Strategies"
- "Smart Maintenance"
- "Job Shop"
- "Production Scheduling Optimization"
- "Manufacturing Scheduling"
- "Optimization"
- "Operations Research"

The terms presented here are only generic terms; synonyms have not been listed. The literature from the years 2013 to 2023 was taken into account. The snowball technique was also used when conducting the SLR. This resulted in the discovery of additional older, relevant literature sources published before 2013. The SLR was carried out in scientific databases such as Dimensions.ai and Scopus Elsevier. A total of 45 sources were identified, from which a selection was made for further analysis. Relevance to the research topic and methodology were used to select the studies.

The SLR shows that many studies have been conducted on the link between production planning and maintenance. However, most studies do not focus on the integration of preventive maintenance strategies into production control in the operational planning horizon. In addition, they only marginally consider the effects of a volatile production environment, as in the area under review, and the reaction to unplanned events and production downtime [41].

The results of the SLR were discussed in a brief summary in section 0.

2.2. Selection, evaluation, and combination of maintenance strategies

The method presented is an essential part of the concept for linking preventive maintenance with single and small series production of complex products. The core of the method is the selection and combination of preventive maintenance strategies that are to be integrated into production control. These maintenance strategies are listed in Figure 2. A significant aspect is the investigation of the downtimes of critical machines to bring forward maintenance measures in unused time slots caused by unplanned events. The method focuses on the downtimes of critical machines that are in the transition from the Useful-Life phase to the Wear-Out-Failure phase. This can be recognized by the failure rate of a machine. The basic course of the failure rate of a machine over its service life is often described with a so-called "bathtub curve" [14]. In this work, the Wear-Out-Failure phase of the bathtub curve is considered, which means that these machines have a higher risk of failure. Different stresses, such as increased strain or improper operation by untrained personnel, as well as operating outside the specified parameters, can shorten the Useful-Life phase (low and constant failure rate) of a machine (see Phase 2 in Figure 3) [6], [44].
In addition, maintenance measures are selected and prioritized, which can be brought forward in unused time slots if necessary. Decision-making is to be supported by a Job Shop Scheduling model, creating a solid production and maintenance plan for the operational planning horizon. This method promises an improvement in maintenance processes and integration into production processes, which leads to an increase in resilience.

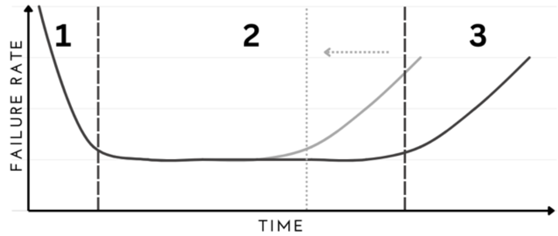

Figure 3: Bathtub Curve, Phase 1: Early-Failure Phase, Phase 2: Useful-Life Phase - Random Failures, Phase 3 - Wear-Out-Failure Phase. Own representation based on [2].

2.3. Job Shop Scheduling

The application and integration of a mathematical optimization algorithm, in this case, the Mixed Integer Programming (MIP) model, is central to the linking of production control and maintenance planning in this work [42], [43]. By using MIP, both integer and continuous variables can be included in order to efficiently manage the complex requirements of the Job Shop Scheduling and to find an optimal solution [42], [45]. Job store scheduling is a method of scheduling many jobs (tasks) on a limited number of machines in such a way that throughput time is minimized and efficiency is maximized [46].

This systematic framework enables improved production control and increases the resilience of maintenance processes by efficiently allocating production orders and maintenance measures in the event of unused time slots caused by unplanned events. Time dependencies and resource availability are taken into account in the operational planning horizon. This means that the model can flexibly react to unplanned events by planning maintenance activities in these time slots without disrupting the production flow [47].

In a typical MIP model, decisions are represented by integer variables, while continuous variables can represent aspects such as time, costs, or quantities [20]. Integer variables can be, for example, the number of machines or the assignment of jobs to machines, while continuous variables represent times or the duration of operations [46]. The challenge is to find an optimal combination of these variables [48]. This combination should maximize or minimize a given objective function while at the same time satisfying a set of linear constraints [46].

The objective function in this work is to minimize the total production time over a given time period, while constraints ensure that no machine runs multiple orders simultaneously and that the delivery dates of the orders are met [47]. Especially in the problem of production control, a MIP model is suitable for problems with different variables and constraints to find feasible solutions in a reasonable time [42].

In summary, mixed-integer programming provides a framework for modeling and solving decision problems involving both discrete and continuous variables. The MIP model plays a further relevant role in the development of the concept with regard to rapid response in the case of short-term decisions [45].

2.4. Expert knowledge of industry comparison

Another method focused on is a comparison with industry partners through semi-structured expert interviews in order to gain practical knowledge about the integration of maintenance into production control. Expert interviews are conducted by selecting experts from relevant industry sectors to record experiences, challenges, and best practices [49]. The evaluation of these interviews makes it possible to compare the concepts with real conditions and gain practical insights for the work. For the systematic evaluation of the information gained from the expert interviews, the qualitative content analysis method according to Mayring is to be used [50].

2.5. Research design approach to method development

When selecting and developing the methods for answering the research gaps and the present research theses (see section 1.1 and section 1.2), the context is discussed below. The methods are processed in a partially specific order (see Figure 4). The methods (sections 2.1 - 2.3) have already been started in the thesis. The following section provides a brief overview of the methodological approach in relation to the individual research theses and shows which methods could be adopted directly and for which a new approach is being pursued. For theses 1 and 5, the systematic literature review led to the identification of the current state of research, which serves as the basis for the development of a decision support concept for linking maintenance and production control.

This analysis makes it possible to gain deep insights into existing research work and proven methods, which can not only be adopted but also used as abasis for further research.

Particularly useful in this context is the own development of the selection of maintenance strategies, which will be specifically linked to Job Shop Scheduling in order to react quickly to unplanned events and thus create a resilient process. These methods and their integration into the concept play a central role in providing decision support for planners in dynamic production environments such as the area under review.

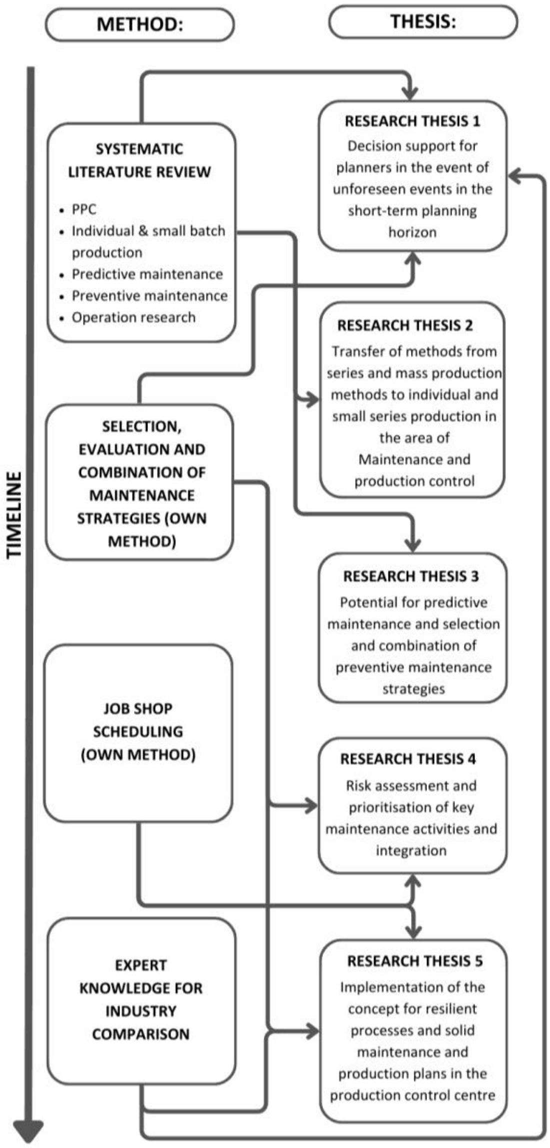

Figure 4: Research Design

Theses 2 and 3 focus on adapting mass production methods to single and small series production of complex products, as well as researching the limits of predictive maintenance in dynamic and complex production environments. The systematic literature review deepens this knowledge and provides information on methods and strategies. In addition, interviews with experts from the industry will provide direct insight into practical challenges and current solution approaches in order to enable a comparison.

To answer research thesis 4, a systematic approach for selecting preventive maintenance strategies is developed. This establishes the link between Job Shop Scheduling and the application and thus increases the responsiveness of production control. The combination of these maintenance strategies represents a separate development in order to create a solution specifically for the problem in the area under review. As part of answering the 4th research thesis, a strategy for selecting preventive maintenance strategies will be developed and implemented by integrating it with job stop scheduling. This link is intended to increase resilience and the ability to react to unplanned events. The combination of these maintenance strategies as a separate development method is central to creating specially tailored solutions for the area under review.

3. Results and Discussion

3.1. Results

The SLR was briefly introduced in chapter 0. It highlighted the gaps in the field of research. These consist of the consideration of individual maintenance strategies, the neglect of a dynamic and complex production environment, and the insufficient consideration of the specific requirements of single and small series production [16]. Another result of this work is the development of the mixed-integer programming model to solve the complex Job Stop scheduling problem regarding the integration of maintenance tasks (see Figure 5). This approach makes it possible to efficiently distribute many jobs, consisting of several subtasks (maintenance and work orders) with specific sequences, to different machines [47].

The model is characterized by the fact that it takes into account not only integer decisions, such as the allocation of orders to machines but also continuous variables, such as the time and duration of the orders. The resources can also be considered. The objective function is to minimize the lead times of all orders to ensure an optimal production sequence. By including the earliest possible start times, processing durations, and the latest due dates for each job part, the model enables exact planning. It also considers the possibility of multiple machines performing the same tasks and integrates maintenance activities directly into the manufacturing process. The challenge of creating an efficient production plan that both minimizes the overall duration and reduces waiting times between jobs is solved by optimizing the decision variables within the MIP framework [47].

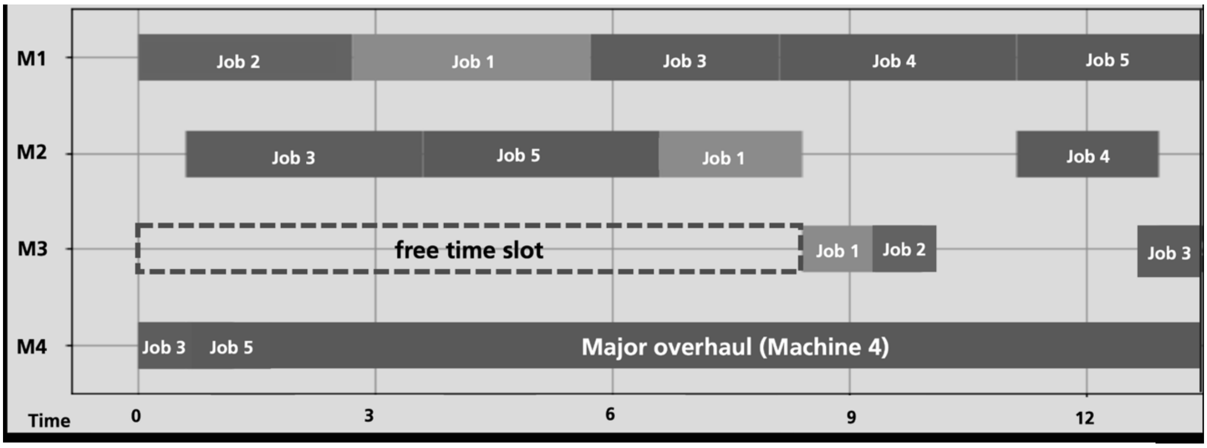

Figure 5: Output Job Shop Scheduling - Machine allocation plan (maintenance and work orders)

3.2. Limitation and possibilities

Job Shop Scheduling problems belong to the NP-hard problems [42], [46]. This means that the time required to find the optimal solution increases exponentially with the number of jobs and machines. This complexity results from the need to consider a large number of possible job-machine assignments and their order [48]. The model is therefore more suitable for an operational planning horizon [46]. Another aspect where the model reaches its limits is the quality, accuracy, and completeness of the underlying production data. Due to information islands or inadequate recording systems, it can be difficult to obtain this detailed data in practice. Integration into existing systems also presents a challenge.

The implementation of the MIP model or the entire concept requires seamless integration into the existing IT infrastructure of manufacturing companies. Challenges in the technical and organizational sense, such as incompatible IT systems and employees' reservations about new processes, can make it difficult to use. In addition, the risk of user acceptance is a critical factor that should not be underestimated. Accepting and using new technologies often depends on the ability of end users to accept change.

3.3. Verification and validation

To ensure the effectiveness and reliability of the proposed methodological approach for the selection, evaluation, and combination of preventive maintenance strategies, verification, and validation is beneficial. A theoretical review can be carried out by critically comparing the SLR results with established theories and models from the literature. For the MIP model and the selection of preventive maintenance strategies, this review is particularly relevant. The plausibility can be verified by comparing it with existing models. The next step in validating the methodology is to obtain feedback from experts.

A comparison from the areas of maintenance and production is important in order to gain insights into the practicability and possible potential of the approach. This feedback not only provides an external perspective but can also help to increase the relevance and effectiveness of the approach in real-life application scenarios. In addition, the peer review process at scientific conferences plays a role in the validation of research results. Publication at scientific conferences makes it possible to subject the approach to a critical review by the scientific community. Two scientific papers have currently been submitted to conferences for the present work:

- Concept for a Robust and Reliable Manufacturing and Logistics System that Combines Production Planning and Control with Predictive Maintenance – published [16]
- Job Shop Scheduling in the operational planning horizon for the integration of maintenance measures into production planning and control – unpublished [47]

4. Conclusion

The scientific paper follows a concept of integrating production and maintenance planning into the production control of single and small series production. A key result is the provision of decision recommendations for production planners and maintenance staff in the operational planning horizon. This enables them to react quickly to unplanned events and make effective use of unused time slots.

Other important targeted results are:

- methods for selecting and combining preventive maintenance strategies,
- development of the Job Shop Scheduling algorithm and
- combination in a concept with possible visualization through mock-ups.

Next Steps

In the next publication "Job Shop Scheduling in the operational planning horizon for the Integration of maintenance measures into production planning and control", which is still in the submission phase, the mathematical model for Job Shop Scheduling was presented, which shows a step toward a closer link between maintenance and production processes. [47]

The next step is to plan the implementation and visualization of the model, using fictitious data to test the model. When real data is available, it will be exchanged with the fictitious data and tested in order to ultimately increase the practical relevance of the research. Another planned step is the development of the concept for selecting and combining preventive maintenance strategies, as described in section 2.2, with the aim of integrating maintenance measures into production control in such a way that the resilience of the overall process is increased while at the same time minimizing susceptibility to unexpected disruptions.

Finally, it is planned to evaluate the model and the concepts developed in consultation with industry. This discussion with experts from the field will serve to improve the model and validate its practical suitability. The comparison should not only provide valuable insights into the practical feasibility but also improve the adaptability of the model to various use cases, for further work and to identify points of contact. One approach for further work is the integration of artificial intelligence (AI), metaheuristics, or heuristics into the developed concept. These extensions offer the potential to improve the speed and accuracy of production and maintenance planning with more data and over a longer planning horizon. The decision to use Job Shop Scheduling as the focus of this scientific paper was made due to its established foundations and proven methods, which offer a solid basis for developing and evaluating innovative approaches before integrating complex solutions such as AI.

5. References

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Processing strategy for catalytic residues containing vanadium

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Abstract

Vanadium is a strategic element which is on the list of raw materials in a critical state, mainly due to the depletion of the mineral deposits that contain it, so it is important to recover it from industrial wastes that contain it. Among these wastes are the spent catalysts from the manufacture of sulfuric acid, which contain between 4-9 % of V_2O_5, and are therefore classified as contaminants. The objective of the work is to develop a strategy for processing catalytic residues from sulfuric acid manufacture, to recover the vanadium contained in them, without generating new pollutant residues. The work proposes a hydrometallurgical processing strategy for the waste from the Patricio Lumumba Plant, which consists of leaching with sulfuric acid and subsequent precipitation with sodium carbonate. The result is a recovered product with ~38 % V_2O_5. On the other hand, the process generates a solid residue, consisting of 98 % silica, and a liquid residue consisting mainly of sodium sulfate and water. The proposed process allows the recovery of vanadium in the form of concentrate and the generation of two new residues, without vanadium, which can be used in other applications. The developed process constitutes a viable alternative for the processing of spent catalysts from the manufacture of sulfuric acid, which allows the recovery of a metal considered strategic and contributes to the protection of the environment.

1. Introduction

Vanadium is a metal of strategic and industrial importance due to its applications in many technological fields, which is on the list of raw materials classified as critical. This, together with the low vanadium grade in ore concentrates and the depletion of ore concentrate deposits in the world, makes it necessary to make full use of secondary resources containing vanadium, including spent catalysts [1], [2].
The spent catalysts from the manufacture of sulfuric acid contain more than 3% V_2O_5, resulting in an important source of vanadium (≥ 1.68% V), a strategic metal of which there are no reported deposits in Cuba. There are few deposits with high concentrations of this element, which is obtained industrially from different ores and industrial residues [3].
Spent catalysts are among the preferred secondary raw materials for vanadium extraction, as they contain 4 to 9 wt% V_2O_5 along with other valuable components, in the form of oxides or sulfates, and have an average lifetime of 2 to 5 years (up to 10 years) [4], [5].
Vanadium catalysts are used in the sulfuric acid production process by the contact method, since they contribute to the transformation of SO_2 into SO_3. With the pass of time the catalyst is spent "poisoning" and must go out of service, being considered hazardous waste, so it is obligatory for the companies to store it indefinitely, increasing the costs and the amount of residual stored [6].
According to a 2018 report, Cuba stores more than 900 tons of catalytic waste from the production of

sulfuric acid from plant A in Pinar del Río, located in the westernmost part of the country, and plant B in Holguín, in the eastern region of Cuba [7].
On the other hand, investments have been made in plants B and C in Matanzas to increase the production of sulfuric acid, which leads to an increase in the amount of catalytic waste generated, in addition to those already existing in the country, for which there is no defined processing strategy. Plant B generates about 21 tons of catalytic waste per year and plant C generates about 14 tons every two years.
In the case of Plant C in Matanzas, also located in the western region, the catalytic residues generated are used as an additive mixed with cement for paving surfaces [7], which avoids the environmental problems generated by the catalysts, but misses the possibility of recovering the vanadium contained in them.
In Cuba there is currently no defined processing strategy for catalytic wastes, and they are stored indefinitely in the National Confinement of Hazardous Wastes, in the province of Cienfuegos, an institution created to confine hazardous wastes in the country, which is located in the central and southern region of the country. The confinement of waste solves the environmental problem in the short term, but since the space available is limited, it is not a viable option on a permanent basis.
These aspects validate the need to find alternatives for processing spent catalysts in order to avoid their confinement and environmental contamination, and also to recover the vanadium.
Therefore, the objective of this research is to evaluate at laboratory scale a procedure for the treatment of spent catalysts from sulfuric acid manufacturing to recover vanadium.
In order to realize the objective, it is necessary to use equipment that is feasible to assemble in Cuba, using mainly reagents of national origin. Therefore, the results of the process can be achieved from the establishment of the main operation parameters, such as temperature, concentration, among others, which influence the output variables of the process, such as yield, vanadium concentration, etc.
Then, the research is important because the treatment proposed for the spent catalysts contributes to the preservation of the environment, since it would allow processing the catalytic residues considered pollutants. In addition, it offers the possibility of extracting the vanadium contained in the catalysts, a strategic metal of which there are no deposits in Cuba, and whose import cost is high, due to the price of the metal and the difficulties Cuba has to import products in the international market.

2. Methods or experimental part

2.1. Methods of catalytic waste treatment

In the case of spent catalysts from the manufacture of sulfuric acid, which use vanadium pentoxide as an active component, it is generally established that their final disposal as solid waste can be carried out in two fundamental ways: processing to recover the vanadium or disposal in landfills [3]. The metal can be recovered as a vanadium salt or as ferrovanadium, for which it has been established that the vanadium pentoxide content in the waste must be higher than 3%, establishing the following as the required parameters of the catalytic waste [3]:

- V_2O_5: min. 3% weight
- K_2O: max. 10% weight
- P: max. 0.5% weight
- Sn, Pb, As, Sb, Bi, Cu, Zn, Cd, Hg: max. 0.1% weight

Landfill disposal can be carried out in two ways: by fixation or direct landfill. In the case of fixation, the residue is fixed in an inert matrix, usually concrete or glass, prior to controlled deposit in an authorized landfill, a process designed to avoid leaching of metals. For direct landfill, the catalyst is deposited directly into a suitable licensed landfill, and it is common practice to mix it with lime to neutralize the acidity of the residue [3].
From the options available for the final disposal of catalytic residues, several studies have focused on the extraction of vanadium, due to its high cost and industrial importance.
Among the methods used for the recovery of vanadium from spent catalysts are pyrometallurgical methods, using for this purpose: carbothermia and aluminothermia. In the case of carbothermia, it is not a generally economical route unless a large amount of spent catalyst is processed and the prices of vanadium metal are high [8], a method characterized by its high energy consumption, which is why it would not be feasible to apply in Cuba. As for aluminothermic processing, the vanadium content in the alloy would be relatively low [9]. Another traditionally used method is hydrometallurgical, in which liquid solutions are used for the extraction and recovery of metals from ores and residues, in which leaching plays a fundamental role [10]. In these cases, leaching can be acidic or basic, selecting for the particular case of Cuba leaching with sulfuric acid because it is produced in the country in the same plants where the waste is generated, which facilitates the supply of raw materials for processing.
Therefore, if an adequate chemical processing of the spent catalysts from the manufacture of sulfuric acid is carried out, it is possible to recover the vanadium present in them, without the

generation of new polluting residues. In order to develop this strategy, it is necessary to take into account technical and economic factors that allow the recovery of vanadium.

2.2. Selection of the catalytic residual and processing site

For the development of the research, catalysts from Plant A, which has not worked for more than two decades, were selected. These catalysts are still stored in the plant installations.

On the other hand, for the location of the catalytic waste processing plant, the province of Cienfuegos was considered to be the most appropriate place, due to its location in the central region of the country and the Bay of Cienfuegos to the south of the province, which would facilitate the logistics of control and collection of catalytic waste from the sulfuric acid plants located at the ends of the country.
Figure 1 shows a map of Cuba with the location of the sulfuric acid plants mentioned and the proposed location of the waste processing plant.

Figure 1: Location of the sulfuric acid plants and the proposed residuals processing plant

Figure 1 shows the location of Plant A at the westernmost tip of Cuba, about 455 km from the province of Cienfuegos, via the East-West Highway and the National Highway. On the other hand, the distance from Plant B to Cienfuegos would be about 709 km and from Plant C about 172 km, both along the Central Highway of Cuba.
Another aspect that influences the location of the processing plant is its proximity to the sulfuric acid factory located at Plant C (172 km), a reagent necessary to develop the leaching stage of chemical processing.

2.3. Raw material and reagents

The spent catalyst sample selected for the study came from Plant A, in the province of Pinar del Río. The chemical characterization was carried out by the Center for Environmental Studies of Cienfuegos by means of X-ray fluorescence [11] and the results are shown in Table 1.

The spent catalyst sample was crushed in a disk mill to a particle diameter < 0.25 mm [11].
The following reagents were used to process the catalytic residue:
- technical grade sulfuric acid for leaching.
- sodium carbonate solution to neutralize the excess acid and as a precipitating agent.

Table 1: Elemental chemical composition of the spent catalysts from the Sulfometal Plant

Content (%-wt)		Content (mg/kg)	
Si	30,03	P	809,20
S	7,17	Mn	323,37
Fe	6,35	Ni	269,13
V	1,92	Zn	183,25
Na	1,09	Cr	181,40
Mg	0,78	Cu	139,73
Ca	0,62	As	64,57
Pb	0,16	Sr	62,09
Total	48,12	Total	2032,74

2.4. Processing of spent catalyst

The first stage of the working procedure consisted of mixing the spent catalyst sample with a dilute sulfuric acid solution (leaching agent), in order to separate the soluble (leachable) elements from the rest of the compounds that make up the residual, which remain as insoluble residues [11].
When the leaching stage is finished, the mixture is filtered under vacuum and the liquid phase is separated from the solid residue. The solid residue is washed with water to remove any remaining solution and then dried at 120 °C.
The second processing stage consists of adding a sodium carbonate solution to the liquid phase obtained, until a pH value of pH=7 is reached, then

the precipitated product is filtered and separated by filtration, generating a liquid residual.
The precipitated product is calcined at 450 °C for two hours.

2.5. Product characterization

The determination of the vanadium content in the liquid phase coming from the leaching and in the liquid residual remaining after the precipitation stage was carried out by means of visible ultraviolet spectroscopy, applying a technique available at the Spectroscopy Laboratory of the Agricultural Research Center, belonging to the Faculty of Agricultural Sciences, at the "Marta Abreu" Central University of Las Villas.
The technique consists of the formation of a complex between hydrogen peroxide and vanadium. Vanadium ions in sulfuric acid and hydrogen peroxide react according to equation 1 to form a reddish brown color, where the color intensity depends on the concentration of vanadium [12]. Measurement of solution absorbance at a wavelength of 455 nm can be used for quantitative analysis of vanadium.

$$(VO)_2(SO_4)_3 + 2H_2O_2 \leftrightarrow [V(O_2)]_2(SO_4)_3 + 2H_2O \quad (1)$$

The phasic characterization of the recovered product and the solid residual generated was carried out by X-Ray Diffraction (XRD). The diffractograms were processed using the software X Pert High Score Plus (2011) and Profex version 5.1.1. The databases used for the identification of the phases present were the Crystallographic Open Database 2014 and the ICSD Database FIZ Karlsruhe 2008-2.

3. Results and Discussion

3.1. General methods for obtaining vanadium from residuals by leaching

Vanadium processing depends largely on the nature of the raw material, but all processes have common features, which include the stages of physical beneficiation, roasting, leaching, solution purification and precipitation [13].
In the case of spent catalysts, the surface may be poisoned with organic compounds, unburned substances, carbon residues, sulfur, which often requires preliminary calcination. These catalysts are used in processes such as hydrodesulfurization (HDS), fluidized catalytic cracking (FCC), hydrotreating (HDT) and sulfuric acid production, so their chemical composition is very varied [14].
Therefore, the roasting stage is performed with the aim of removing substances from the catalyst, such as water, light hydrocarbons, and carbon and sulfur by oxidation [15].
In the case of spent catalysts from sulfuric acid manufacture, they consist of an inert support with a highly porous surface, typically natural or synthetic cristobalites, with pores containing a mixture of vanadium pentoxide as the active component, together with alkali metal sulfate promoters, usually potassium sulfate or cesium sulfate. In addition, they may contain small concentrations of other elements, which is a function of the catalyst manufacturer and the characteristics of the sulfuric acid production process [16].
Therefore, the catalytic residues from the manufacture of sulfuric acid do not contain the same pollutants as the rest. In these, the main pollutant is sulfur.
In the case of the catalyst studied, the roasting stage was not included. Table 3.1 shows the chemical composition of the catalyst, where it is possible to observe the presence of sulfur as the main contaminant, and to a lesser extent other elements such as phosphorus, arsenic, strontium and lead. These elements should be found as $Ca_3(PO_4)_2$, As_2S_5, SrO, PbO and sulfur in its elemental form [11].
Therefore, the roasting stage would only eliminate the sulfur, for which a temperature higher than 450 °C would be necessary, making the production process more expensive [17].
Taking into account the possible reactions that must occur during leaching between the components of the catalyst and the sulfuric acid [11], sulfur and As_2S_5 are not dissolved, so they will remain as insoluble residues, forming part of the residue generated. $CaSO_4$, $PbSO_4$ and $SrSO_4$ should form precipitates, which would become part of the insoluble solid residue [11], [18].
Therefore, these elements that are found contaminating the catalytic residue should not interfere with the quality of the main product of the process, i.e., the vanadium concentrate.
On the other hand, the precipitation stage is accompanied by separation and purification, with the aim of obtaining a product of higher purity. In this sense, several authors have carried out studies with solvent extractions, selective precipitation, oxidation, among others [4], operations that require adding certain steps and equipment to the general scheme, which implies a considerable increase in the cost of the process.
The vanadium concentrate to be obtained will be used in the production of welding consumables. Therefore, none of the operations mentioned previously is essential, since the other elements that precipitate with the vanadium (iron, magnesium, chromium fundamentally) would not affect the development of the electrode, since they commonly form part of its composition.

The final product obtained is reduced to obtain metallic vanadium or ferrovanadium, which depends largely on the final application of the product. Sometimes this product is refined to improve its purity, especially if the purpose is to market it directly, an operation that is also not required in view of the intended use of the alloy. The reduction of the metal oxides obtained in the recovered product must be carried out by means of aluminothermia, a process that is capable of developing in a self-sustained manner from the heat generated by the redox reactions, so it does not require additional energy supply, only that necessary to start the process.

3.2. Proposed processing scheme

Based on the studies carried out on this subject and the procedure developed [11], [19], the diagram shown in Figure 2 is proposed. The diagram shows the different stages through which the process passes and the products generated in each one of them.

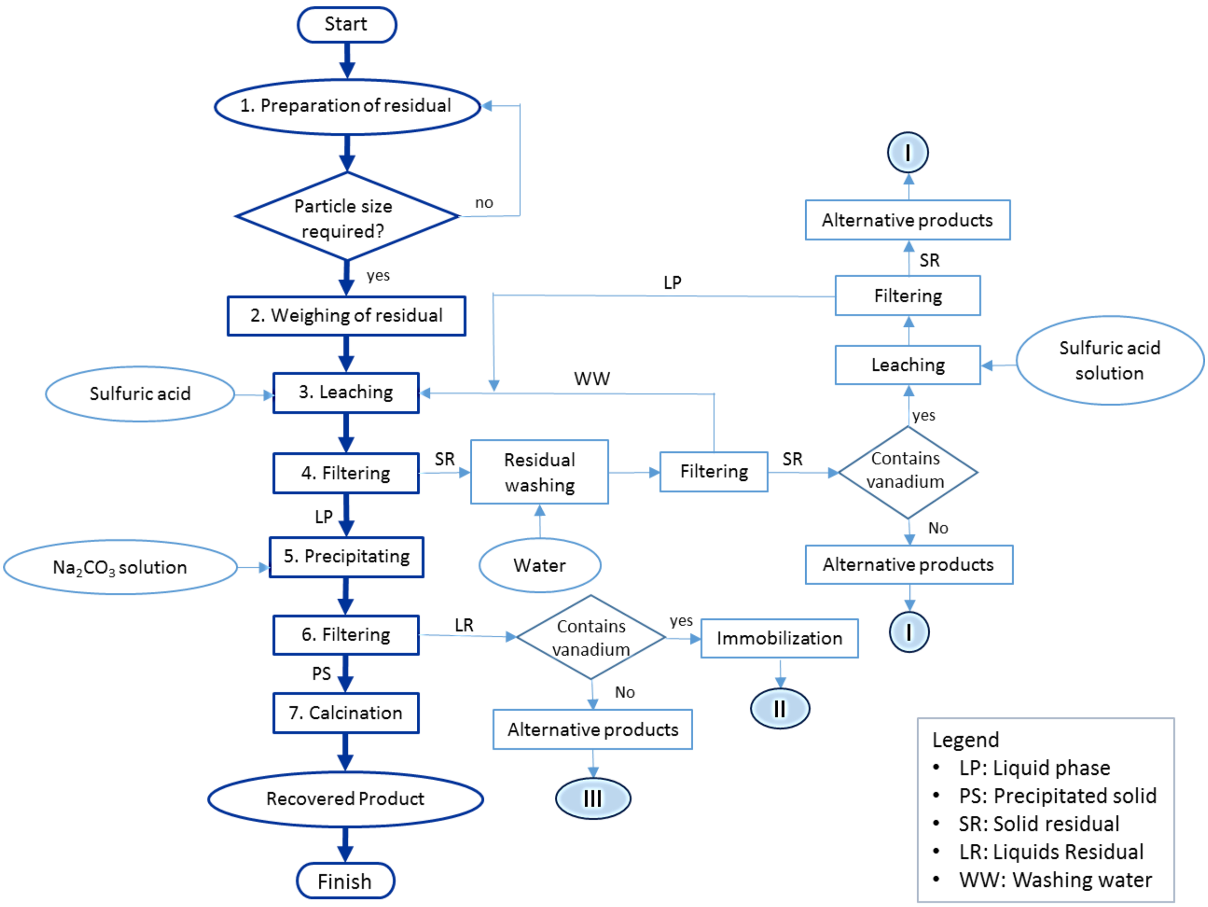

Figure 2: Schematic diagram of catalytic residue processing

3.2.1. Catalyst preparation

The first step in the processing of the catalyst is the preparation of the raw material: crushing and screening, since the catalysts are commercialized in different forms such as pellets, rings or stars. Figure 3 shows a figure with the different forms in which the V_2O_5 catalyst can be presented [3].

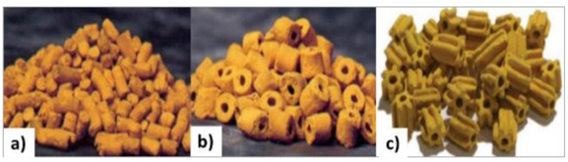

Figure 3: Shapes of the vanadium pentoxide catalyst. a) Pellets, b) Rings, c) Stars [8]

Generally, these catalysts have ceramic separators whose function is to avoid caking of the catalyst pellets, and thus guarantee the SO_2 flow through the adsorption towers. These parts must be removed prior to catalyst milling.

Particle size is one of the factors involved in the efficiency of the extraction process, since the smaller the particle size, the greater the interfacial area between the solid and the liquid and therefore the greater the transfer and the shorter the distance that the solute must diffuse within the solid. However, the production of very fine material that can occupy the interstices of the larger particles and impede the flow of the solvent must be avoided [20].

Several authors have carried out studies varying the particle size, selecting values in the range of 0.1 to 4 mm depending on the operating conditions [21], [22], [23].
A particle size of less than 0.25 mm was selected, which is in agreement with several researchers [22, 24]. It is important to maintain control of the working particle size to ensure vanadium recovery values at similar levels.

3.2.2. Acid leaching

Leaching is performed in a reactor and a set of factors such as solvent, solid-liquid ratio, leaching time, agitation, temperature, etc. must be taken into account [20].
The leaching agent can vary, and the use of various reagents is found in the literature. Among the acid leaching agents, the most studied are nitric, sulfuric and hydrochloric acids, using in some cases mixtures of them in different proportions [17], [23], [25], [26], also using organic acids such as citric acid, oxalic acid [21]. As for basic lixiviants, sodium and potassium hydroxide, sodium carbonate and ammonia solutions have been studied [4], [22], [27].
Alkaline leaching is selective for vanadium over iron, but dissolves some silica and is more expensive in terms of reagents [4].
On the other hand, good results have been obtained using sulfuric acid [17], [25], which is a reagent produced in Cuba, currently in two plants: Plant C in Matanzas and Plant B in Holguín.
As a result of the leaching stage, a greenish colored liquid phase was obtained, from which the vanadium content was determined by UV-visible spectroscopy and from this value the leaching yield was determined, taking into account the vanadium content in the catalytic residual. These results are shown in Table 2.
Vanadium solutions in acidic media are found in VO_2^+ form as $(VO_2)_2SO_4$ and in VO^{2+} form as $VOSO_4$. Furthermore, in the presence of sulfate ions, VO_2^+ cations form compounds such as $VO_2SO_4^-$. Therefore, three ionic species of vanadium can be found in solution, which have characteristic colors: VO_2^+, with a pale yellow coloration, VO^{2+}, with a blue coloration, and $VO_2SO_4^-$, with a yellow coloration. The combination of these ions in solution produces a greenish coloration [5].

Table 2: Leaching stage results

V (mg/L)	Leaching yield (%)
3611,7	93,9

Table 2 shows that as a result of the leaching stage, approximately 94 % of the vanadium present in the catalyst could be extracted to the liquid phase. These values are in similar ranges to those reported in the literature [17], [23], [25].

3.2.3. Precipitation

Once the liquid phase is obtained after leaching, precipitation takes place, with the objective of converting the metallic sulfates present in the liquid phase into solids (precipitate).
This is the final processing operation in which pH control and the addition of the precipitation agent are key or fundamental parameters [13].
Different compounds (salts or hydroxides) have been studied for precipitation, the most widely used being ammonium compounds, which lead to a high purity of the product, but produce large quantities of waste water and gases containing ammonia, constituting a threat to the environment [2], [13], [28].
On the other hand, Na^+ ions can combine with vanadium during precipitation to form sodium polyvanadate, which crystallizes later [2]. Several authors have evaluated the use of sodium compounds, such as sodium hydroxide and sodium carbonate of concentration 1 mol/L or 2 mol/L [17], [25], the latter being used to achieve and maintain the ideal pH during precipitation [29]. Therefore, based on these criteria, sodium carbonate was selected as the precipitating agent for precipitation.
Once the precipitation was completed, the mixture was filtered and the precipitated product was calcined at 450 °C for two hours.
As a result of this stage, the product shown in Figure 4 was obtained, which was analyzed by XRD, obtaining the diffractogram shown in Figure 5.

Figure 4: Recovered product

From the diffractogram obtained, the presence of several phases can be observed, among them ternardite (Na_2SO_4), which is produced as a consequence of precipitation with a sodium salt. In addition, it is observed that vanadium is present in the phases of molecular formula: $Fe_4Mn_3V_6O_{24}$, $KNaV_2O_6$, V_2O_5, V_3O_8, $Ca_3MnNaV_5O_{17}$ predominating the latter, which represents 12.6 % of the recovered product. On the other hand, the determination of the vanadium content in the recovered product gave a value of 37.8 % of V_2O_5, which indicates that the recovery was favorable.

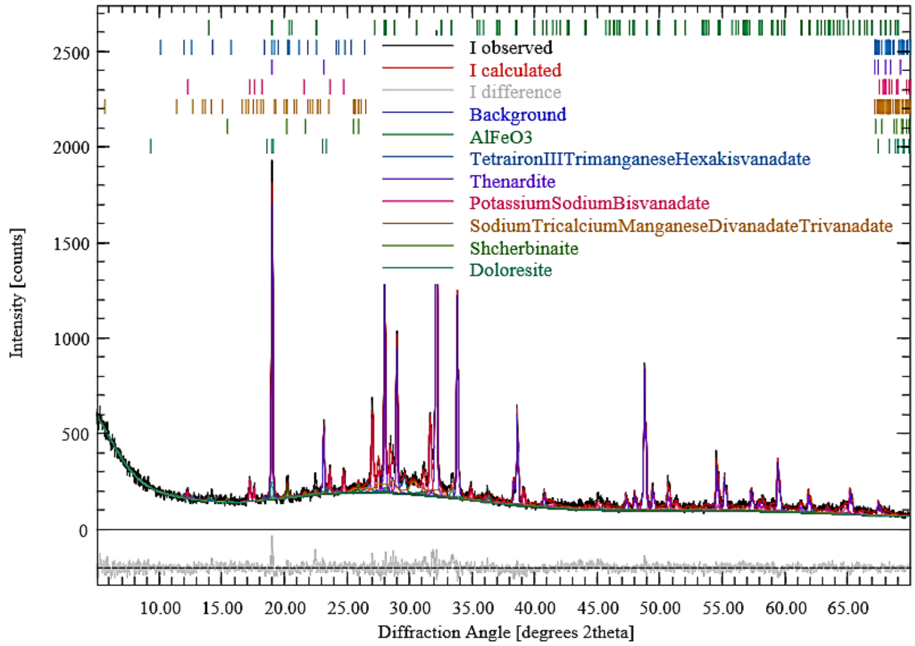

Figure 5: X-ray diffractogram of recovered product

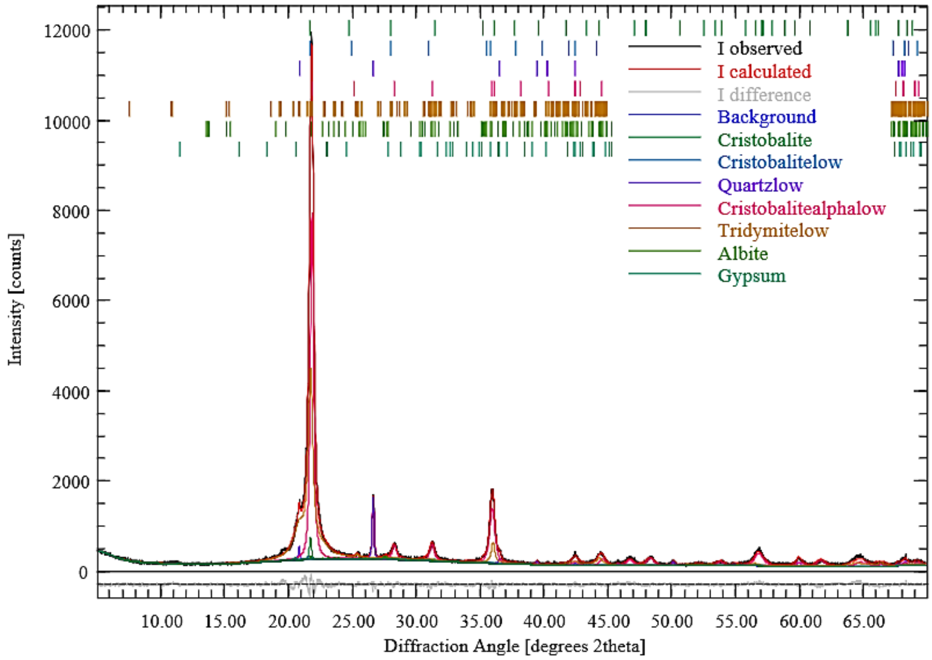

Figure 6: X-ray diffractogram of solid residual

3.2.4. Waste generated from processing

After the sulfuric acid leaching stage, a solid residue formed mainly by silica is generated, which must be washed, since it is contaminated with vanadium from the liquid phase. The wash water resulting from this stage must be recirculated to the leaching reactor in order to take advantage of the metallic elements that were removed from the residual during washing. Finally, the residue is dried at 120 °C.

In the case of the catalytic residual sample analyzed, the solid residual obtained after leaching was analyzed by XRD, obtaining the diffractogram shown in Figure 6, from which the preliminary semi-quantitative analysis was carried out, obtaining the data shown in Table 3, where it can be seen that the residual is composed of 98 % silica.

Table 3: Preliminary semi-quantitative analysis of solid residual (%-wt)

Phase	H_2O	Na_2O	Al_2O_3	SiO_2	SO_3	CaO
%-wt	0,28	0,14	0,24	98,31	0,62	0,44

The vanadium-free solid residue is an output product (product I in Figure 2). In this case, since it consists mainly of silica, its use in other

applications can be valued, for example, in construction materials as industrial aggregate or filler material [27].
It is important to highlight in this case the absence of peaks corresponding to vanadium compounds, evidencing the non-presence of the element in the residual, indicating that the extraction during leaching was efficient. Therefore, it is affirmed that the residue generated from the chemical processing of the spent catalysts does not constitute a pollutant for the environment.
On the other hand, during the precipitation stage, a liquid residue is also generated as a result of the reactions between the excess sulfuric acid and the metal sulfates with the sodium carbonate. In this case, the residual consists mainly of sodium sulfate and water.
In the precipitation stage, pH control plays a fundamental role in order to avoid redissolution of the vanadium into the liquid phase.
If the liquid waste contains vanadium (product II in Figure 2), it must be immobilized, which can be achieved by incorporating it into construction materials. If it is free of contaminating metals (e.g. vanadium), alternative uses can be evaluated (product III in Figure 2), especially to take advantage of the sodium sulfate content present in the waste.
The qualitative determination of vanadium in the liquid waste with hydrogen peroxide showed that the waste does not contain vanadium.

3.3. Basic process considerations

From the study developed at laboratory level, it is important to point out some aspects that should be taken into consideration for a possible scaling up of the evaluated procedure, which would allow to achieve the highest efficiency in the processing of catalytic wastes, and therefore the highest vanadium recovery. It is therefore important to control each stage of the process.
Among the main factors that can cause failures in the system are those associated with the leaching stage, since the maximum extraction of vanadium and the avoidance of generating a new contaminated waste depends on it. In this case, there may be aspects related to the operation of the leaching reactor, such as the temperature of the system due to problems in the heating system or in its control system. Another problem may be related to the agitation of the mixture, which is necessary to favor the transfer of matter between the phases.
Fundamental aspects to guarantee the stable operation of the plant are those related to the plant's equipment in each of its operations. In the leaching stage, an acid pulp is processed, which is filtered under pressure. Therefore, the equipment required for the development of these operations must be resistant to sulfuric acid solutions.
According to Perry and Peters [30], [31], alloys of aluminum-bronze, copper, cast iron with 14 % silicon and lead are resistant to sulfuric acid solutions with concentrations < 50 % and at temperatures of 20, 60 and 100 ºC. In addition, some polymeric materials such as polytetrafluoroethylene (Teflon), polychlorotrifluoroethylene (PCTFE or kel-F), polyvinylidene fluoride (PVDF), among others, can be used. In the case of polyvinyl chloride (PVC), it is limited to working temperatures of up to 60ºC.
Therefore, it is necessary to give special attention to the selection of the pumping system and the filter. In addition, it is advisable to install a second pump to increase the reliability of these operations.
As for the precipitation stage, as mentioned above, among the fundamental factors are pH control and agitation. In this case, the precipitation stage begins in an acid medium, where the pH of the medium gradually increases to a neutral value, therefore, the reactor must be made of a material resistant to sulfuric acid solutions, but the pumping equipment and the filtration of the pulp (precipitate) can be carried out with conventional pumps and filters.
In this second stage it is also advisable to duplicate the pump to guarantee stability in the process.
On the other hand, it is advisable to maintain control over the solid and liquid residual, especially in relation to the vanadium content, which avoids the exit of a contaminating product from the process. The storage and handling of raw materials, intermediate and final products must be taken into consideration to avoid possible spills or contamination of these products.
In the case of raw materials, there must be strict control during the transfer and storage of concentrated sulfuric acid, since it is a highly corrosive reagent [32], capable of causing serious accidents to plant operators.
The catalytic residue must also be stored in safe conditions.
During all stages of plant operation, the safety and work protection rules established for chemical plants must be followed [33].
With respect to the proposal for a pilot plant to scale up the procedure evaluated at the laboratory level, it should be taken into account that the quantities of catalytic waste generated in Cuba are relatively low; therefore, the pilot plant should be capable of processing other industrial waste containing vanadium, such as the ashes from oil combustion.

3.4. Importance of vanadium in the development of electrodes for the recovery of parts in Cuba

In Cuba there are two plants for the manufacture of coated electrodes, with an installed capacity of five thousand tons per year, whose production does not correspond to this capacity, mainly due to the lack of raw materials; neither does it satisfy the demand, in variety or quantity, for the electrodes required by the country's economy. In addition, the electrodes for hardfacing are not produced in Cuba, so it is necessary to import them. The demand for electrodes for the recovery of parts and, specifically, for manual electric arc welding hardfacing is not satisfied due to financing limitations. These electrodes are priced much higher than conventional welding electrodes (E6013 and E7018). For example, the UTP 620 electrode, widely used in the sugar industry for hardfacing a wide variety of parts, is 10 times more expensive than conventional electrodes [34].

In Cuba, at the José A. Echevarría Polytechnic Institute in 1986, a pilot plant was set up to manufacture electrodes for manual welding hardfacing, mainly for the sugar industry, with a production capacity of 200 tons per year. Among the electrodes produced in Cuba at that time was the Vanadin 25 electrode, an electrode with a basic coating for welding and cold filling of lamellar and spheroidal gray cast iron. This electrode made it possible to replace in many applications the nickel and nickel iron base electrodes [35], the vanadium used for the manufacture of the Vanadin 25 electrode was imported. Retaking the manufacture of these electrodes by using the capacities installed in the factories and using part of the raw materials of national origin for the coating contributes to reduce imports and costs.

Morales Rodríguez [36], obtained by means of carbothermal processing in an electric arc furnace, a Cr-V alloy, which was evaluated in the manufacture of electrodes for manual electric arc welding, obtaining welding deposits with 17% Cr and 1.89% V, feasible to use in the recovery of parts working in abrasive wear conditions [34], resulting in this being the first alloy with vanadium obtained in Cuba, using Cuban chromites and catalytic residues from the manufacture of sulfuric acid.

Subsequently, Perdomo González obtained vanadium alloys from the aluminothermic processing of catalytic residues from the manufacture of sulfuric acid from the B and A plants, where the maximum vanadium content obtained in the alloy is limited by the characteristics of the residue and the method of obtaining it [37], [9]. These alloys have been evaluated by Rodríguez Pérez [38], [39], [40] in the manufacture of coated tubular electrodes for the recovery of parts, where they were combined with other ferroalloys.

For example, the effect of V and Si, incorporated from the Fe-V-Si alloy obtained, on the microstructure of the deposits obtained with high Mn content (Hadfield) was evaluated. As a result of the work, the properties of the obtained strands were improved, especially those related to wear resistance [37]. Coated tubular electrodes were also developed, using FeCrMn alloys, evaluating the influence of the addition of the Fe-V-Si alloy on the abrasive wear of the deposits obtained by welding, achieving a significant improvement in the properties of these deposits [38].

On the other hand, FeSiV alloys were used in different proportions of the alloy load in coated tubular electrodes, which allowed studying their influence on the microstructure of hypoeutectic white cast iron, being able to determine their behavior for their use in the surface coating of parts subjected to low or moderate abrasive wear [39].

All the previously mentioned validates the importance of obtaining vanadium concentrates from the chemical processing of spent catalysts, feasible to process by aluminothermia, which will allow obtaining vanadium alloys suitable for their use in the manufacture of welding consumables. Using these alloys, it will be possible to obtain different variants of hardfacing electrodes, which will allow covering a greater number of applications in the recovery of parts in Cuba. These special electrodes developed with these alloys constitute a contribution to the development of welding consumables, allowing the country to be independent from the international market, thus constituting an economic contribution and contributing to the preservation of the environment.

4. Conclusion

- The chemical processing proposed for the spent catalysts from the A plant allows obtaining a vanadium concentrate of ~38 % V_2O_5.
- From the chemical processing of the spent catalysts, two new residues are generated, one solid and one liquid, which do not contain vanadium, being possible their reuse in other industrial applications.
- The control of the process parameters and the selection of the appropriate equipment is important to achieve efficiency and stability during processing.
- The proposed methodology constitutes a contribution to the environment and the economy, complying with the principles of the circular economy.

- The obtaining of a concentrate with 38% of V2O5, will allow its use in the development and evaluation of welding electrode prototypes.

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Smallholders and the Impact of the Agri-food Supply Chain

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Abstract

As the main drivers of primary food production, smallholders play a central and indispensable role in the agri-food supply chain (AFSC). Their responsibilities extend far beyond cultivation to include the prudent use of resources, the implementation of sustainable agricultural practices, and adaptation to changing environmental and market conditions. As smallholders, they are responsible for the journey of food from field to fork, shaping the quality, sustainability and resilience of the entire AFSC. As well as producing a wide range of crops, their work includes soil health, water management and biodiversity conservation, which are critical to the long-term sustainability of agricultural systems. In addition, the decisions that smallholders make about seed varieties, farming practices and the management of climate challenges have a direct impact on food security by determining the availability, accessibility and nutritional value of the food they produce. However, smallholders are increasingly confronted with a variety of challenges that affect their work and the sustainability of agricultural production, and these challenges have a significant impact on the entire AFSC. This study will examine the key challenges facing smallholders in today's agricultural economy and the potential impact of smallholders on actors within the AFSC, and will explore possible ways to overcome these challenges from an expert perspective. In order to gain an overview of these critical issues, the study uses a qualitative approach to consider 17 expert perspectives from various actors in the agricultural sector gathered in January-March 2023. This included consulting firms, agricultural cooperatives and actors in the AFSC, from seed producers to retailers. This should ensure an integrative understanding of the challenges and enable the formulation of possible strategies to overcome them. The results reveal that smallholders are confronted with an immense amount of documentation due to the various regulatory requirements. This tends to overwhelm their knowledge and ability to deal with it, and ultimately confronts them with uncertainty about their efforts to provide the documentation. The question of how to implement digitalisation on the farm and how to deal with price pressures from the market are also major challenges for smallholders. At the same time, AFSC companies have recognised that smallholders can make a significant contribution to achieving company goals, and have taken strategic steps such as integrating smallholders into their own digital systems. In conclusion, in the immediate future, actors in the AFSC sector will seek to collaborate closely and support smallholders through knowledge sharing, digital integration and market-driven strategies to increase the sustainability and efficiency of food production.

1. Theoretical Background

Smallholders[1] play an essential and often underestimated role in the global AFSC [1], [2], [3]. Their decisions, practices and challenges have a far-reaching impact on the availability, sustainability and quality of food production [4], [5], [6]. The involvement of smallholders in the AFSC is not only a question of agricultural productivity, but also touches on aspects of social justice, environmental sustainability and economic

[1] Smallholders are a diverse group of farmers, typically characterised by small farms, often with limited resources and less than 10 ha of land [68].

resilience [7], [8]. The role of smallholders in ensuring food security and building a resilient AFSC is vital in a world where population growth, climate change and resource scarcity are putting increasing pressure on AFSC systems [9], [10]. Their agricultural methods, which are often based on traditional knowledge and sustainable practices, are crucial for the preservation of biodiversity and soil health [11]. By cultivating small plots of land and diversifying their crops, smallholders make an important contribution to resilience in the face of climatic and economic changes [12], [13], [14]. However, smallholders also face considerable challenges [15]. Access to markets, financial resources and modern technologies is often restricted, which limits their productivity and income [16], [17]. In addition, political decisions and global trade dynamics that favour large-scale industrial farming models can weaken the position of smallholders in the AFSC [18], [19]. These inequalities mean that their potential role in food security and the sustainable development of agriculture is not fully realised [20], [21], [22]. The choices that smallholders make - such as the crops they grow, the techniques they use and how they manage natural resources - have a direct impact on the AFSC [23], [24]. By choosing to cultivate traditional varieties they contribute to the preservation of genetic diversity, while the use of sustainable agricultural practices can ensure long-term soil fertility as well as the satisfying the requirements of AFSC actors and consumers [25], [26], [27]. These decisions affect the resilience of the AFSC as a whole to environmental change and socio-economic disruption, as well as the quantity and quality of food production [28], [29]. The ability of smallholders to respond to rapidly changing market conditions and consumer preferences is often limited by the abovementioned challenges and the lack of linkages to distribution channels that would allow smallholders direct access to consumers [30]. These constraints make it difficult for smallholders to capitalise on high-value markets or niche products that could offer higher added value [31], [32]. In addition, consumer habits are changing, and demand for diverse, high-quality and sustainably produced food is increasing [33]. While this can create opportunities for smallholders who use traditional or agroecological farming methods, it also puts them at risk of being displaced by industrial agriculture, which can produce on a larger scale and at lower cost [34], [35]. The resilience of AFSCs depends largely on their ability to adapt to change and withstand disruption. Smallholders play a key role in this, as their practices and knowledge of agrobiodiversity conservation are an essential pillar of the adaptive capacity of the AFSC system. As smallholders collectively represent significant market power that is often underestimated despite their important contribution to the food economy, it is crucial to analyse their challenges in detail from a practical perspective [36]. This includes considering expert opinions and involving companies whose activities significantly shape and influence food production. The need for such an approach arises from the fact that through their direct link to food production, smallholders play a key role in food security and the sustainability of food supply chains, and have a significant impact on the AFSC. The development of targeted, evidence-based strategies that consider the specific conditions and needs of smallholder is therefore essential in order to strengthen their resilience, increase their productivity and promote their sustainable integration into global food supply chains.

In light of this background, this study addresses the following research question:

"What are the main barriers and impacts of smallholders within AFSC systems, and what can be done to overcome them, from the experts' point of view?"

In order to answer the research question, a qualitative research method of expert interviews was chosen in order to gain deeper and more practical insights into the issues facing smallholders. This method allows the complex dynamics and challenges faced by smallholders to be captured and understood at first hand. Expert interviews provide the opportunity to gather detailed information and perspectives that go beyond quantitative data and shed light on the nuances of farming practices, decision-making processes and the impact of policy frameworks on smallholders. By engaging directly with experts working in various areas of agribusiness, policy-making and sustainable development, valuable insights can be gained that can help formulate targeted recommendations for strengthening the role of smallholders in the AFSC. To enable a structured investigation, the study was divided into the following sections. Section 2 is dedicated to the methodology of the study in detail by presenting the expert groups and describing the analysis tool used to evaluate the interviews. Section 3 presents the key results of the study, summarising the most important aspects and findings from the expert interviews. Finally, section 4 discusses the results and draws conclusions that not only reflect the findings but also formulate recommendations for future research and policy measures.

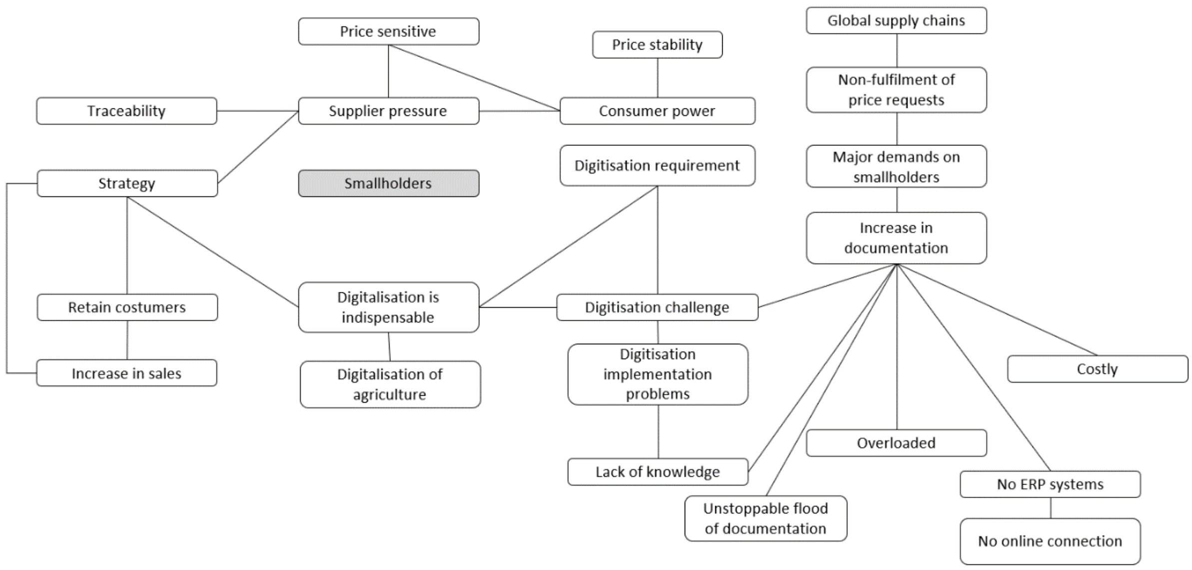

Figure 1: Associations with current challenges

2. Research Methodology

In order to understand the impact of smallholders and the impact of the AFSC, the study involved interviewing experts from three main groups of companies that influence the AFSC: (a) extension agencies, (b) AFSC actors ranging from seed producers to retailers, (c) agricultural cooperatives. The interviews were conducted between January and March 2023, involving 17 experts with between 4 and 35 years of experience and using methods such as web applications, phone calls and face-to-face meetings. Open-ended questions guided the interviews to delve into the challenges involved in digitizing the AFSC to improve efficiency. The data was analyzed using the qualitative GABEK method and WinRelan® software, focusing on understanding individual and organizational perspectives on the topic [37, 38, 39]. The analysis involved preparing the data, breaking down the interviews into meaningful units, manually coding these units with key terms, and visualizing the connections between terms in order to map collective thoughts and knowledge about the challenges of the digitizing process [40]. This approach provided in-depth insights into the research topic.

3. Results and Discussion

The ever-increasing focus on sustainability, particularly within the food industry in the EU, means that all of the actors involved must increasingly fulfill higher standards in order to operate their businesses and ultimately market their products [41, 42, 43]. This shift is evident in various initiatives. Throughout the years, the EU Commission has issued numerous directives that affect smallholders, such as the Integrated Pest Management (IPM) directive, the Sustainable Use of Pesticides Directive (SUD) or genetically modified organisms (GMOs) [44]. In addition, there is a growing emphasis on promoting sustainable practices among smallholders, as highlighted by the need to precisely define and adjust legislative efforts to acknowledge and support the seed systems used by smallholders [45]. This aligns with the overarching objective of improving food security while conserving resources, as evidenced by the adoption of agroecologically efficient agricultural systems that contribute to food sovereignty [46]. However, from the smallholders' point of view, these standards lead to a documentation requirement that they cannot adequately cope with (see Figure 1). An expert reported:

"(...). But you just can't absorb this flood of documents to fulfil them all perfectly, no matter what." (Ek6)

Rather, smallholders are confronted with a great deal of uncertainty regarding the standards. One expert report on this:

"(...) half [of them] (...) I didn't understand at all, but not because I hadn't heard it, but because I have no idea about it." (Bp1)

Another expert reported the following effect of documentation requirements:

"(...) we would basically have to be almost (...) civil servants to see through it, because you don't even know, am I going to declare it like this? What does that mean for me? What costs will I incur? Another example: I have an old machine shed in my backyard where I keep a few of my machines. This is categorized as agricultural land. But I can't enter

a building unless I click on "Garden shed larger than 30 square metres" and that's definitely not correct either. And that's how you find your way through, and that's the case with many things." (Ek7)

In the course of smallholders meeting documentation requirements, the digitalization of farms is becoming unavoidable, which in turn represents a major challenge for smallholders when it comes to implementation. Challenges such as insufficient investment, technological complexity, limited internet access, adjustment to new workflows, and staffing shortages have been recognized as major obstacles [47], [48], [49]. In addition, the integration of digital tools in agriculture faces additional challenges due to inadequate infrastructure, poor connectivity, skills shortages and a lack of appropriate decision support tools [50]. Moreover, the shift towards digitalization requires a strategic approach and a clear understanding of the implications. Studies have shown that responses to digitalization in agriculture are often ad hoc, indicating the lack of a structured approach as well as uncertainty about the digital transition in the sector [51]. Furthermore, the uneven transformation of farming practices through automation and digitalization is closely tied to the political and sustainability dynamics within specific agricultural settings, highlighting the complexity of integrating digital technologies into traditional farming practices [52]. One expert stated that

"If you are a smallholder, you are no different from any consumer. Imagine you would like to have a digital solution that helps you in many ways. Trying to connect all these services that you need is a challenge." (Fg4)

Another expert reported briefly and concisely on the aspect of digitalization:

"(...) we are too small for that." (Bn6)

In conclusion, another expert summarised the situation regarding the lack of digitalisation as follows:

"(...) no online connection and therefore this is a manual process, which means that employees are behind it, employees would then have to search for information on request and then forward it manually or by scan or whatever (...)." (Ec6)

Both the increasing documentation effort and the need for digitalization represent an internal operational challenge that smallholders are increasingly forced to deal with. Another important discussion area for smallholders and market actors is the price situation and the resulting price pressure. The price pressure that smallholders experience from customers can be attributed to various factors within the agricultural supply chain [53]. Customers, including retailers and consumers, exert price pressure on smallholders for several reasons, impacting the profitability and sustainability of farming operations. One key reason for this pressure is the increasing consumer demand for lower-priced agricultural products, driven by factors such as competition among retailers, the price sensitivity of consumers, and economic conditions [54]. This is confirmed is by one expert as follows:

"Yes, absolutely. Of course, it's deliberately stronger now due to inflation. During corona, nobody paid that much attention to money. You could clearly feel that, sales have shot up everywhere." (Cw6)

As a result, smallholders often face downward pressure on prices to meet the expectations of cost-conscious customers. Moreover, the consolidation of retail power in the AFSC has contributed to price pressure on smallholders [55]. Large retailers and supermarkets hold significant bargaining power, allowing them to negotiate lower prices with suppliers, including smallholders, in order to maintain their profit margins and competitive pricing strategies [56], [57]. An expert reported the following:

"Sometimes it's the case that someone can't produce below a certain price and the customer then says we can't pay it either. That's just the way it is sometimes, then they look around for a new one. I think that there are also shifts (...)." (Ce5)

This power dynamic leads to a situation where smallholders are compelled to accept lower prices for their produce in order to secure contracts with major retailers. One expert reported:

"Yes, I think the biggest challenge is that we have it when you think about price negotiation." (Fd2)

In addition, globalization and international trade play a role in exerting price pressure on smallholders. The interconnected nature of the global economy means that smallholders are not only competing with local producers, but also with international suppliers [58]. This competition can drive prices down as smallholders strive to remain competitive in the global market, facing challenges such as price volatility and fluctuating demand [59]. In addition, one expert summarised this by stating:

"Most of the challenges really show up when something in the global supply chain doesn't meet the quality you need, doesn't meet the price you said it would, doesn't meet the requirements." (Fd6)

Furthermore, changing consumer preferences and market trends influence the price pressure that smallholders experience. Shifts towards organic, sustainable, or ethically sourced products can require smallholders to make investments in new practices or certifications in order to meet evolving customer demands, potentially increasing production costs and affecting pricing strategies [60]. While the demands on smallholders are increasing, both within the farm and in relation to market players, smallholders have an immense impact on the entire AFSC. Smallholders make an indispensable contribution to the functioning and maintenance of the AFSC and therefore play a central role in the agricultural and food system [61]. This role is characterized by their fundamental function in the production of food and raw materials, which form an essential basis for feeding the population [62], [63]. Through their decisions regarding cultivation methods, plant breeding and resource management, smallholders have a decisive influence on the efficiency and sustainability of food production and thus on the availability and quality of food [28], [29]. However, the role of smallholders goes far beyond pure food production. They are equally important players in overcoming challenges such as climate change, the preservation of biodiversity and the sustainable use of natural resources [64], [65]. By using innovative and sustainable agricultural practices, smallholders can help to reduce greenhouse gas emissions, improve soil quality and protect water resources [66]. In addition, the adaptation and integration of modern technologies into farms plays a crucial role in increasing productivity and efficiency while minimizing environmental impacts [67]. The importance and influence of smallholders on the food industry has been recognised by food sector stakeholders, whose responses to the main challenges faced by smallholders included the following:

"The actors have all realized at the end of the day that it is the smallholders who bring the money into the company and when I have understood that, then I look for ways to serve my customer, my smallholders, in the best possible way and in the future it will be the case that the breeders will be more and more committed to the smallholders, more to the smallholders than to the trade and that also means that the most diverse companies (...) will have a rethink and there will be a new way of thinking, which yesterday was fully related to wholesale and retail, tomorrow will be related to the smallholders." (Ef6)

With regard to providing smallholders with support in overcoming these challenges, one expert reported the following experience:

"Business processes are being developed, online solutions, (...) which are aimed at the smallholders, which are then aimed at the real end customer in order to do business with him and, above all, to do business sustainably, which also means we are talking about retaining customers." (Ef7)
The expert added:

"(...) we will then work more than ever on the smallholders and in the future, there will be digital solutions such as partial patch-specific sowing or variety recommendation programs, which we have collected under the guise of "crop wise." (Ef8)

4. Conclusion

This study emphasises the complex and central role of smallholders in the food value chain and the many challenges they face in today's agricultural economy. As the linchpin of primary food production, the smallholder is not only responsible for growing a wide range of food crops, but also for maintaining sustainable farming practices, efficient resource management and the preservation of diversity. These tasks are crucial for the long-term sustainability of agricultural systems and thus for global food security. The research highlights several critical challenges facing smallholders, including overwhelming documentation requirements, the daunting task of farm digitalisation and significant market-driven price pressures. These challenges, exacerbated by stringent regulations and rapid technological change, place smallholders at a turning point that requires adaptability and resilience. The study also emphasises the indispensable contribution of smallholders to the AFSC. Involving and supporting smallholders through knowledge sharing, digital inclusion and market-orientated strategies is seen as crucial to improving the sustainability and efficiency of food production. The study therefore emphasises the need for close cooperation and support of smallholders by all AFSC stakeholders in order to overcome the challenges and strengthen the role of smallholders in the AFSC. Although this study has provided some insight into the barriers and opportunities for smallholders to influence the AFSC, there are two main limitations. The study focused mainly on smallholder fruit and vegetable farmers and less on cereal, dairy or livestock farmers. The latter are likely to have different constraints and impacts on the food chain than fruit and vegetable farmers. Furthermore, the analysis is mainly focused on the German food market and the results are only partly transferable to other countries. In conclusion, future research should focus more on the strategic orientation of smallholders, and the extent to which they are better able to assert their market power and are less exposed to the influence of wholesalers and retailers, and ultimately consumers.

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Perception of Waste and Waste Transfer Cost

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Abstract

Since its existence, humans have been interacting with their environment to encounter its basic needs. It is obvious that these interactions cause both humans to affect the environment and the environment to affect mankind. And, environment issues are constantly, too, ubiquitous problems. Hence, waste management and waste perception are problems that municipalities should have worked on for a long time. But study has not been carried out on the waste perception and waste transfer problem relations which would base on the term of cost of this issue and previous studies of relation waste perception and waste transfer cost have not directly dealt with this issue.

Hence, it could conceivably be hypothesized that major component of waste collection operational cost can basically be seen fuel cost and personnel cost but one of the main obstacles is waste perception. The argument of this paper relies too heavily on the term of waste perception.

The amount of waste collected and total cost of waste are based on the characteristics of the waste, types of transfer vehicles and the distance between the cities and the transfer stations are other parameters affecting the cost yet waste perception has a most pivotal role in process. Therefore, waste perception could be a major factor, if not the only one.

In this study, in order to determine the effect of solid waste perception on total collection and transportation cost, a realistic survey was conducted and the analysis was carried out.

1. Introduction

With its widespread use among people, waste generate service stands out as the most basic service provided by municipalities. This task, simply called waste generate by people, involves massive planning, feasibility and costs in the background. Illustrate this fact that waste generate is the collection of waste, taking it to the transfer station, and from the transfer station to the disposal facility in vehicles with larger bodies. Generate and transportation constitute the biggest cost in waste management.

However, waste receptacles are places on the streets in residential district should be collected without delay. The reason for this is to prevent diseases from spreading in cities.

In this connection, the process of time management is so important, the amount of waste generated daily by per person per day should be based on waste perception. This also affects appropriate vehicle sizes and correct transport distances.

A main driving force behind this paper is that waste management is the pyrrhic problem under waste perception and waste transfer cost and logistic cost and its effect. The aim of this study is to explain how effective waste management and high level of waste perception against high cost of waste transfer.

Green energy and the sustainable development are encouraging the recovery of waste. Municipal waste management is less costly in the poorest countries than in emerging or developed countries. [1]

The highest cost item in the integrated solid waste management system is the collection and transportation of waste. The costs can reach up to 80% of total waste management. [2]

Generally, waste collection around the world is done or outsourced by district municipalities (local governments).

The main operating costs are fuel expense, vehicle depreciation and personnel expenses.
Other variables that affect the cost are the amount of waste collected, the physical properties of the waste, the types and capacities of collection vehicles and the distance between the settlement and the transfer center.
In this study, a survey appropriate to the conditions was developed, accepting the perception of solid waste and its impact on transportation costs.

In order for the survey application to be realistic, the survey was created based on waste amount and literature review, and with information received from authorized persons in the private sector and local governments. However, the profits derived from the sale of recycled products rarely cover the expenses required for their conversion. Nevertheless, the absence of waste management causes negative externalities that are even more expensive.

For example, the Global Waste Management Outlook of the United Nations Environment Program (UNEP) 2022 estimates that the global health and environmental costs related to the pollution by waste deposited in the wild or burned in open air, up to 400 million tons of heavy metals, solvents, toxic sludge and other industrial wastes are released annually into the world's waters [3], hypothesized that major component of waste collection operational cost can basically be seen fuel cost and personnel cost but one of the main obstacles is waste perception. The argument of this paper relies too heavily on the term of waste perception.

The parameters and questions were determined after the literature review was done and information's were taken from the authorized persons in municipalities to achieve realistic conditions in the survey.

During this study, the necessary calculations have been made for the survey where the waste transfer cost is admitted on waste perception.

Within the scope of the research, a survey was conducted with 215 students, considering their age, gender and information about waste perception and the specific research questions, as a representative of the research. Few published studies have been conducted to determine the possible effects of these relations. Because, when asked specifically about "waste": "I separate plastic and paper in waste", it was seen that the perception of waste from the past continues. When waste is mentioned, it seems that an anti-hygienic pile that needs to be disposed of as soon as possible comes to mind.

Shortly, these findings are that waste transfer cost decrease as the students' waste perception increases.

As a result, it has been understood from this study that students' awareness of waste perception is not at a sufficient level, but the majority of those who are aware have insufficient opinions about its impact on the cost of waste transportation. Therefore, it is necessary to quickly explain to the society by underlining that the waste problem is not just about the citizens throwing the waste into the container and the municipality collecting it without any delay. In sociology, he puts the positive into himself and the negative into himself.

The amount of waste collected and total cost of waste are based on the characteristics of the waste, types of transfer vehicles and the distance between the cities and the transfer stations are other parameters affecting the cost yet waste perception has a most pivotal role in process. Therefore, waste perception could be a major factor, if not the only one.

1.1. Literature review

Reviewing the results of the sources concludes that the waste perception that there is no an increasing importance on waste management. Hence It has not been found in literate that there is an increasing importance on the role of waste perception that promotes the idea that important external sources of waste cost, which can be eliminated by completing certain strategies either. Various theories of waste perception how societies that there are many factors that influence waste cost.

In order to provide comparison in the study, the results of the source examination are based on these titles that solid waste modelling for municipalities with real data on municipal waste [4], municipal waste as a common good in public economics and economic value of waste [5], externalities and total cost [6], Cronbach alpha [7] and Cronbach's alpha estimation and hypothesis [8].

After reviewing the previous scientific publications by provided International Institutions and other scholars (journal articles, dissertations, books, studies) and preparatory work, the following conclusions which questions that there have not been answered by any of the existing studies or research:

- It is necessary to ensure equal access to adequate sanitation and sanitation for all, and end littering in public places and paying particular attention to waste perception and "people in vulnerable situations" in the future due to waste transfer cost.
- It is necessary to ensure universal and equitable access to the problem of safe and accessible waste for cities in the future
- It is necessary to improve waste quality by reducing pollution, minimizing the release of harmful substances, and significantly diminishing waste transfer cost globally.
- Drastically increasing waste perception efficiency across all societies, ensuring a sustainable supply of waste recycling will decrease and significantly reducing the number of cities suffering from waste problem in the future.

1.2. Concrete research questions

In design research, it has been posed research questions to define the scope and the modes of inquiry. Due to the importance of research questions, research provides on the term of waste perception we need to have appropriate survey questions on how to construct research questions. We have filled this gap by using ways of constructing semi structural interview and questions and analyzing the research questions in a survey. Based on analysis, it has been provided guideline and pattern that help students formulate research questions:

- What is the most important impact of waste perception on waste transfer cost in municipalities?
- What kind of keys on age, education, and cultural origins and others affect whether people will develop waste generate? and how can these common traits be used to help diminish the waste transfer cost?
- How do waste transfer cost outcomes compare between low-income people with lack of waste perception living in the cities?
- What are the similarities and differences of the waste perception of in Turkish students and foreign at different classes and different departments at Anadolu University's Faculty of Economics and Administrative Sciences?

Finally, this paper has a new field in variation database and questions but most previous research studies are contained only standard survey questions. Moreover, the project has unique survey that is more engaging in order to get reports and metrics and it has not been online survey. In addition, no research has been found that surveyed which was based on these questions and previous published studies are limited to local surveys and has been compared different countries residents. Findings are discussed with qualify the previous literature, and directions for future empirical research are pointed out due to waste perception and waste transfer in cost problems.

1.3. Research gaps

There is a substantial large number of current researches on waste management, waste problems, landfills, waste generate. But the gaps in research are remarkable both in terms of subject matter, and size or scope of studies related with the term of waste perception. The term of waste perception should be characterized by case study research, often having the benefit of a regular approach. Along with the gaps in specific subject matter of waste perception, there is a lack of large-scale research that would allow a more complete view of the relations of waste perception and waste transfer problems.
The research gaps are listed below because of the potential value of gap of research literature on waste perception.

Table 1: The research gaps

There are not student's waste perception patterns related to the term of waste.
There is not a systematic study of waste perception: including an assessment of conditions in current waste problems.
There is not proper study related with links between waste perception involved age and gender.
There is not proper study related with attitudes and beliefs of students with regard to waste perception.

Moreover, this study argues waste perception considering transfer costs and waste logistic associated with each attribute. The term of waste perception in this study too considers mainly transfer costs of as well as how and when waste is disposed.
This study argues waste perception considering transfer costs and waste logistic associated with attribute. The term of waste perception in this study too considers mainly transfer costs of as well as how and when waste is disposed.
Considering all the explanations above, with research, I have traced the adequate of approaching the relationship between waste

perception and waste transfer cost, the difficulties of waste management in cities. Since, waste management in cities is an element of environmental regulation and harmonization in the subject of diminishing huge economic cost. It is also a dynamic analysis in terms of waste management problem, waste perception and adaptation in the context of logistic management. Hence, in order to help familiarize participants that survey was conducted in two level.

Cronbach's alpha is to measure of internal consistency because it has been used because we have multiple "Likert questions" in survey that form a scale and to determine if the scale is reliable due to fact that we have concerned with inter-rater reliability. Cronbach’s alpha is to demonstrate that survey and scales that we have constructed or adopted for research projects are fit for purpose.
Survey was used the question methods defined in case evaluation of waste perception. The survey is specifically designed to measure waste perception and more.
Consequence, researchers have determined that waste management and waste problems have a relationship with effects. Therefore, these factors have been interlinked. But despite this, not many academic studies have focused on addressing waste perception impact on the linkage between waste transfer cost and waste perception. This is another critical research gap.

1.4. The novelty of research

In this study, the novelty of research is based on the relationship between waste perception and waste transfer cost. Hence, this relation has been discussed as a new part of the explanatory research design. The survey questions have been generated after a thorough investigation of the literature and the waste problems and waste transfer problems identified.
Completed the survey, the descriptive research design has been used for analysis in order to explain the respondents’ characteristics of the indicators used. Results have been analyzed using Cronbach’s Alpha is used to ensure internally consistent. Moreover, these results will be used for Machine Learning that will have new data that is another the novelty of research.

2. Method

2.1. Study area

This study was conducted at Anadolu University in Eskisehir where has one of the highest students’ populations among Turkish universities. The survey was conducted in February and March 2024. The survey had been translated from Turkish to English and to Persian language before it was conducted. This is a demo survey to determine the suitability of the questions has been used was tested out. However, by a group of students as a part of their waste perception, in which it will be collected the following data regarding the data at university in a locality.

Table 2: Descriptive statistics of items related to the scale

Subject Titles		I completely agree	I agree	I am undecided	I disagree	I completely disagree	$\bar{x}$	ss
Q1. I separate plastic and paper from waste	f	25	24	62	72	33	2,30	1,199
	%	11,6	11,1	28,7	33,3	15,3		
Q2. I collect used batteries	f	78	35	40	35	28	1,54	1,443
	%	36,1	16,2	18,5	16,2	13,0		
Q3. I don't use paper towels	f	93	32	31	20	40	1,45	1,554
	%	43,1	14,8	14,4	9,3	18,5		
Q4. I separate plastic, metal and paper	f	39	22	71	47	37	2,10	1,314
	%	18,1	10,2	32,9	21,8	17,1		
Q5. Do you think recycling waste is important?	f	183	23	5	1	4	0,24	0,694
	%	84,7	10,6	2,3	0,5	1,9		
What do you think is the main reason for people's littering behavior?								
Q7. No waste container	f	54	20	49	39	54	2,09	1,509
	%	25,0	9,3	22,7	18,1	25,0		
Q8. Waste container far away	f	49	18	56	43	50	2,13	1,453
	%	22,7	8,3	25,9	19,9	23,1		
Q9. Waste container is small	f	61	31	47	37	40	1,83	1,472
	%	28,2	14,4	21,8	17,1	18,5		
Q10. Waste container dirty	f	72	40	34	33	37	1,64	1,497
	%	33,3	18,5	15,7	15,3	17,1		
Q11. Waste container is too far away	f	55	30	47	29	55	2,00	1,523
	%	25,5	13,9	21,8	13,4	25,5		
What do you do with plastic bottles?								
Q13. I throw it in the trash at home	f	20	12	37	44	103	2,92	1,306
	%	9,3	5,6	17,1	20,4	47,7		
Q14. I throw it in street containers	f	27	19	57	53	60	2,46	1,318
	%	12,5	8,8	26,4	24,5	27,8		
Q15. I throw it in recycling bins	f	15	17	64	49	71	2,67	1,208
	%	6,9	7,9	29,6	22,7	32,9		
Q16. Waste container for plastics is dirty	f	56	33	50	41	36	1,85	1,426
	%	25,9	15,3	23,1	19,0	16,7		
Q17. I throw plastics into any container	f	35	38	50	43	50	2,16	1,39
	%	16,2	17,6	23,1	19,9	23,1		
Have you heard the following two concepts before?								
Q18. “Circular economy” and “Recycling”	f	9	4	43	61	99	3,10	1,05
	%	4,2	1,9	19,9	28,2	45,8		

Have you heard the following concepts before?

Q19. SO2, NOx, PM2.5, CH4, fossil CO2 and NH3 emissions	f	38	30	51	51	46	2,17	1,382
	%	17,6	13,9	23,6	23,6	21,3		
Q20. --Do you think waste should be incinerated for recycling?	f	75	27	66	19	29	1,54	1,391
	%	34,7	12,5	30,6	8,8	13,4		

2.2. Data collection and data analysis [9]

Table 3: Frequency and Percentage of participants demographic variables

	Frequency (f)	Percentages (%)
Gender		
Women	109	50,5
Men	105	48,6
Total	214	99,1
Age		
17	3	1,4
18	9	4,2
19	16	7,4
20	52	24,1
21	42	19,4
22 and over	93	43,1
Total	215	99,5
Department		
Business Management	13	6,0
Economics	35	16,2
Public Finance	160	74,1
Other	7	3,2
Total	215	99,5

Table 3 shows the gender, age and department distribution of the participants. In this dichotomy, 50.5% of the participants are women and 48.6% are men.

3. Results and Discussion [10]

Table 4: Reliability results for the scale (Cronbach's Alpha)

Subjects	**Multiple Correlation Coefficient**	**CR value when subject is deleted**
Q3. I don't use paper towels	0,074	0,641
Q5. Do you think recycling waste is important?	0,100	0,633
Q7. No waste container	0,279	0,588
Q8. Waste container far away	0,542	0,565
S9. Waste container is small	0,371	0,583
S10. Waste container dirty	0,362	0,586
S11. Waste container is too far away	0,450	0,579
S13. I throw it in the trash at home	0,334	0,603
S14. I throw it in street containers	0,366	0,605
S16. Waste container for plastics is dirty	0,187	0,630
S17. I throw plastics into any container	0,278	0,592
S18. "Circular economy and "Recycling"	0,040	0,646
S20. Do you think waste should be incinerated for recycling?	0,083	0,630

*Table 5: Descriptive statistics regarding distribution normality and participants' waste perception levels, *, p<0,05*

	Min	**Max**	$\overline{x}$	**Standard deviation**	**Skewness**	**Kurtosis**	**the Kolmogorov-Smirnov (KS) test statistic / p-value**
Waste perception	0,46	3,38	1,95	0,586	0,028	-0,264	0,057 / **0,090***

*Table 6: Testing whether participants' waste attitudes differ according to their gender (T-test), *p<0,05*

	$\overline{x}$	**Standard deviation**	**T-test**	**p-value**
Women	1,80	0,579	-3,998	**0,00001***
Men	2,11	0,553		

When Table 4 is examined, the multiple correlation numbers for the items and the Cronbach's Alpha coefficients that will done when the item is deleted are given.

In this context, Q1 "I separate plastic and paper in the waste." item, Q2 "I collect used batteries." item, Q4 "I separate plastic, metal and paper." article,

Q15 "I throw it in recycling bins." Since item and item Q19 "SO2, Nox, PM2.5, CH4, fossil CO2 and NH3 emissions" reduce Cronbach's Alpha coefficient, they are not included for mean difference tests.

Accordingly, the current Cronbach's Alpha coefficient was determined as 62.7, and it seems to be at appropriate levels (Cronbach's Alpha value before the items were removed was 52.2).

Table 4 presents descriptive statistics regarding the participants' waste perception levels and the Kolmogorov-Smirnov results applied for the normality test.

Table 7: Testing whether the waste perception of the participants differ according to their age and department (ANOVA)

	$\overline{x}$	**Standard deviation**	**F**	**p-value**
Age				
19 and under	2,07	0,538	0,684	0,563
20	1,99	0,607		
21	1,93	0,569		
22 and over	1,96	0,586		
Department				
Business Management	1,89	0,739	0,232	0,874
Economics	1,95	0,585		
Public Finance	1,96	0,577		
Other	2,12	0,584		

4. Conclusion

The participants were asked to complete a 20 questions survey about waste perception and the survey significance were analyzed using analysis of variance and Cronbach alpha as appropriate method. The following conclusions can be drawn from this study.

Firstly, a significant number of the students have knowledgeable about the solution to the waste problem, but this knowledge is not sufficient. This result shows that the infrastructure and system work implemented by local governments regarding waste management are not well known by students. In addition, municipal systems cannot be used efficiently enough for this reason.

Secondly, regarding the responsibility and impact of individuals and the administration towards solving the waste problem, most of the students tends to leave the responsibility to the local municipalities and this effects to waste transfer cost. Every student should have known they can influence the level of their own waste cost. Because waste perception is depending on waste pay off. This saves money and protects our environment and decrease waste transfer cost. Students do not awareness of these costs that include waste transfer and this can be conjectured irredeemable perpetual problem.

Therefore, it was concluded that the reliability levels of these data were good. In the subsequent validity analyzes, it was concluded that the method was valid as well. And, students have to be ensured their participation within certain rules from early age associate with waste perception.

Consequently, as the perception of waste increases, the cost of waste collection and the need for a transfer station decreases or the transfer cost disappears. This is a rather significant outcome.

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Resilient supply chains: quantitative methods and modeling approaches

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Abstract

In today's volatile global landscape, ensuring resilience in supply chains is paramount for businesses to withstand disruptions and maintain operational continuity. This paper presents a comprehensive investigation about supply chain resilience, focusing on indicators, quantitative methods, and modeling approaches. Furthermore, research gaps and future directions are identified, emphasizing the need for long-term resilience, integration of emerging technologies, collaboration among supply chain actors, and alignment with sustainability principles. This review provides a comprehensive foundation for advancing research and practice in SCR, underscoring the importance of holistic and proactive approaches to address challenges and risks in supply chains.

1. Introduction

The supply chain (SC) comprises a network of organizations engaged in various processes and activities, through up-stream and down-stream links, ultimately delivering value in the creation of products and services to the end consumer. Integration within the SC hinges on key elements that are contextual and unique to each process and link [1].

Companies need to innovate and cultivate collaborative practices to improve the interdependence this causes. However, these efforts can increase susceptibility to operational disruptions and jeopardize their long-term viability [2]. SC are particularly vulnerable to disruptions, not only because of their direct impact, but also because of the cascading risks they propagate [3]. Given these dynamics, proactive risk management in supply chains has become critical to ensure long-term stability, adaptability, and competitiveness. SCs must be designed to endure disruptions (low vulnerability) and recover quickly from them at minimal cost (high recoverability). [4]. This situation has led to a growing interest in the study of resilience in supply chains.

Resilience is understood as the capacity to recover, and evolve in response to disruptions, strengthening its ability to maintain a continuous flow of operations in the presence of disruptive events [5]. Resilience focuses on building recovery, robustness, and flexibility [6].

It is essential to develop quantitative indicators and methods to assess the current level of resilience within the SC and its relationship with other key performance indicators. In addition, it is necessary to develop modeling approaches that allow a better understanding of the overall resilience of the system and how it can be improved [7].

While literature reviews on supply chain resilience (SCR) are not scarce, those available are fundamentally conceptually and empirically oriented. There is a paucity of studies focusing on quantifying resilience attributes within SCs [6]. The literature provides insights into resilience frameworks and strategies, there remains a distinct absence in comprehensive quantitative modelling approaches and quantitative methods tailored specifically for enhancing resilience across SC.

The aim of this paper is to conduct a comprehensive review of the SCR literature, to identify gaps in existing research, formulate relevant research questions, and outline novel contributions.

This will be achieved by analyzing the main quantitative methods to assess resilience and their interaction, as well as to examine different modeling approaches proposed in the literature for designing supply chains resilient.

The document is structured as follows: in section 1 a contextualization of the problem of resilience in the supply chain, justifying the importance of approaching resilience from analytical and mathematical perspectives. Section 2 describes the methods used to examine the existing literature. A set of research questions were defined to assess the state of the art. In section 3 Analysis of Findings derived from the literature review, including analysis of the current landscape and assessment of quantitative advances. Identification of gaps and limitations in existing research. Interpretation of the results in the context of the research objectives and possible future directions for research.

2. Methods

In this section, we will employ a systematic methodology for the comprehensive examination of literature proposed by Denyer and Tranfield [8]. This adopts an iterative approach encompassing the definition of study scope, research question, identification of pertinent keywords and research strings, literature selection and evaluation, analysis, and synthesis of the literature through bibliographic techniques.

2.1. Research context analysis and question formulation

The initial phase is pivotal in accurately and clearly delineating the scope of the research study, achieved through the formulation of pertinent research questions. Among the questions that will guide the review are: How has the concept of resilience been defined within the context of supply chains? What quantitative metrics are frequently employed to measure resilience in supply chains? What are the predominant operations research methods utilized in modeling SCR? What are the remaining challenges in research on resilience within supply chains, and what future directions should be pursued?

2.2. Sourcing of relevant literature and analysis and synthesis of results through bibliographic techniques

The search equation used is TITLE-ABS-KEY (("resilien*" OR "risk*") AND ("indicators" OR "quantitative methods" OR" model approaches") AND ("supply chain*" OR "supply network*"))

An initial search is carried out in the databases Web of science, Scopus, ScienceDirect and Google Scholar, for a total of 135 articles.

For a comprehensive analysis of scientific literature, the Tree of Science (ToS) tool was utilized. Based on graph theory metrics, this tool visualizes works in a field of knowledge as a tree, where the roots are classic articles, the trunk represents articles that allow the area to grow, and the leaves are recently published articles.

The classic articles, represented by the roots in the knowledge tree, have laid the foundation in risk management in logistics and SC activities. In these initial works, fundamental concepts on risk identification and evaluation are addressed, as well as strategies to mitigate them. Topics such as inventory management, supplier management and transportation route optimization are explored, focusing on improving operational efficiency and reducing vulnerability to potential disruptions. [9-13].

In the papers represented by the tree trunk, there is an evolution towards a more holistic approach to risk management. The keywords are framework, model, information, customer satisfaction, recognizing the interconnection of different aspects in the supply chain. Quantitative approaches to defining and modeling SCR, as well as empirical analysis of SC risks and their impact on business performance, are also explored. These works represent an intermediate stage in the evolution of the field, combining traditional approaches with new methodologies [14-18].

On the other hand, the most recent articles, represented by the leaves of the tree, show a change in focus towards emerging topics such as sustainability and industry 4.0. These works explore how SC risk management relates to environmental, social, and economic sustainability. [19-21]. It discusses how digitalization, technology, artificial intelligence, and the Internet of Things, are transforming risk management in the industry. [22-24]. There is growing interest in the application of these concepts in specific sectors, such as health, food and automotive, with the aim of improving the efficiency, resilience, and sustainability of supply chains.

The examination of keyword co-occurrence in the articles was conducted using the VOSviewer software, employing the technique of visualization of similarities clusterization for bibliometric mapping. Throughout the analysis, a minimum threshold of five keyword occurrences was established, following the default value within the software. The outcome revealed a total of 41 keywords and provided a detailed temporal description, corroborating that in recent years, research related to resilience in the SC has begun to be investigated (Figure 1).

Management of resilience in the SC has evolved considerably over time. Initially, it focused on reactive strategies and recovery measures after disruptive events. However, this perspective has broadened its focus to include proactive elements such as adaptation and anticipation. In more recent developments, the conceptual framework has expanded further, encompassing not only prevention and impact minimization strategies, but also a greater emphasis on continuous learning and continuous improvement. This evolution reflects a dynamic response to changing SC challenges, promoting a comprehensive and forward-looking approach to resilience management.

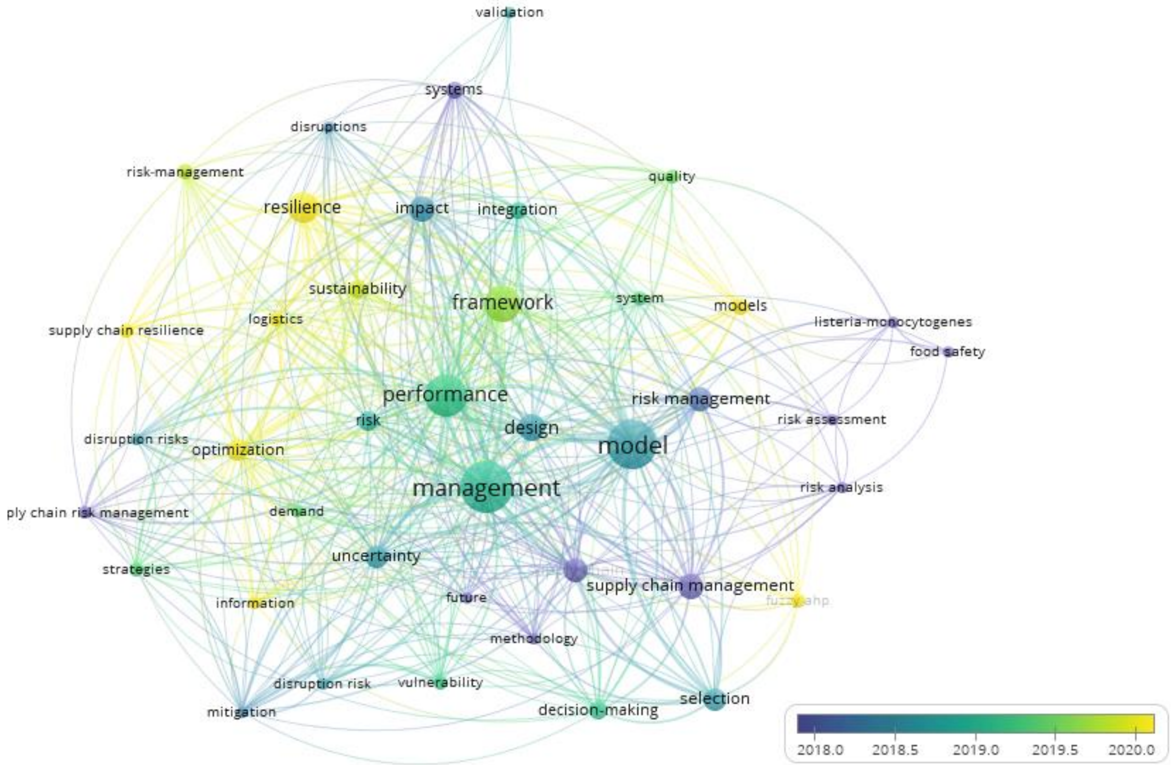

Figure 1: Co-occurrences analysis - VOSviewer software

3. Results and Discussion

Pressure on margins has led to a lot of organizations going for low-cost solutions. This may have resulted in leaner but much more fragile supply chains. Resilient SC, though not being the cheapest, are able to face contingencies in the business milieu.

Sheffi [25] suggests that resilience plays a crucial role in business competence by promoting an organizational culture, systems and processes that facilitate rapid and effective detection and response to disruptive crises.

Several authors have in common that the ability to recover from a disturbance is closely related to response capabilities through flexibility and redundancy. While robustness, some claim that it is a special case of resilience since it implies the return of the system to the original state after a disturbance occurs [26].

Sheffi [27] more precisely details the different phases of a SC crisis and its impact on performance as a function of time (Figure 2).

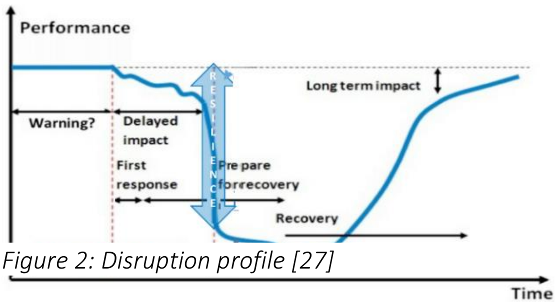

Figure 2: Disruption profile [27]

3.1. Quantitative methods of SCR

The review of the literature shows the lack of complete clarity in the internal and external

variables that can affect the resilience of the supply chain. Consistent with this are models that do not comprehensively present a set of quantitative metrics with the goal of addressing SC resilience, but instead present models that contain what we can now infer as resilience concerns.
As an illustration of this diversity of approaches, we will present representative indicators found in the literature that seek to measure resilience from different perspectives.
Cecere and Mayer [28] suggest that the resilience factor in a company is determined by the proximity between two key financial metrics: operating margin and inventory turns. Companies whose values on these metrics are closer to each other are assumed to demonstrate greater resilience compared to those whose values are further apart. In practical terms, this means that companies that manage to maintain a strong operating margin while maintaining high inventory turns have a greater ability to adapt and recover from shocks or changes in the business environment. Therefore, if the distance between these two metrics is smaller, the company is considered to have greater resilience.
To develop the values, a representation of the dispersion between the operating margin and inventory turnover was made. Where *ij* is calculated with the Euclidean distance between pairs of points *i* and *j*, and m is the total number of pairs. In equation 1, *R* measures the firm's resilience factor, defined as the average distance of all possible pairs of points at the intersection.

$$R = \frac{1}{m} \sum_i \sum_{j>i} d_{ij} \quad (1)$$

Torabi et al. [29] proposed a resilience metric based on absorptive capacity (through inventory prepositioning), adaptive capacity (through the existence of backup suppliers), and restorative capacity (through recovery of disrupted suppliers). Let's assume that the amount of lost capacity recovered by inventory prepositioning, backup supplier, and restoration of disrupted supplier is denoted by *A, B*, and *C*, respectively, and that LT_A LT_B and LT_C denote the time of receiving items associated with the *A, B*, and *C* resilience strategy. The loss of resilience can be mathematically calculated by equation 2. A lower value of *RE* results in higher supply resilience.

$$RE = A \times LT_A + B \times LT_B + C \times LT_C \quad (2)$$

Ojha et al. [30] developed a metric to quantify the resilience as a measure of service loss in the aftermath of disruption. Let's assume that SL_{kw} and SL_{k0} represent the service level of node *k* in week *w*, and service level of node *k* when there is no disruption. Suppose there are n nodes (suppliers) in the supply network, and the resilience index of node *n* denoted by RI_k is measured by equation 3.:

$$RI_k = 1 - \frac{\sum_{w=w_0}^{w_n}\left(1-\frac{SL_{kw}}{SL_{k0}}\right)}{(w_n - w_0)} \quad (3)$$

Garrido Acevedo et al. [31] proposes an index with the objective of quantifying the level of resilience behavior B_R of a company *j* of SC. To do this, he considers different variables and suggests that these should be weighted based on the experts' criteria. As shown in equation 4.

$$(B_R)_j = \sum\left(w_{Ri} \times (P_R)_j\right) \quad (4)$$

P_{R1}= sourcing strategies to allow switching suppliers
P_{R2}= flexible sourcing
P_{R3}= strategic stock
P_{R4}= lead time reduction
P_{R5}= creating total SC visibility
P_{R6}= flexible transportation

In this case, the calculation of the value of resilience does not depend on economic indicators but on operational strategies that are evaluated from 1 to 5 on a Liker scale.
Wang [32] the resilience of a logistic network can be defined as the weighted sum of all demand nodes. The weight of a node can be defined as the percentage of its demand to the total demand. For a demand node *i,* its weight w_i is defined as:

$$w_i = \frac{d_i}{\sum_{l=1}^{n1} d_i} \quad (5)$$

Let the resilience index of the logistic network is calculated by following formula:

$$R = \sum_{i=1}^{n1} w_i r_i \quad (6)$$

where is the node resilience calculated depending on the network structure.

$$r_i = \frac{\sum_{j=1}^{q} p_j \left[1-\prod_{l=1}^{h}\left(1-q_{(j,i)}^{l}\right)\right] min\left\{d_i, s_j \sum_{l=1}^{h} c_{(j,i)}^{l}\right\}}{d_i} \quad (7)$$

$n=n_1+n_2$ total number of 2 kinds of nodes.
$m=|E|$ number of edges in the set *E.*
di, i = 1, 2,…,n1 demand of node *i ϵ D.*
sj, j = 1, 2,…,n2 available supply of node *j ϵ S*
pj, j = 1, 2,…,n2 supply reliability of node *j ϵ S.*
ck, k = 1, 2,…,m flow capacity of edge *k ϵ E.*
qk, k = 1, 2,…,m reliability of edge *k ϵ E.*

Carvalho et al. [33] classify the economic performance indicators associated with resilience and agility into six categories: (1) cost, (2) economic value added (EVA), (3) net operating profit, (4) return on assets, (5) cash cycle and (6) expense efficiency.
Zavala et al. [34] state that a low resilience capacity affects both operations, finances and sales, deteriorating levels of service quality, inventory performance and gross margin, and that together they lead to a high capital consumption that can lead to financial chaos, destroying the return on investment (ROI), so a series of both financial and non-financial metrics must be implemented that constantly monitor the evolution of investments, with special focus on spending in operations and inventory buffers.

3.2. Modeling approaches of SCR

Authors pursue various approaches in constructing quantitative models, with much consideration given to their objectives regarding the scope, depth, and application of the model.
Table 1 shows a summary of the main modeling approaches.

Table 1: Modeling approaches of Supply Chain Resilience

Modeling approaches		References
Graph theory	Complex network analysis methods, such as graph theory, are used to identify critical nodes and evaluate network connectivity and robustness. These models incorporate centrality and flow measures to determine the propagation of the disturbance, considering the structure of network, redundancy of nodes and alternative routes that exist in case of interruption.	[35]
Bayesian network	BNs capture dependencies between suppliers and manufacturers, especially in scenarios where supplier failure affects manufacturing. They excel at analyzing the domino effect of disruptions in complex supply networks and analyzing forward and backward propagation, updating the probabilities of unobserved variables based on observations of disruptions.	[15], [30]
Game theory	These consider the strategic interaction between CS actors and how this influences resilience. It can model conflict and cooperation situations and analyze how the strategic decisions of each actor affect the overall performance of the SC. Nash equilibrium models can identify optimal strategies to maximize the joint benefit of all participants while minimizing risks and vulnerabilities.	[36], [37]
Markov chain modeling	It allows analyzing how the transition probabilities between different chain states evolve in response to disturbances over time. By considering various sources of uncertainty and disruptive events, such as delivery delays or raw material shortages, this approach provides information to identify vulnerabilities and design strategies to mitigate risks.	[38]
Structural equations	It allows resilience to be modeled and evaluated by considering the causal relationships between key variables.	[39]
Multi-criteria decision-making	MCDM methods, such as TOPSIS, AHP, ANP, ELECTRE, VIKOR allow identifying key resilience criteria, selecting appropriate strategies, assessing risks and vulnerabilities, and optimizing resilience by considering multiple objectives and constraints.	[12], [40], [41]
Optimization models	These models focus on allocating resources efficiently and effectively. For example, they can optimize the location of facilities, establish optimal inventory levels, and design alternative transportation routes to ensure continuity of operations and reduce vulnerability.	[42]
Bi-objective stochastic programming	Addresses problems that have two conflicting objectives and where there are uncertainties in the decision variables due to random factors.	[43]
Simulation models	It captures the complex dynamics of the SC and create disruption scenarios and assess the impact on operational performance.	[44], [45]
Risk analysis models	Risk analysis techniques, such as failure and effects analysis (FMEA), fault tree analysis (FTA), and scenario-based risk analysis (SRA), to identify adverse events and their potential consequences.	[46]
Hybrid approaches using digital technologies	These methods integrate real-time data, predictive analytics, and simulation tools to improve SC responsiveness and adaptability to disruptions. For example, combining optimization models with cloud based SCM systems allows for more agile and flexible planning, while the use of IoT sensors and big data analytics enables continuous monitoring and early detection of problems. A digital twin represents the physical SC with real data in real time. Simulation on the digital twin can show the propagation of the outage, quantify its impact and test recovery and adaptation policies according to the situation.	[47], [48]

3.3. Resilient practices in the SC context

Among the main practices that we can find related to improving resilience in the SC are [4], [5], [7], [9], [18]:

Resilient practices developed upstream:

- Diversify suppliers and sources of supply to reduce dependence on a single source.
- Establish solid communication and collaboration relationships with suppliers and other business partners.
- Establish robust supplier performance metrics and monitoring mechanisms to assess supplier reliability, quality, and responsiveness.
- Implement interconnected technologies and automated systems that improve visibility, efficiency, and rapid response to interruptions.
- Maintain adequate and strategically located inventories. Having a clear view of upstream inventories and supply conditions.

Resilient practices implemented optionally:

- Design processes that can quickly adapt to changes in demand, or external conditions.
- Desing production systems to accommodate multiple products and real-time changes.
- Have a versatile workforce and reserve capacity.
- Produce minimum batch sizes.
- Minimize setups times and product changeovers.
- Reduce development cycle time.
- Have a strategic provision of additional capacity and/or inventory in possible "hot spots".
- Adopt a culture of continuous improvement to identify and address inefficiencies in internal processes. This involves regular monitoring, evaluation, and optimization of workflows and procedures.
- Develop contingency plans and response protocols for various scenarios, such as natural disasters, geopolitical events, or supplier failures, to ensure rapid and effective response during crises.
- Establish clear and efficient communication channels within the organization to disseminate critical information, updates and instructions during emergencies or disruptions.
- Invest in advanced technologies and digital tools to automate processes, improve operational efficiency, and improve responsiveness to changing conditions or disruptions.
- Implement systems and technologies for real-time monitoring and visibility across the SC to detect early warning signs of potential disruptions and enable timely interventions.

Resilient practices developed downstream:

- Ensure compliance with relevant regulations, standards, and industry best practices to minimize legal and regulatory risks that could disrupt SC operations.
- Create visibility to have a clear view of production and purchasing schedules.
- Maintain a flexible transit fleet.
- Silently transfer product.
- Have demand-based management.
- Increase the speed in the levels of product customization and introduction of new products to the market.

3.4. Research gaps and future directions

The COVID-19 pandemic has exposed vulnerabilities in global supply chains, highlighting the need for resilience in economic, industrial, and health systems. To mitigate systemic collapse, strategies include designing resilient systems, quantifying resilience, managing system complexity, adding redundancies, and developing real-time decision support tools. Adopting a resilience mindset is crucial, as unforeseen shocks can lead to rapid system degradation and collapse. The pandemic disrupted supply chains worldwide, exacerbating economic challenges and revealing weaknesses in demand, supply, transport, logistics, regulation, and information dissemination.

Based on the literature review conducted, it can be concluded that the scientific field of SCR is experiencing significant progress. However, further research is still required and should focus on several key directions, as discussed below.

Most studies focus on short-term resilience. Additional research is needed on how to improve long-term resilience, considering the adaptability and transformational capacity of the SC in the face of structural changes and long-term trends.

Although some incipient studies have been conducted, research is needed to investigate how emerging technologies, such as artificial intelligence, the Internet of Things and cloud computing, can be leveraged to improve resilience in the SC by improving visibility, automated decision making and real-time risk management.

It is crucial to investigate how to improve collaboration and coordination between different SC actors to strengthen resilience, including developing information sharing mechanisms, building support networks, and promoting trust and transparency between partners.

There is a need to integrate holistic approaches that address resilience from a multidimensional perspective, considering not only operational aspects, but also social, environmental, and economic factors.

The interplay between resilience and sustainability within SCM presents a complex paradox with both

conflicting and symbiotic elements. On one hand, strategies aimed at enhancing resilience, such as implementing flexible SC designs and redundant operations, can lead to increased resource consumption and higher inventory levels. This contradicts the fundamental principle of sustainability, which advocates for the efficient use of available resources.
International tools and compulsory standards are crucial in resilient supply chains. The ISO 28000 standard provides a framework for supply chain security management, while the ISO 31000 standard addresses risk management across various organizational areas. ISO 31000, applicable to a wide range of risks including financial, operational, and environmental, facilitates informed decision-making and continuous improvement.

4. Conclusion

This article highlights the critical importance of resilience in an increasingly complex and dynamic business environment. Throughout the research, various techniques, and approaches to assess and improve resilience in supply chains are explored, ranging from indicators, optimization models to simulation and decision analysis. The need to consider multiple criteria and integrated approaches to address emerging challenges and disruptions in supply chains is highlighted. In addition, research gaps and areas for future development are identified, such as the integration of emerging digital technologies, long-term assessment of resilience, and interorganizational collaboration. As well as the importance of considering the empathy and conflict relationships that exist between achieving a resilient supply chain and a sustainable supply chain. Ultimately, this article provides a solid foundation for future research and practice in the field of supply chain resilience, highlighting the importance of taking a holistic and proactive approach to addressing challenges and risks in an increasingly volatile business environment.

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Participating Institutions

Otto von Guericke University Magdeburg

The Otto von Guericke University (OVGU) was founded in 1993 from three institutions of higher education:

- the Technical University Magdeburg,
- the Teacher Training College and
- the Medical Academy of Magdeburg.

It is named after the famous scientist Otto von Guericke (1602-1686), whose research on the vacuum, especially his hemispheres experiment, earned him fame beyond German borders.

Some facts & figures:

- 9 Faculties (Logistics is part of Mechanical Engineering)
- More than 100 academic programs
- About 12 500 students
- About 4000 of them are international students
- Double degree in Logistics with Free University Bozen (Italy) & Chiang Mai University (Thailand)
- Career-integrated study programme options
- More and more English-language study programmes and modules.

The OVGU has 65 years of experience in training and research in the fields of conveying technologies, logistics and material handling systems. It initiates also many modern topics such as AI engineering and mobility topics and autonomous driving.

Research areas are:

- Analysis, diagnosis, modelling, simulation& design in logistics and SCM
- Fundamentals of technical logistics
- Design and improvement of process chains (1PL to 4PL)
- Planning methods and tools in logistics
- Mobility topics and sustainability
- Evaluation, planning and design of logistics networks
- Industry 4.0 and Logistics 4.0
- Further education, business games and in-house training in Logistics & SCM
- Application of artificial intelligence (AI) in production and logistics.

www.ilm.ovgu.de

Photo: Jana Dünnhaupt

Universidad Central “Marta Abreu” de Las Villas

The Universidad Central »Marta Abreu« de Las Villas (UCLV) was founded in 1948 in Santa Clara. Approximately 11000 students are enrolled at the university, which consists of 12 faculties. The green, spacious campus is located on the outskirts and makes up its own small student town that could be reached by car, bus or train. UCLV is the third-biggest university of Cuba. It has ranked on top places in all national evaluations of the quality of teaching and research. UCLV is part of several national and international research networks and has scientific cooperation with 130 institutions around the world. Intensive collaboration with the OVGU in Magdeburg focuses on the departments of manufacturing, engineering and quality management, mechanics, construction, computer science, automotive technology, process and environmental technologies and especially logistics and material handling systems.
In 2016, the university immersed in an integration process where industrial engineering and mechanical engineering came together in a single faculty named Faculty of Mechanical and Industrial Engineering.
Out of the 90 faculty members, 60% hold a Doctorate in a specific science, and 70% have attained a higher teaching rank. The faculty has two teaching departments (Mechanical Engineering and Industrial Engineering), two Study Centers (Center for Energy Studies and Environmental Technologies, Welding Research Center).

The most important fields of research within the Department of Mechanical Engineering related to logistics and material handling systems are:

- Technical logistics,
- Quality management, quality engineering, metrology, measurement uncertainty
- Manufacturing (manufacturing engineering and welding technology),
- Environmental technology.

Furthermore, researches conducted in the fields of biomechanics, mechatronics, development and construction. The central fields of research pertaining to logistics and material handling systems at the Department of Industrial Engineering are:
Quality management, quality engineering, Mathematical statistics, operations research, design of experiments, statistical simulation, Reliability and safety, Logistical networks.

www.uclv.edu.cu

Photo: Norge Coello Machado

National Aerospace University “KhAI”

National Aerospace University, Kharkiv, Ukraine (KhAI) was established in 1930. Its history is closely connected with the development of aircraft engineering and science. The University is well-known for its achievements in aviation industry, namely for the creation of the first European high-speed airplane with a retractable landing gear and the design of the turbojet engine. At present about 9.500 students and 160 post-graduate students are trained at the University; 650 teachers and 2.500 employers work here. Among them there are 120 Professors and PhD. This makes KhAI one of the leading institutions of higher education in that trains specialists for aerospace industry in Ukraine and abroad. During the period of its existence the University has trained about 80000 engineers. More than 80 % of the experts with higher education who work in Ukrainian aerospace area are the graduates of the NAU KhAI.

The NAU KhAI is a member of International Association of Universities, EASN, PEGASUS organizations as well as is a signatory of Magna Charta Universitatum. Together with European partners it received the highest number in Ukraine of scientific and educational grants TEMPUS FP-7 and the European Union. The NAU KhAI is a co-executor of many scientific and educational programs which are carried out with universities and companies of EU, Mexico, China.

In 1994 KhAI signed a partnership agreement with OVGU, thus setting new joint educational and research tasks in aircraft design, composite component design, technologies for rapid processing of steel structures etc.

National Aerospace University is persistent in raising its bar, being always ready to welcome and support students and young researchers from all over the world.

https://khai.edu/en/university/

University of Miskolc

The history of the University of Miskolc refers to Mining and Metallurgy back in 1735. Since those times, the organization of the University changed and was extended several times with new faculties, now being named since 1990 the University of Miskolc. While technical education has the longest tradition at the University of Miskolc, during the recent decades the institution was transformed into a true university. Currently it has eight distinct faculties. At present, faculties have more than 9000 students, who are assisted in their academic advancement by an educational staff of more than 550 and a non-educational staff of more than 650 members.

On most faculties, B.Sc. and M.Sc. programs are both offered for the students. The University of Miskolc started Ph.D. programs on the basis of accredited doctoral programs on October 1, 1993. Currently six Faculties of the University offer doctoral programs and award Ph.D. degrees in seven disciplines: Earth Science, Materials Science and Technologies, Engineering Science, Information Science, Law, Economics and Management Science, Literary Studies.

The University of Miskolc is the largest higher education institution in Northern Hungary. With its highly qualified experts, instrument infrastructure and laboratories, it contributes to scientific research and technical development in Hungary.

The Institute of Logistics is part of the Faculty of Mechanical Engineering and Informatics. The Institute has a wide range of educational activities at 3 Faculties of the University of Miskolc in the frame of full time and part time trainings. The focus of research activities of the institute lies in the following fields:

- Design of materials handling machines,
- Controlling and planning methods for modular materials handling systems,
- Computer integrated logistics, information logistics,
- Production and service logistics,
- Warehouse logistics, stock management,

- Design of materials handling machines,
- Controlling and planning methods for modular materials handling systems,
- Computer integrated logistics, information logistics,
- Production and service logistics,
- Warehouse logistics, stock management,

www.uni-miskolc.hu

Photo: Uni Miskolc

Anhalt University of Applied Sciences

Innovation, cosmopolitanism, creativity and culture are traditions of the Anhalt region to which the Anhalt University of Applied Sciences with its three campuses in Bernburg, Dessau and Köthen and its seven departments feels particularly committed. Therefore, since its foundation in 1991 the university feels responsible for making a significant contribution to the economic and social development of the region and the state of Saxony-Anhalt through its practice-oriented education and applied research. The bachelor's and master's degree programs at the various departments have one thing in common - in addition to imparting specialist knowledge, they prepare the 8.000 students of the Anhalt University of Applied Sciences, from whom 2.000 have an international background, for a successful start to their careers.
In May 2021, the extension of the right to award doctorates to universities of applied sciences in Saxony-Anhalt gave rise to the "Social, Health and Economic Sciences" doctoral center at Anhalt University of Applied Sciences, which is a collaborative effort between Anhalt University of Applied Sciences and three other universities in the state.
The Chair of Business Administration, in particular Supply Chain Management, Operations Management and Digitization, situated at the Department of Economics at Anhalt University of Applied Sciences and headed by Prof. Dr.-Ing. Trojahn, deals with current developments along entire supply networks with regard to various thematic research focuses such as:

- Supply Chain Network Design, Planning & Operations
- Operations Research
- Process Optimization
- Digitalization and Logistics 4.0
- Resilience
- Sustainability

www.hs-anhalt.de

Photo: Hochschule Anhalt

Magdeburg-Stendal University of Applied Sciences (h2)

Since the Magdeburg-Stendal University of Applied Sciences was founded in 1991, it has earned an excellent reputation for a well-founded academic education and for a committed student body. Prospective students can choose from around 50 courses at three departments in Magdeburg and two departments at the Stendal site. Around 130 professors guarantee a very good supervision rate for around 3,700 students in Magdeburg and more than 1,800 in Stendal.

The research profile at the Magdeburg-Stendal University of Applied Sciences is characterized by future-oriented research and development activities tailored towards key markets in the state of Saxony-Anhalt and the requirements of regional businesses and institutions. To this end a large number of innovative research and development projects in the fields of engineering, economics, public health, communications and the social sciences is implemented. By concentrating specific skills in a number of competence centers it is possible to take a holistic, cross-disciplinary approach to research themes.

At the Magdeburg-Stendal University of Applied Sciences there are a total of 9 main research areas, from electrical engineering and information technology, innovative technologies, machines and components to water and recycling management. In the concrete field of application of the economy, the focus is on the following research topics:

- Management in the fields of public health, service provision, and demographics
- Entrepreneurship and risk management
- Production and process management and simulation
- Logistics and Digitalization
- Technology and investment management
- Marketing, especially for regional enterprises, institutions, and networks
- Change and sustainability management

Staff development and inter-cultural competence

Since 2022, the Magdeburg-Stendal University of Applied Sciences has made it possible to do a PhD in the cross-university doctoral center "Social, Health and Economic Sciences" in association with the universities of applied science of Anhalt (HSA), Harz and Merseburg and in the university's own doctoral center "Environment and Technology". Already in the first phase of the acceptance applications, four doctoral projects in the context of logistics and under the supervision of Prof. Behrendt (h2) and Prof. Trojahn (HSA) were approved.

https://www.h2.de/home.html

Photo: Hochschule Mageburg-Stendal

Merseburg University of Applied Sciences

Study. Research. Live. – This is far more than just the motto of Merseburg University of Applied Sciences. As a center for applied sciences located in the south of Saxony-Anhalt in an industrial and cultural region, steeped in tradition, the university offers everything necessary to guarantee that students can enjoy success in their studies on a vibrant, green campus.

With approximately 3,000 students, Merseburg University of Applied Sciences (HoMe) is one of the smaller universities in the federal state of Saxony-Anhalt. This creates a friendly atmosphere on campus, conducive to studying as well as personal and uncomplicated support from the professors - you can easily approach them and ask for help. In addition to this, the International Office and the Registrar's Office provide help and support for international students.

Merseburg University of Applied Sciences offers students a wide range of bachelor and master programs, run by three departments:

- Department of Engineering and Natural Sciences
- Department of Social Work.Media.Culture
- Department of Business Administration and Information Sciences

At HoMe students can study in modern lecture halls, in small working groups and in practice-oriented projects. Here we place great importance on independent, team oriented and problem-solving work. The technical equipment of our laboratories, workshops and practical training rooms is state-of-the-art, thus providing students with an excellent education.

So, benefit from the pleasant studying and learning atmosphere on our green campus and become part of the HoMe!

https://www.hs-merseburg.de/

Photo: Hochschule Merseburg

Université Le Havre Normandie (ULHN)

Université Le Havre Normandie (ULHN) was established in 1984 and it now counts over 8200 students. It is committed to supporting personal and professional development of all its students.

The ULHN is composed of three Training and Research Units –Teaching and Research Unit of Sciences and Technology, Faculty of International Affairs, Teaching and Research Unit of Arts and Humanities – of a University Institute of Technology, an Engineering School, a Higher Institute of Logistic and different departments.

The training focuses on four main thematic areas: Arts, Literatures and Languages; Law, Economics, Management; Humanities and Social Sciences; Sciences, Technology, Health. In order to prepare professional integration of students and to promote their mobility in Europe, it is based on three main guidelines: professionalization, international openness, multidisciplinary.

The scientific potential of the University is based on eleven research laboratories, two of which are associated to CNRS and one to INERIS. Research has been articulated around 4 sectors: Human and social studies; chemistry – biology; Mathematics – information technology; Engineering Science. Some works are also carried out around interdisciplinary areas. These research activities nourish and enrich teaching.

The ULHN was born out of the determination of all the local actors and it was built in harmony with the development of a port city, open to the world, attentive to its socio-economic environment and to public expectations.

https://www.univ-lehavre.fr/en/

Photo: Université Le Havre Normandie

News and dates

Academic honours:

Prof Béla Illés (University of Miskolc) was appointed by the Universidad Central Marta Abreu de Las Villas (Cuba) in November 2023 with the honorary title of

Dr. h.c. in Technical Sciences

honoured.

Prof Béla Illés (University of Miskolc) was appointed in April 2024 by the Otto von Guericke University Magdeburg (Germany) with the

Otto von Guericke Plaque

honoured.

Photo: Gábor Nagy

Photo: Elke Glistau

New degree programmes, doctoral schools and professional associations:

Since 2023: New joint degree programme at OVGU and the universities in Saxony-Anhalt:
AI Engineering = Künstliche Intelligenz in den Ingenieurwissenschaften (in German language)
Bachelor's degree programme, 7 semesters, common foundations, followed by a choice of 5 specialisations:
(1) Agricultural Science and Technology, (2) Biomechanics and Smart Health Technologies,
(3) Manufacturing, Prodution and Logistics, (4) Green Engineering and (5) Mobile Systems and Telematics.
For more information: https://ai-engineer.de/wp/

Since 2021: Doctoral Centre 'Social, Health and Economic Sciences.
Universities of Applied Sciences Anhalt, Magdeburg, Merseburg and Harz; Academic title: Dr rer. pol.
Contact: dirk.sackmann@hs-merseburg.de & sebastian.trojahn@hs-anhalt.de & fabian.behrendt@h2.de

Bundesvereinigung Logistik, Regionalgruppe Sachsen-Anhalt:
Speakers: Prof. Dr.-Ing. Fabian Behrendt & Prof. Dr.-Ing. Sebastian Trojahn
For more information: https://www.bvl.de/anhalt

Academic dates in 2025:

Germany:

Every Thursday from
10. April 2025 to July 2025, from 5 to 6:30 p.m. **Guest lecture series "logistics"** (via Zoom, in German language)
For more information: https://www.gvrlog.ovgu.de/

Monday & Tuesday
16. & 17. June 2025 18th International Doctoral Workshop Logistics, Supply Chain and Production Management, For more information: sebastian.trojahn@hs-anhalt.de

Cuba:

From Monday to Friday
13.- 17. October 2025 COMEC 2025 (International **Co**nference of **Mec**hanical Engineering, with a special session "Logistics")
For more information: norge.coello@ovgu.de & andre.katterfeld@ovgu.de

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