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EMBOK 5.0 - Industry 4.0/5.0 Manifest and Latent Dimensions Mapping to the ASEM EMBOK

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EMBOK 5.0 – INDUSTRY 4.0/5.0 MANIFEST AND LATENT DIMENSIONS MAPPING TO THE ASEM EMBOK

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Abstract

Industry 3.0 automation emerged replacing human labor with high volume processes and robotics. Industry 4.0, cyber-physical systems, and Industry 5.0, mass customization and cognitive systems, are in the early stages of emergence. Research into the impact of Industry 4.0 and 5.0 is focused at the strategic or organizational levels or on the technological challenges. Research into the impact of Industry 4.0 and 5.0 on engineering management has been limited to their impact on project management. This leaves open the question of the directions in which ASEM should evolve the Engineering Management Body of Knowledge (EMBOK) under the emergence of Industry 4.0 and 5.0. This paper reports an initial mapping of Industry 4.0 and 5.0 onto future EMBOK cyber-technical-socio engineering management systems. The research method began with the Boston Consulting Group nine technologies of Industry 4.0 (2015) and added the Industry 5.0 technologies of cobots, smart machines, block chain, virtualization, hyper-intelligent networking, genetic engineering, and quantum computing as the initial conceptual framework. Key word searches were performed, and a corpus of journal articles was assembled within each technology. Content analysis was performed on the corpora to identify manifest and latent cyber-technical-socio dimensions. The manifest and latent dimensions were mapped to the domains of the ASEM EMBOK. The mappings provide the basis of a proposed theoretical framework for researching revisions to the ASEM EMBOK, which is termed EMBOK 5.0.

Keywords

EMBOK, Industry 4.0, Industry 5.0, Cyber-Technical-Socio Systems.

Introduction

While some of the nine Industry 4.0 technologies (Boston Consulting Group, 2015) have evolved out of Industry 3.0 automation (additive manufacturing, data analytics, robots, simulation, the Internet, and cybersecurity), others such as augmented reality, cloud computing, and massive horizontal and vertical system integration are more recent innovations. To assist its industries with digitalization, the German government presented its future high-technology strategy at Hannover Messe in 2006 and established an advisory working group to develop innovation policy. The working group presented its Industry 4.0 innovation policy proposal at the Hannover Fair in 2011 as a roadmap for German manufacturing to remain competitive in the future global marketplace. Industry 4.0 was adopted by the German government with a focus on development of new business models based on cyber-physical systems. Industry 4.0 business models achieve competitive advantage through individualized product customization, inclusion of customers and stakeholders in value creation from design to use, and horizontal-vertical integration of the production and delivery of smart products and services.

Two significant events occurred in 2017 initiating the parallel development of Industry 5.0. Society 5.0 emerged from a Japanese government program launched in 2013 to revitalize its economy through evolution of smart human-centered society. The program was revised annually until 2017 when it was formally released as Society 5.0. In parallel, the United Nations General Assembly established Sustainable Development Goals in 2015 with objectives of building resilient infrastructure, promoting sustainable industrialization, and fostering innovation. In 2017, the United Nations altered its Charter of Corporate Behavior to drive implementation of its Sustainable Development Goals proactively through integration with Society 5.0. From 2017 to 2021, there were dispersed academic research initiatives into the structure and implementation of what was then termed the Fifth Industrial Revolution. The European Commission held virtual workshop discussion among its funding agencies, research organizations, and technology providers from July 2 to 9, 2020. Out of these workshops, the European Commission developed and released the document *Industry 5.0: Towards a Sustainable, Human-centric, and Resilient European Industry* in January 2021. United States investment into Industry 4.0 cyber-physical systems has been more dispersed. In 2021, the White House announced $1 billion funding to establish twelve research and development hubs for artificial intelligence and quantum information. Funding is scheduled to be distributed through the National Science Foundation and the Department of Energy over a five-year period. In 2023, the White House budgeted $210 billion for federal research and development into STEM innovation. Individual US companies and initiatives provide targeted investments in Industry 4.0 and 5.0 technologies.

Despite governmental initiatives and investments into Industry 4.0/5.0 research, multiple studies (Paschek, Mocan, and Draghici, 2019; Yu, Mostafa, Rahayu, and Liu, 2019; Tyagi and Sreenath, 2021; Adel, A., 2022) note that most organizations have struggled and continue to struggle with Industry 4.0 digitalization of their business operations and implementation of Industry 5.0 human-centric, resilience, and sustainability initiatives. This paper reports the first in a series of ongoing research initiatives to define and re-define emerging manifest and latent impacts of Industry 4.0/50 cyber-technical-socio systems on the Engineering Management Body of Knowledge (EMBOK) knowledge domains and propose ongoing revisions to the EMBOK domains with a goal of assisting organizations with Industry 4.0/5.0 digitalization.

Content Analysis Methodology

The problem-driven content analysis methodology (Crowley and Delfico, 1996; Neudndorf, 2002; Krippendorff, 2004) was applied with the following modifications to strengthen validity and reliability of observed manifest and discovered latent dimensions of Industry 4.0/5.0 digitalization.

Research Questions.
Q1: What are the manifest and latent dimensions of Industry 4.0/5.0 technologies digitalization?
Q2: How do the manifest and latent thematic dimensions map to the Engineering Management Body of Knowledge?
Q3: How must the Engineering Management Body of Knowledge be revised to assist academia, industry, the service sector, government, and military digitalization to achieve the benefits of Industry 4.0/5.0 technologies.

Conceptualization and locating relevant articles.

- Factors used to guide the study – identified Industry 4.0 and Industry 5.0 technologies. Search terms included Industry 4.0 + additive manufacturing, augmented reality, autonomous robots, cloud computing, cybersecurity, data analytics, horizontal and vertical integration, Internet of things, simulation and Industry 5.0 + cobots, smart machines, block chain, virtualization, hyper-intelligent networking, genetic engineering, and quantum computing since 2017 to account for the effects of Industry 5.0 introduction on Industry 4.0 technologies development..
- Systematic literature review searches were conducted via a university database that accessed 442 databases including EBSCO, JSTOR, Sage Journals, Science Direct, and Scopus with parallel searches in Google Scholar. Only peer reviewed scholarly or professional society articles or U.S. government publications were admitted. During the search additional articles discussing broader Industry 4.0 or Industry 5.0 implementation issues were identified. To address these articles, additional corpora were created for Industry 4.0 Management and Industry 5.0 Management based on search terms Industry 4.0 + and Industry 5.0 + benefits, challenges, governance, implementation, management, oversight. Article inclusion criteria included: (1) Articles discussing implementation of only each Industry 4.0 or Industry 5.0 technology for the individual technology corpus. (2) Articles discussing implementation of multiple Industry 4.0 or Industry 5.0 technologies (greater than three) or discussing broader cyber, technical, or organizational/social implementation issues. Article exclusion criteria were articles published before 2017 to reflect the introduction of Industry 5.0 effects on Industry 4.0 research and articles not directly related to implementation or management of Industry 4.0 or Industry 5.0 technologies. The criterion of saturation (Bowen, 2008) was applied to terminate article admission. Admission was terminated when no new article titles were returned for each search Industry 4.0 + or Industry 5.0 + combination of terms. As is the practice of some content analysts, this systematic literature review did not acquire articles listed in references of admitted articles because of the potential for introduction of thematic bias relative to original admission-exclusion criteria.

Unit of analysis – modification using text mining as an independent second coder. During the systematic literature review search, the coder's identified themes were used as sampling units.

Text mining (Elder, Miner, and Nisbet, 2012), using the R package tm, was applied to each corpus (text files each of title, abstract, keywords, and body of text) to independently group factors and dimensions into broader themes and to identify the relevant number of latent dimensions. Text mining was used as a second independent analyst to mitigate any potential bias in the single coder's identified themes increasing validity and to provide reliability due to the lack of multiple coders.

Thematic coding – Systematic literature review themes and text mining themes and latent dimensions were recoded into thematic units for content analysis.

Thematic content analysis – R packages quanteda and topicmodels were used to perform content analysis of each Industry 4.0 and Industry 5.0 corpus based on the recoded thematic units into topic-specific dictionaries. Thematic units were assigned to dictionary concept categories and thematic words with synonyms were coded to the concept categories.

Industry 4.0/5.0 Manifest and Latent Dimensions

This paper provides a preliminary report to the ASEM community addressing research questions *Q1* and *Q2* for the Industry 4.0 Management and Industry 5.0 Management corpora. The Industry Management 4.0 corpus consists of 28 articles, and the Industry 5.0 Management corpus consists of 21 articles. At the time of preparation of this paper, the remaining Industry 4.0 and 5.0 technologies corpora consists of 140 articles, which were beyond the capability of the single analyst to read and code in time for the 2023 ASEM IAC

Exhibit 1 and 2 summarize re-coding of Industry 4.0 and 5.0 systematic literature review themes and text mining themes and latent dimensions into thematic concept/word-synonym dictionary units for content analysis. Topic content analysis of the Industry 4.0 management corpus using the assigned dictionary terms supplemented with term synonyms was performed in R using the quanteda, topicmodels, and ldatunning packages. The boxplot in Exhibit 3 indicates that the "production" theme dominates Industry 4.0 research followed by the "cyber" theme. Themes "physical," "economic," and "system" received approximately equal low research consideration followed by the "measurement" theme. Principal components analysis of these themes indicated that the first two latent dimensions explain 87.2% of the information variation. The principal components scree plot in Exhibit 4 support the mapping to the first two latent dimensions.

Exhibit 1. Re-coding of Industry 4.0 Themes for Dictionary-based Content Analysis.

Systematic Literature Review	Text Mining	Dictionary Concept-Word Assignments
cyber-physical systems integration IoT smart factories cloud computing economics big data analytics digitalization technologies additive mfg autonomous robots interoperability simulation standards augmented reality	production manufacturing technology systems data integration industrial product cyber-technical digitalization information management system	production < additive, data, commodity, fabrication, factory, factories, horizontal, industry, industries, industrial, integration, manufacture, manufacturing, product, production, technical, technology, vertical cyber < analytics, augmented, cloud, compute, computing, cybersecurity, digital, digitalization, interoperability, information, Internet-of-things, IoT, simulation, smart physical < autonomous, cobot, robot economic < benefit, cost, economy, economic, expense, value measurement < criteria, criterion, standard, requirement, specification system < system

The principal components biplot in Exhibit 5 show that the first two themes "production" and "cyber" load primarily onto latent dimension one. Theme "production" loads positively on to both dimensions, and theme "cyber" loads negatively onto dimension one but positively onto dimension two. This suggests concern about positive and negative impacts of cyber digitalization on productive capabilities. Industry 4.0 research is oriented toward maintaining productive capabilities while integrating Industry 4.0 cyber digitalization The remaining Industry 4.0 themes load primarily onto latent dimension two. The "physical" theme loads moderately and equally negative onto latent

Exhibit 2. Re-coding of Industry 5.0 Themes for Dictionary-based Content Analysis.

Systematic Literature Review	Text Mining	Dictionary Concept-Word Assignments
cyber-physical systems	cyber	cyber < cobot, cloud, computing, data, digital, information, interoperability, IoT robot
sustainability	data	technical < customization, integration, personalization, physical, research, technology
human-centric	intelligent	socio < collaboration, human
human-machine collaboration	robot	economic < benefit, cost, economy, economic, expense, value
integration	digitalization	resilience < resilience
resilience	technical	sustainability < sustainability
economics	integration	system < system
6G	research	
cloud computing	technology	
digital twin	physical	
Industry 5.0	socio	
interoperability	human	
IoT	collaboration	
mass customization	system	
Society 5.0		

Exhibit 3. Pareto Importance of Industry 4.0 Thematic Topics.

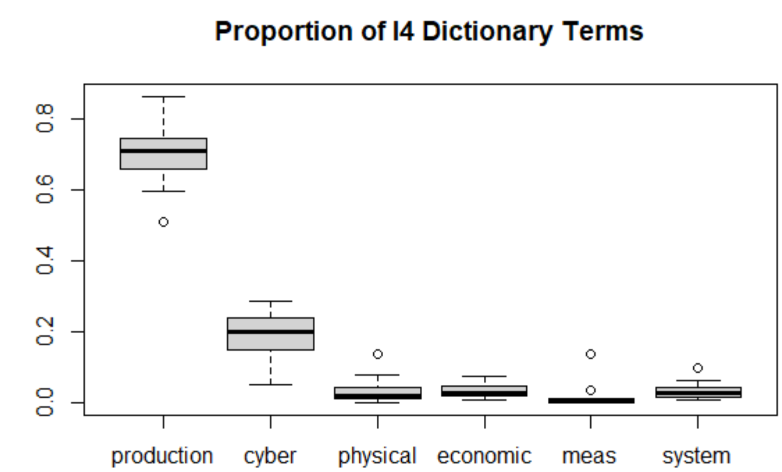
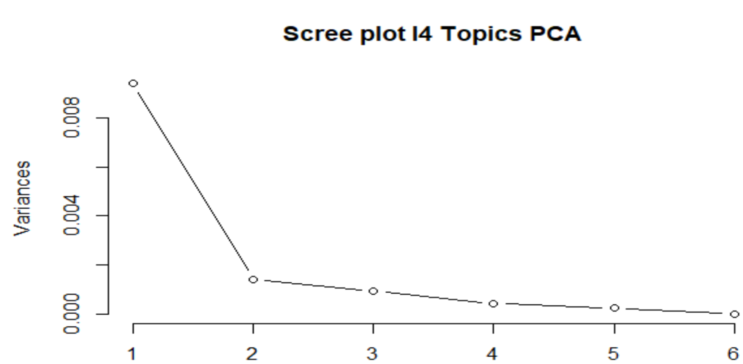
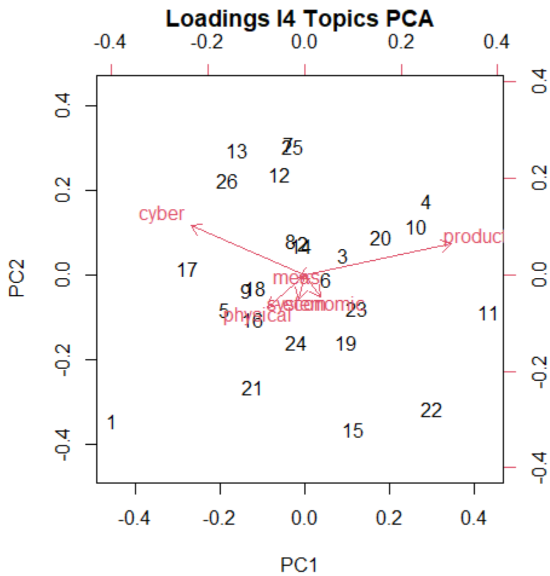


Exhibit 4. Industry 4.0 Principal Components Scree Plot.



dimension one and two indicating that integrating autonomous robots and cobots into current productive capabilities is of lesser concern than the broader cyber digitalization issues. Note that the negative loading direction of the "physical" theme is almost opposite the positive loading of the "production" theme indicating concerns about the impact of autonomous robots and cobots on productive capabilities. "Economic" and "system" themes load moderately negative onto dimension two indicating that benefit/cost value and broader systemic impacts are of secondary concern. The "measurement" theme exhibits almost no loading on to either latent dimension indicating that, although discussed in the literature as being important to interoperability and wide adoption of Industry 4.0 technologies, standards development receives little research consideration.

Exhibit 5. Industry 4.0 Theme Loadings onto the First Two Principal Components.



We can now summarize Industry 4.0 content analysis findings for research question one. The manifest dimensions of Industry 4.0 research are the widely recognized BCG Industry 4.0 technologies. Principal components latent dimension one can be labeled as the cyber-productive dimension. Research along this dimension is concerned with maintaining productive capabilities while integrating Industry 4.0 cyber digitalization. Latent dimension two represents the joint secondary issues of autonomous robots and cobots, benefit/cost value determination, realigning Industry 3.0 automation systems into Industry 4.0 cyber-production systems, and development of Industry 4.0 digitalization standards to promote interoperability and acceptance.

Topic content analysis of the Industry 5.0 management corpus using the assigned dictionary terms supplemented with term synonyms was performed. The boxplot in Exhibit 6 indicates that the "technical" (customization, integration, personalization, physical, research, technology) and "cyber" (cobot, cloud, computing, data, digital, information, interoperability, IoT, robot) themes are the primary drivers of Industry 5.0 research. Next was the "socio" social theme of human collaboration. The "eco" economic value and "sustain" sustainability followed in importance and can be considered as statistically equivalent. The "resil" resilience and "meas" measurement themes came last. Principal components analysis of these themes indicated that the first two latent dimensions explain 84.7% of the information variation. The principal components scree plot in Exhibit 7, however, suggested that the first three principal components, with 96.5% variation explanation, may be necessary.

The principal components biplot in Exhibit 8 show that the Industry 5.0 theme loadings onto the first two principal components and Exhibit 9 show the loadings onto the second and third principal components. The "technical' theme loads equally onto the positive axes of dimensions one and two. The "cyber" theme loads primarily onto the negative dimension one axis. The "socio" social theme loads primarily onto the dimension two negative axis. Note that the rotation between the technical-cyber and the cyber-socio loading are almost orthogonal indicating that research into these themes is fundamentally independent of the other themes. In Exhibit 9, the sustainability theme loads moderately negatively onto the third dimension. Note that sustainability loading is essentially orthogonal to the cyber and social themes, again indicating independence in research, and essentially opposite to the technical theme.

The economics, resilience, and measurement (standards) themes did not significantly load onto any of the first three principal components.

Exhibit 6. Pareto Importance of Industry 5.0 Thematic Topics.

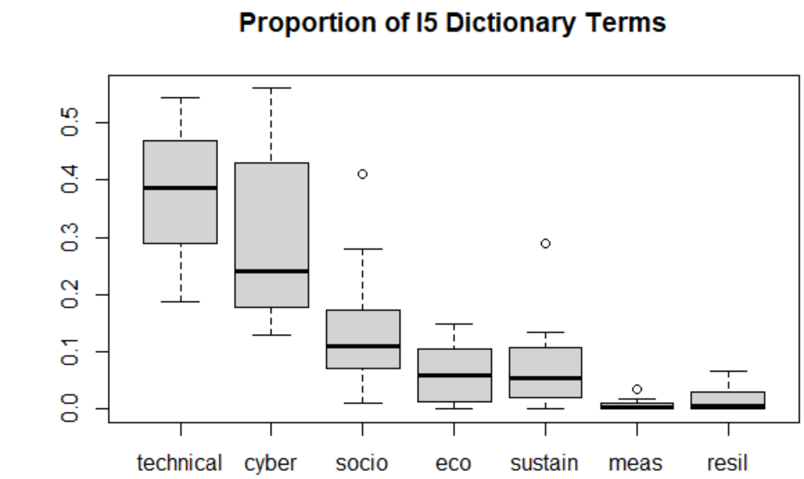
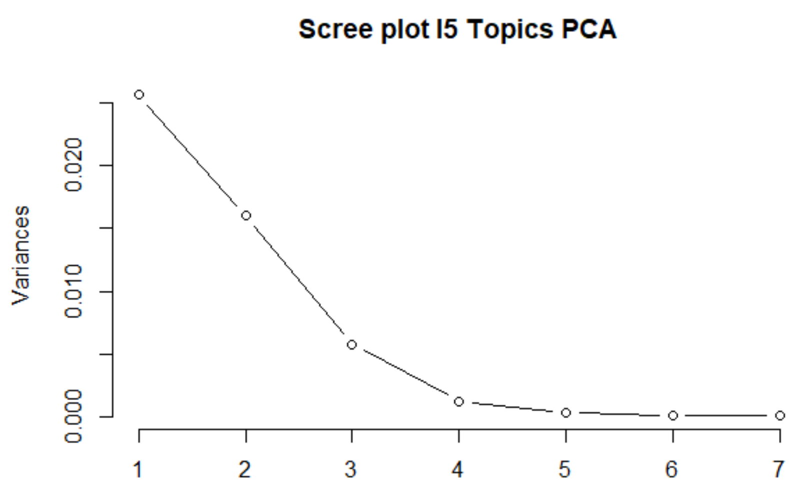


Exhibit 7. Industry 5.0 Principal Components Scree Plot.



We can now summarize Industry 5.0 content analysis findings for research question one. The manifest dimensions of Industry 5.0 research are the published EU goals of human-centric, resilience and sustainability. The suggested Industry 5.0 technologies of cobots, smart machines, block chain, virtualization, hyper-intelligent networking, genetic engineering, and quantum computing are not supported in this content analysis. This lack of support may, however, be due to the fledgling state of Industry 5.0 research. Principal components latent dimension one can be labeled as the cyber-technical dimension, latent dimension two as the socio-technical dimension, and latent dimension three as the sustainability dimension. The cyber-technical dimension is concerned with digitalization of Industry 4.0 technologies into Industry 5.0 technologies. The socio-technical dimension extends its Industry 3.0 roots to the design and performance of 21st century cyber-technical-socio systems. The sustainability dimension focuses on socially responsible implementation of Industry 5.0 technologies while managing their environmental impact.

Exhibit 8. Industry 5.0 Theme Loadings onto the First Two Principal Components.

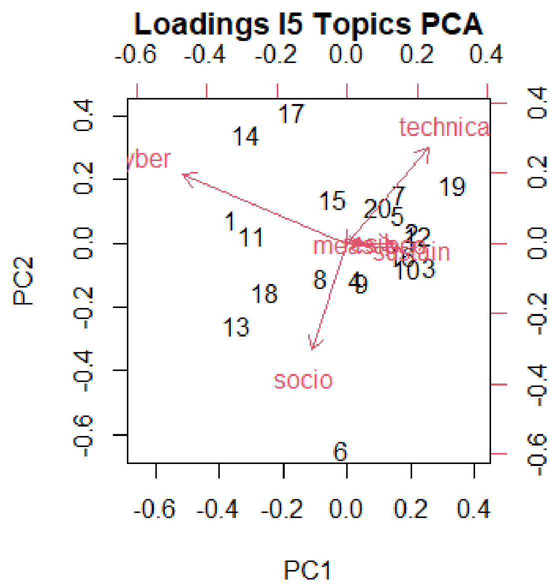
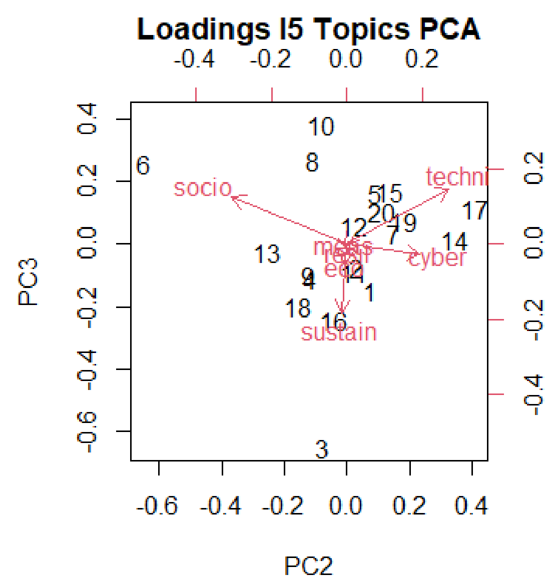


Exhibit 9. Industry 5.0 Theme Loadings onto Principal Components Two and Three.



Theoretical Framework for Industry 4.0/5.0 Engineering Management Research

Formal Concept Analysis (Ganter and Wille, 1999) was conducted in the application Concept Explorer using the concept-word assignments in Exhibits 1 and 2 (word synonyms were omitted) to establish the theoretical framework for Industry 4.0/5.0 engineering management research. The concept theoretical framework is set forth in Exhibit 10. Duquenne-Guigues basis implications were generated for development of Industry 4.0/5.0 theoretical propositions. Rule-supported basis implications are set forth in Exhibit 11.

Exhibit 10. Industry 4.0/5.0 Concept Theoretical Framework for Engineering Management Research.

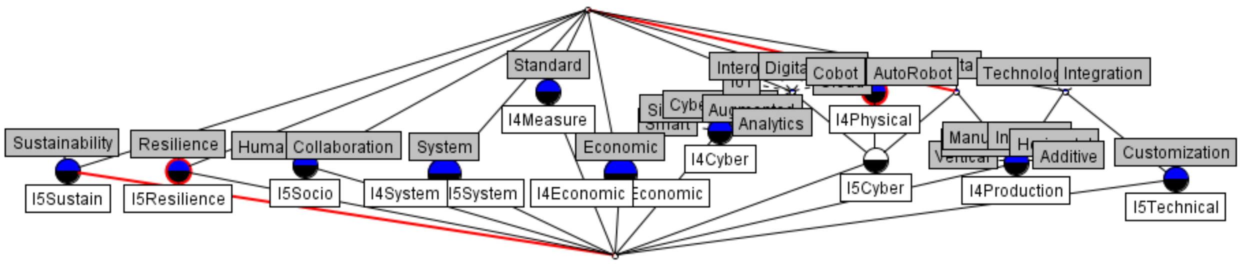
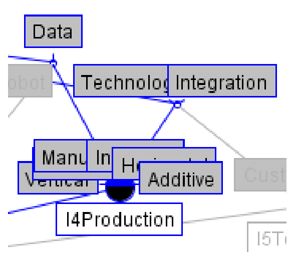


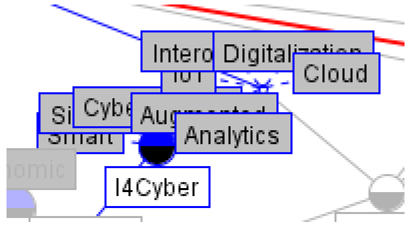
Exhibit 11. Duquenne-Guigues basis Implications of Industry 4.0/5.0 Theme Concepts.

Additive ==> {Data, Horizontal, Industrial, Integration, Manufacturing, Product, Technology, Vertical}
Analytics ==> {Augmented, Cloud, Cybersecurity, Digitalization, Interoperability, IoT, Simulation, Smart}
Cloud ==> {Digitalization, Interoperability, IoT}
{Cloud, Digitalization, Interoperability, IoT, AutoRobot, Cobot} ==> Data
Collaboration ==> Human
Customization ==> Customization
{Data, AutoRobot, Cobot} ==> {Cloud, Digitalization, Interoperability, IoT}
{Data, Cloud, Digitalization, Interoperability, IoT} ==> {AutoRobot, Cobot}
{Data, Integration, Technology} ==> {Additive, Horizontal, Industrial, Manufacturing, Product, Vertical}
Economic ==> Economic
Integration ==> Technology
Resilience ==> Resilience
Standard ==> Standard
Sustainability ==> Sustainability
System ==> System

I4 Production - Proposition 1: Implementation of Additive ==> {Data, Horizontal, Industrial, Integration, Manufacturing, Product, Technology, Vertical} ∪ {Data, Integration, Technology} ==> {Additive, Horizontal, Industrial, Manufacturing, Product, Vertical} ∪ Integration ==> Technology, where {*} denotes a joint set, is a multivariate optimization problem for which the optimal solution is dependent on the joint organizational {culture, capabilities, environment, technology, value} set.

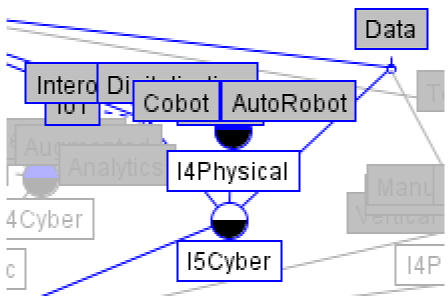


I4 Cyber - Proposition 2: Implementation of Analytics ==> {Augmented, Cloud, Cybersecurity, Digitalization, Interoperability, IoT, Simulation, Smart} ∪ Cloud ==> {Digitalization, Interoperability, IoT} is a multivariate optimization problem for which the optimal solution is dependent on the joint organizational {culture, capabilities, environment, technology, value} set.



I4 Cyber / I5 Physical - Proposition 3-1: Joint optimization of {Cloud, Digitalization, Interoperability, IoT, AutoRobot, Cobot} ==> Data ∪ {Data, AutoRobot, Cobot} ==> {Cloud, Digitalization, Interoperability, IoT} ∪ {Data, Cloud, Digitalization, Interoperability, IoT} ==> {AutoRobot, Cobot} is an Industry 4.0/5.0 technology maturity problem. As Industry 4.0/5.0 maturity increases, joint optimization increases.

I4 Cyber / I5 Physical - Proposition 3-2: Joint implementation of {Cloud, Digitalization, Interoperability, IoT, AutoRobot, Cobot} ==> Data ∪ {Data, AutoRobot, Cobot} ==> {Cloud, Digitalization, Interoperability, IoT} ∪ {Data. Cloud, Digitalization, Interoperability, IoT} ==> {AutoRobot, Cobot} is an Industry 4.0/5.0 technology maturity problem to which an organization may respond to by choosing the technology combination that jointly optimizes *I4 Production - Proposition 1* and *I4 Cyber - Proposition 2*.



I4 Measure – Proposition 4: The Standard ==> Standard set is an Industry 4.0 technology maturity problem. As Industry 4.0/5.0 maturity increases, joint optimization increases. An organization can only contribute to the development of Industry 4.0 technology standards.

I5 Socio - Proposition 5: The Collaboration ==> Human set must be managed independently of the selected Industry 4.0/5.0 technologies. Human-to-human or human-to-technology is a collaboration issue. Technology-to-technology is a joint interoperability-integration issue.

I5 Technical - Proposition 6: The Customization ==> Customization set is a customer value proposition set that must be engineered and managed independently of the selected Industry 4.0/5.0 technologies.

I4 Economic / I5 Economic – Proposition 7: The Economic ==> Economic set is a stakeholder and customer value set that affects organizational viability and must be managed independently of the selected Industry 4.0/5.0 technologies.

I5 Resilience – Proposition 8: The Resilience ==> Resilience set must be managed independently of the selected Industry 4.0/5.0 technologies. Resilience to environmental, societal, economic, and technological impacts has always affected and will continue to affect organizational systems.

I5 Sustainability – Proposition 9: The Sustainability ==> Sustainability set must be managed independently of the selected Industry 4.0/5.0 technologies. Sustainable management of resources has always been and will continue to be a systemic survival issue as evidenced by past civilizations.

I4 System / I5 System – Proposition 10: The System ==> System set is a broader horizontal-vertical system of systems design, implementation, and management problem that must be engineered and managed independently of the selected Industry 4.0/5.0 technologies.

Industry 4.0/5.0 Theoretical Framework Mappings to EMBOK 5.0 Domains

Exhibit 12 sets forth a suggested mapping from the Industry 4.0/5.0 theoretical framework propositions to the current EMBOK domains. The objective of the mapping is to suggest the impacts of Industry 4.0/5.0 cyber-technical-social systems on the EMBOK knowledge domains.

Exhibit 12. Mapping Industry 4.0/5.0 Concept Theoretical Framework Propositions to EMBOK Domains.

EMBOK Domain	**I4/I5 Proposition**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1 Intro Eng Mgt										
2 Leadership & Mgt	**X**	**X**	**X**		**X**					**X**
3 Strategic Planning	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
4 Financial Res Mgt	**X**	**X**	**X**				**X**			**X**
5 Project Mgt		**X**	**X**	**X**	**X**					**X**
6 Quality Mgt	**X**	**X**	**X**	**X**		**X**				**X**
7 Opr Supply Chain	**X**	**X**	**X**	**X**	**X**	**X**				**X**
8 Mgt Technology	**X**	**X**	**X**	**X**	**X**	**X**				**X**
9 Systems Eng	**X**	**X**	**X**							**X**
10 Legal			**X**	**X**	**X**	**X**				
11 Prof Code/Ethics			**X**		**X**					

I4 Cyber / I5 Physical Proposition 3 will have the greatest impact on EMBOK knowledge domains due to digitalization of information exchange, artificial intelligence, and autonomous robots and cobots effects of all aspects of engineering organizations and the design of products and services. I4 Cyber Propositions 2 and I4 System / I5 System Proposition 10 will have the next broad impact on EMBOK knowledge domains due to the transition from information-based to intelligence-based engineering systems. Propositions 1 and 5 and propositions 4 and 6 will have the next level of joint impacts. Propositions 1 and 5 will affect the socio-technical productivity of engineering organizations. Propositions 4 and 6 effects will result from cyber-technologies standardization and mass customization of products and service designs. I4 Economic / I5 Economic Proposition 7, I5 Resilience Proposition 8 and I5 Sustainability Proposition 9 will mainly impact strategic and financial planning and management.

Industry 4.0/5.0 Implications for 21st Century Engineering Management

This work can now address research question three.

> *Q3*: How must the Engineering Management Body of Knowledge be revised to assist academia, industry, the service sector, government, and military digitalization to achieve the benefits of Industry 4.0/5.0 technologies.

This research suggests that the fundamental engineering management knowledge needed to manage 21st century cyber-technical-socio engineering organizations and projects will be radically different from that set forth in the current EMBOK. Engineering managers will need broad knowledge in Industry 4.0/5.0 digitalized intelligent cyber-technologies. The current EMBOK does not address Industry 3.0 information systems knowledge let alone future digitalized intelligent cyber-technologies. The future engineering manager will also need updated knowledge of the impacts of evolving Industry 4.0/5.0 digitized cyber-technologies on design, engineering, and project processes and of the international state of Industry 5.0 human-centric, resilience, and sustainability goals on strategic and financial outcomes. Given the complex interrelationships among Industry 4.0/5.0 intelligent cyber-technologies identified by content analysis and Formal Concept Analysis, this research initiative will not be so bold as to set forth specific recommendations. Rather, this research will recommend that ASEM establish an appropriate number of working groups to track evolving Industry 4.0/5.0 cyber-technical knowledge and Industry 5.0 human-centric, resilience, and sustainability research and incorporate new knowledge into the EMBOK through ongoing cumulative revisions culminating in periodic EMBOK update releases. Transitioning to 21st century cyber-technical-socio engineering management knowledge and systems will require a whole ASEM organization systems effort.

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