

## Thesis Changes Log

**Name of Candidate:** Mikhail Yurievich Nikolaev

**PhD Program:** Engineering Systems

**Title of Thesis:** Concept Selection of Innovative Complex Engineering Systems Considering Systems Emergent Properties

**Supervisor:** Full Prof. Clement Fortin

<i>The thesis document includes the following changes in answer to the external review process.</i>
<p>I would like to express my gratitude to all reviewers for their feedback and comments on the prepared PhD thesis. All the information from the provided reports was very valuable to me and allowed better explaining obtained research results and improving the thesis. All the changes and associated comments are given below.</p> <p>Kind regards,</p> <p>Mikhail Nikolaev.</p> <p><b>General changes:</b></p> <ul style="list-style-type: none"> <li>• As the PhD thesis text is to be published online, light grey squares were put above the signatures of the representatives from “WARPA” and “Digital Petroleum,” who signed the acts on the implementation (Appendix A on p. 153, Appendix B on p. 154). It reflects the need to protect personal data of these people from the unauthorized copying on the Internet. This way of protecting signatures is a common practice in the leading Russian universities for doctoral theses, and was supported by the Head of Doctoral Studies at Skoltech Dr. Dmitry Artamonov.</li> <li>• Access dates to web-links in the “Bibliography” section (from p. 134) were updated (from 14.09.2022 to 05.12.2022) to reflect performed re-checking of their accessibility.</li> <li>• p. 13 (Introduction): the sentence “The Russian Federation nowadays encounters the need to be energy-efficient for its successful socio-economic development” was replaced by “The Russian Federation <u>and the whole world</u> nowadays encounter the need to be energy-efficient for its successful socio-economic development.”</li> <li>• Figure 20 on p. 82 was replaced by the “traditional” House of Quality (HoQ) compared to the Modified House of Quality (MHoQ). The caption of the Figure 20 was changed from the “Modified house of quality (MHoQ) for CDMM-1 (adapted from [99])” to “MHoQ developed from HoQ in CDMM-1 (adapted from [107]).”</li> </ul>
<p><b>Associate Professor Henni Ouerdane</b></p> <p>1.1 The abstract is revised by sharpening or making it less “jargonic” from the outset, hence more accessible to non-specialist readers. Note that sentences like: “As the basis for his work, the author uses research results kindly provided by his colleagues from the Systems Thinking Group of Skoltech: C. Fortin, Y.A. Brovar, and Y.A. Menshenin” are a form of acknowledgment and should not be in the abstract, which should remain a formal brief account of the work.</p> <p>1.2 ...choice is made for the bibliographic referencing style: either numerical or alphabetical order but not a mix of both with numbers in the text and alphabetical order in the reference section.</p>
<p><b>Response:</b></p> <p>1.1 Following the comment of the reviewer, the abstract was re-written (p. 3) and the indicated sentence was moved to the “Acknowledgements” section (p. 5).</p>

- 1.2 The reason for the selected bibliographic referencing style was following the general practice applied to Candidate of Science dissertations, analogs of PhD theses in the Russian Federation. However, it was a choice of the author and was not a compulsory requirement. Therefore, following the comment of the reviewer, the bibliographic referencing style was changed to the numerical one. For this:
- a) Numbers of references in the text of the thesis were changed to those in the order of appearance.
  - b) References in the “Bibliography” section (from p. 134) were numbered according to the order of appearance.
  - c) To maintain an appropriate construction of the text after the changes in numbering, the following small changes were made in the text of the thesis:
    - p. 27: “complex systems” were replaced by “them” in the sentence “Specific disciplines, systems engineering in the USA and systems analysis in the USSR, were created to assist in developing complex systems” (beginning of the section “1.1.2 Complex systems”)
    - p. 32: brackets were removed from the sentence “Concept (or architecture) selection constitutes the specific type of design decision” (end of the section “1.1.4 Systems concept and architecture”)
    - p. 114: the phrase “Regular reach of European and Asian locations” was changed to “Regular reach of Europe and Asia (locations)”, the last column “Citations” was diminished in width (Table 14 “Identified emergent properties and their clarifications for ALTS)

**Doctor of Technical Sciences Fedor Krasnov**

- 2.1 Basic explanation of the term “systems emergent properties” has a very simple example in the Introduction section (p. 12). Although the dissertation is devoted to complex systems, a relatively simple system (train) is used for its clarification. The candidate needs to consider an option of changing this example on a more complex system, which is recommended to be from the oil and gas industry to align with the whole thesis.
- 2.2 It is not obvious why DOI numbers are not used for references in the reference list. Although Russian state standards GOST P 7.0.11-2011 and GOST 7.1-2003 establish no need to put DOI for the reference list, for the PhD degree similar to dissertations defended in many other leading Russian Federation institutions, adding DOI numbers needs to be considered.
- 2.3 The author mentioned the current-day 4th Industrial Revolution, called “digital transformation,” in the early beginning of the Introduction section. In Chapter 2, he noted uncertainties brought by innovations while describing design decision-making specifics of technological innovations. However, it is not obvious from his thesis, how did the author consider such uncertainties in his decision-making models? Innovation process can lead either to success, or to failure, and this uncertainty is definitely to be considered in decision-making models, applied to technological innovations. Therefore, there is a need to provide additional explanation on this in the text.
- 2.4 Although the candidate met all the requirements in publications as set by Skoltech, I would recommend him to think of publishing a good Q1 paper on case study 3 (architecture selection of the LNG transportation system) that can be done after the defense.

**Response:**

- 2.1 Following the comment of the reviewer, an example system was changed to that of a drilling rig. The explanation was re-written to reflect a new example (Figure 1, p. 12). The reference №5 was changed to the Drilling Engineering manual of the Heriot-Watt University, from which an example was taken.
- 2.2 It was properly noticed by the reviewer that DOI numbers were omitted in the “Bibliography” section following the provisions of the listed Russian state standards. For example, point 5.9.3.1 of a newer version of the Russian state standard on bibliography, GOST R 7.0.100-2018, allows providing DOI-numbers to publications in the “Bibliography” section but does not fix it as a compulsory action. According to the recommendation of the reviewer, DOI numbers were added to all references, for which it was applicable (“Bibliography” section, from p. 134).
- 2.3 This comment by Dr. Krasnov required adding a new section “Discussion” in the thesis (from p. 129). Subsection 4.4 “Consideration of uncertainties of the innovation process in CDMM-1 and CDMM-2” in the new section provides an answer to the question by Dr. Krasnov. As the basis for the answer, the related paper by Khasanov and Krasnov on digital transformation in scientific organizations was taken, the reference to it was added. The analysis of the paper revealed the systems thinking approach as the foundation for considering uncertainties associated with the innovation process. Taking into consideration the systems thinking approach as the basis for the proposed decision-making models, an answer of considering these uncertainties via using the proposed ontology of emergent properties, the possibility to adapt the list of emergent properties, and flexibility of models was formulated.

2.4 This recommendation is under careful consideration, and the preparation of the Q1 paper is in progress. It is assumed to be published after the defense. In addition to the personal achievements of the author of the current thesis, this paper will benefit the Systems Thinking Group of Skoltech, to which he belongs.

**Full Professor Rob Vingerhoeds**

- 3.1 [Concerning the phrase on p. 58: “Generally, an ontology in the design represents a documentation of the terminology used to describe objects, properties, and associations in a particular domain. No single correct way exists for its development”] “No single correct way” suggests that any framework would do. In reality, a lot of work has been done, both on engineering domains and beyond, to come up with a framework that can help to structure ontology developments, for example “Ontology Development 101”. It would have been nice if the candidate could have taken this on board in his research and in the thesis. Maybe he did but such approaches were not sufficient, in which case it would have been nice to learn from this and to feed back this experience to the ontology communities. Maybe this can be considered for future work.
- 3.2 It would have been nice if the candidate could have built his ontological model in tools such as Protégé, which tools also would have allowed for verification of the model consistency (class inferences, object property inferences, data property inferences, ...).
- 3.3 The contributions of thesis open up a first step to address these objectives; it needs to be more largely applied and extended on more projects.
- 3.4 .The ontological model could benefit from further attention in future research, such as in the use of specific tools that allow model consistency verification, in addition to validation on case studies.

**Response:**

- 3.1 Following the comment of the reviewer, the following changes were made in the text:
- a) p. 58: the sentence “No single correct way exists for its development” was removed from the text to avoid further confusion. It had a generalized meaning.
  - b) Subsection 4.3. “Consideration of ontology development methodologies and tools” was added to the “Discussion” section to discuss on the reasons, why frameworks like “Ontology Development 101” were not applied, two references were added. The reason for this was that the essential high-level ontology that was presented as STOEP turned out to be well understandable for decision-makers. The idea to explore more on applying various ontology development methodologies and comparing the results was added to the “Conclusion” section as a part of future research (p. 133).
- 3.2. The explanation for the reason why Protégé or other tools were not used was added to the “Discussion” section (see Subsection 4.3). The reason is the same as in 3.1. However, it was noted that for using emergent properties in the preliminary or detailed design stages, use of such ontology-building tools will be necessary to avoid possible logical mistakes. Further development of STOEP using Protégé was added as a part of future research work (p. 133).
- 3.3 The need to apply the proposed decision-making framework for more projects is left for future research. There were two attempts in 2022, but they were unsuccessful.
- 3.4 It is left for future research, assumed as a part of using Protégé.

**Professor of the Practice Alexey Nikolaev**

- 4.1 The notion of “system emergent properties” is among the central ones in the thesis research. As well presenting the novelty of the research the author claims “For the first time, emergent properties were used for design decision making in complex systems...” At the same time point of view stating that ability of a system to exhibit emergent properties is an intrinsic property of the system and the indication that we deal with the system but not separated components, is broadly accepted. In this logic, emergent properties are naturally and automatically accounted for during design decision-making. This is just the target of an engineer to make design decisions assuring that planned emergent properties will be exhibited by the system. In this respect additional clarification of what is meant by the author with the notion of “system emergent properties” would be beneficial for better understanding of novelty proposed by the author.
- 4.2 The author analyses various methodologies related to the analysis of complex engineering systems. Despite broad and extensive literature review, the author is not mentioning TRIZ (theory of inventive problem solving). TRIZ and its further developments deal with “meta-principles” of technical systems evolution. It would be interesting to see additional elaboration and ideas of the author if accounting these meta-principles can/should take place during system design decision making.
- 4.3 The author claims the development of new methodologies and tools for the design decision making for the concept selection of complex systems. In this respect it is important to consider what are the conditions when previous methods (e.g. value-based decision-making approach and “traditional” House of Quality) do not work and to be substituted by STOEP and MHoQ. In turn, limitations for the applicability of the newly proposed approaches and models should be considered as well.

- 4.4 In the Appendix presenting endorsement letters from the organizations piloted the emergence approach, there is a mentioning of the resulting time savings of 1 month and 1.5 month. This leads to the question – what would these organizations do within these 1 and 1.5 months if they do not use newly suggested decision-making methods but use “traditional” ones? Would this time be spent on additional data collection? Or experts’ input gathering? Or experiments? As a result of this additional time, would these organizations come to the same decision as generated using novel approaches?
- 4.5 The Acts mentioned in the previous question are dated by March 2021 and September 2021. Would be interesting to know if these organizations are continuing to use newly suggested approaches for their design decision making? Or they are back to “traditional” ones? Or their workflow implies design decision making once in several years?

**Response:**

- 4.1 Following the comment of the reviewer, additional clarification of what is meant with the notion “systems emergent properties” in the thesis was added as a separate subsection 4.1 “Further discussion on systems emergent properties for decision making” in section 4 “Discussion.” (from p. 129). For the notion “systems emergent properties” the author of the thesis uses the same explanation as do Crawley, Cameron, and Selva in their fundamental book “Systems Architecture: Strategy and Product Development for Complex Systems,” which is referenced in the “Introduction” section. This definition aligns with the explanation of systems emergence in the engineering domain, which is characterized by systems emergent properties, given by Khasanov et al. from “Gazprom Neft” in their book “Fundamentals of Systems Engineering” and Glukhikh from the University of Tyumen in his book “Theory of Systems and System Analysis.” These two books were added as references in subsection 4.1. The reason for using the definition by Crawley et al. is that the thesis is devoted to engineering systems. Definitions from other domains could be used if, for example, socio-technical systems were under consideration in the research. In the thesis, systems emergent properties serve as “characteristics” of systems that could be used for better design decision making. No papers were found to describe their use for the purpose of design decision making. The fact that systems emergent properties indicate, whether a new system is successful or not, is the advantage of these properties for decision making. In contrast, although the value decision-making approach exists, systems values also serve as indicators of systems success – they assist in understanding, whether a new system meets high-level stakeholder expectations.
- 4.2 Subsection 4.5 “Discussion on TRIZ applicability” was added on this in the “Discussion” section (from p. 129), three references to TRIZ-related publications were added. Investigation of TRIZ applicability was left for future research. The reason for this is that no publications were found that use this approach for design decision making, and it is not obvious, whether TRIZ could be applied to complex systems at the conceptual design stage, when engineering characteristics are not precise, and there is the lack of concrete information. However, the possibility of that this approach could be applied for decision support for simple and medium-complexity systems needs further investigation. In addition, the following changes were made in the text of the thesis:
- a) p. 133 (the last page of the “Conclusion” section). The sentence “Finally, additional case studies from various industries can be conducted to provide more advanced validation of the proposed approach and models” was replaced by “Finally, additional case studies from various industries can be conducted and TRIZ applicability for additional decision support can be tested.”
- b) p. 10 (the “List of Abbreviations”): TRIZ abbreviation and its transcript were added.
- 4.3 Subsection 4.2 “Boundary in applicability between traditional and new techniques and tools” was added in response to the comment in the “Discussion” section (from p. 129). The boundary in applicability between previously used and proposed decision-making techniques and tools is in the possibility to use the emergence approach and the proposed decision-making framework only for the conceptual design stage. Previously used techniques and tools are predominantly applied to preliminary and detailed design stages. Meanwhile, it constitutes the main limitation of the proposed decision-making framework. Other limitations are a matter of future research on more case studies. The indicated limitation is a consequence of that emergent properties appear at the conceptual design stage, and the possibility to use them for design decision making during other design stages is left for future research (see section “Conclusion”). For previously used techniques and tools:
- a) HoQ is used only for preliminary and detailed design stages, and MHoQ substitutes it for the conceptual design stage.
- b) The value decision-making approach is not substituted by the emergence decision-making approach, as the emergence approach represents the modification of the value approach well adapted for the conceptual design stage. The emergence approach enriches the value approach.

To avoid further confusion, the following clarifications were made for the formulation of the scientific novelty associated with MHoQ:

- a) p. 20 (“Introduction” section): the phrase “For the first time, the house of quality (HoQ) was modified for making design decisions in complex systems based on emergent properties.” was replaced by “For the first time, the house of quality (HoQ) was modified for making design decisions in complex systems based on emergent properties, enhancing the applicability of HoQ for the conceptual design stage.”
- b) p. 131 (“Conclusion” section): the phrase “...emergent properties were used for design decision making in complex systems and served as its foundation...” was replaced by “...emergent properties were used for design decision making in complex systems (enhancing the applicability of HoQ for the conceptual design stage) and served as its foundation...”

4.4-4.5 The answer to these two comments were united and represented as a new subsection 4.6 “Discussion on the acts of the implementation,” which was added to the “Discussion” section (from p. 129). There is no precise answer to the raised questions. The reason for this is that indicated 1 and 1.5 months are expert judgements from the side of “WARPA” and “Digital Petroleum.” These are two dynamic innovation-oriented companies, and they were searching for opportunities to improve their design decision-making techniques. The value-based decision-making approach was initially used in these organizations, and the results of its use were given in Chapter 3. The application of the proposed emergence approach and CDMM-1 allowed improving their decision-making practices. Thus, these companies evaluated it as saving their time on the design of new systems. As the emergence approach was used in these organizations, it is not known, which techniques they would have used instead. As the collaboration with “WARPA” and “Digital Petroleum” on this topic has finished, and these companies proceeded to the preliminary and detailed design stages, it is not known, whether these techniques are still used in these companies. However, the author of the thesis especially contacted the representatives of these companies, and they confirmed that the emergence approach and CDMM-1 possibly will be used in future projects. To avoid further confusion, the special mark “≈” (approximately) was added to 1 and 1.5 months on: p. 21 (“Introduction” section), p. 102 (3.2. “Case study 2: Abridged CDMM-1 for concept selection of ARCDS), p. 109 (3.2.4. “Descriptive study II”).

#### **Senior Professor Amaresh Chakrabarti**

- 5.1 Page 11: “Such systems, also called technological innovations of new complex systems, possess both characteristics of complex engineering systems and technological innovations.” What are these characteristics? Please enlist the two sets of characteristics upfront in the thesis.
- 5.2 Same page: “The development of successful innovative complex engineering systems cannot be done in the traditional ways and represents a current-day relevant engineering problem.” Why not? Please specify the specific reasons.
- 5.3 Page 19: “Development and approbation of a modified decision-making approach for good concept selection of innovative complex systems from systems engineering and systems analysis positions.” Please explain what ‘good’ in the above sentence means, since that is the criterion that would be used to assess whether the development meets the expectation.
- 5.4 There are a number of typographic and grammatical errors. The author is urged to carry out a thorough revision in this regard. A few examples are given below to illustrate the point:
  - a. Page 17: “The “Intelligence” phase assumes the information-gathering activities on the decision problem.” I suppose this is a typo: and “Intelligence” should be “Investigation”.
  - b. Page 94: “Its hull envelope constitutes one of its most critical subsystems, which preliminary concept selection was performed using the value approach...” should be “Its hull envelope constitutes one of its most critical subsystems, for which preliminary concept selection was performed using the value approach...”
  - c. Page 94: “It allowed, to a first approximation, understand how would be the primary function of the hull envelope (keeping gas inside) converted to its form (a particular type of textile).” The sentence should be “It allowed, to a first approximation, an understanding of how the primary function of the hull envelope (keeping gas inside) should be converted to its form (a particular type of textile).”
  - d. Page 128: “Case study 1 was conducted that tested the possibility to apply STOEP as a tool for concept selection of the hull envelope subsystem for IRTA using the emergence approach.” Should be “Case study 1 was conducted that tested the possibility of applying STOEP as a tool for concept selection of the hull envelope subsystem for IRTA using the emergence approach.”
- 5.5 For each case study, please emphasise and clearly specify what each DRM phase has achieved: research clarification for identifying success criteria, and the overall research objectives and questions. The list

should include all success criteria (e.g. for Case 1, it is to improve performance while reducing the time taken in decision-making) and all objectives/research questions (i.e. the objectives/research questions for DS I, PS and DS II). Similarly, the subsequent DRM phases should clarify what was tried to be achieved and what was achieved (e.g. DS I in Case 1 identified the areas of weakness in current decision making methods in achieving the success criteria, i.e. performance and time of decision making). Where were time getting wasted or performance issues were getting compromised? Similarly, PS should report on identifying what areas of weakness to be addressed in the new decision-making approach and how. DS II should focus on how the new approach was tested as to whether it indeed improved decisionmaking in terms of the success criteria (e.g. performance and time for Case 1).

5.6 Please discuss the specific findings in each case study, especially when the success criteria were partially achieved, and how this learning was used in improving the proposed support.

5.7 The thesis claims that “Good concept selection of innovative complex systems can be achieved through considering their innovativeness and complexity” (P132). However, it is not indicated which of the emergent properties and associated requirements fall in which of these categories, and how novelty and complexity issues are addressed by turning them into requirements. It is important to discuss this.

**Response:**

5.1 Following the comment of the reviewer, the sentence “Such systems, also called technological innovations of new complex systems, possess both characteristics of complex engineering systems and technological innovations” on p.11 was replaced by “Such systems, also called technological innovations of new complex systems, possess both characteristics of complex engineering systems (many elements, many relationships, complex behavior) and technological innovations (invention, economic value, novelty). The information was taken from the relevant subsections 1.1.2 and 1.1.7 of Chapter 1.

5.2 The given phrase caused confusion with its original formulation. The author of the thesis meant the need to apply contemporary design methods for such systems. Therefore, it was reformulated:

a) p. 11 (“Introduction” section): the sentence “The development of successful innovative complex engineering systems cannot be done in the traditional ways and represents a current-day relevant engineering problem” was replaced by “The development of successful innovative complex engineering systems must be based on design research methods and represents a current-day relevant engineering problem.”

b) p. 129 (“Conclusion” section): the sentence “The thesis raised the current-day engineering problem that the development of successful innovative complex engineering systems cannot be done in the traditional ways and requires considering their innovativeness and complexity” was changed on “The thesis raised the current-day engineering problem that the development of successful innovative complex engineering systems must be based on design research methods and requires considering their innovativeness and complexity.”

5.3 There is the explanation on this in the “Conclusion” section on p. 129: “By “good concept selection,” the type of concept selection design decision that leads to the development of successful complex systems was assumed.” This relates to that concept selection is the type of a decision. And there is the term “good decision” given by Bratvold and Begg in their book “Making good decisions,” which is devoted to decision making for the oil and gas industry. Bratvold and Begg specify a good decision as the one “that is consistent with its objectives, alternatives, and available information.” It is explained in subsection 1.1.5 of Chapter 1 on p. 32. Thus, in order to avoid further confusion, the following clarification was added on p. 19: “By “good concept selection,” the author assumes the type of concept selection design decision that leads to the development of successful complex systems. It is the type of a “good decision” – the one that is consistent with its objectives, alternatives, and available information (see 1.1.5. Decision, design decision, and design decision making).”

To maintain an appropriate construction of the text in the “Introduction” section after the changes according to comments 5.1-5.3 were made, the following changes were introduced:

a) p. 11: the following sentence was deleted: “The solution to this problem lies in introducing new and adapting existing design and development techniques and tools.”

b) p. 15-16: the sentence “It also aligns with the recently risen interest of “Gazprom Neft” and the University of Tyumen in systems engineering practices applied to the oil and gas industry in the Russian Federation” was replaced by “It also aligns with the recently risen interest of “Gazprom Neft” in systems engineering.”

To maintain an appropriate construction of the text in the “Conclusion” section after the changes according to comments 5.1-5.3 were made, the last paragraph of the “Conclusion” section was re-written (p. 133).

5.4 The following comments by the reviewer were considered and associated corrections were made:

a) p 17: “The “Intelligence” phase instead of “Investigation.” It was the result of mixing information from different sources. Corner et al. in their paper “Dynamic decision problem structuring” refer to the Simon’s model with “Intelligence”, “Design,” “Choice” phases instead of “Investigation,” “Design,” “Choice.” To avoid confusion, the sentence with the “Intelligence” phase was re-written: “The “Investigation” phase (referred as “Intelligence” by Corner et al.) assumes information-gathering activities on the decision problem.”

b-c) p. 94: the proposed changes were accepted and corrected in the text.

d) p. 128: the proposed change was accepted and corrected in the text.

Following the comment of the reviewer, an additional revision of the text was performed. The list of corrections, which were made in the text, is given in Appendix A.

5.5 A new subsection 3.5 “Deeper representation of DRM” elements was added to Chapter 3 (from p. 128) to reply to this voluminous commentary of the reviewer.

5.6 A new subsection 3.6. “Discussion on case studies’ findings” was added to Chapter 3 (from p. 128) in response to this comment. Answers to overall research questions and conclusions on advantages and disadvantages were given in the last paragraphs of subsections devoted to each case study. In 3.6. the following finding was generalized: the proposed decision-making framework does benefit in time savings, but benefits in decision-making performance. Further improvement is possible, if following the future research activities as given in the “Conclusion” section.

5.7 A new subsection 4.9 “Discussion on emergent properties relating to innovativeness or complexity” was added to the “Discussion” section in response to this comment. The raised question was partially answered in subsection 2.2.1. “Principle of complementarity for design decision making in innovative complex systems.” Innovativeness is oriented toward accomplishing strategic goals by innovative complex systems and is followed by innovation tensions. Therefore, it is distributed between the strategic-level emergent properties (benefit, knowledge, elegance). Complexity is linked with engineering tasks, system structural tensions and is, therefore, distributed between the engineering-level emergent properties (function, performance, ilities, cost, emergency). Novelty (innovativeness) and complexity are not addressed by turning emergent properties into requirements. Emergent properties just serve as “requirements” in decision-making models similar to values in value approach-based decision-making models. Innovativeness and complexity are addressed via the principle of complementarity for design decision making in innovative complex systems, when the complementarity of these two features is considered via emergence using emergent properties. As complementarity can be considered through emergence, then the combination of innovativeness and complexity as complementary features of innovative complex systems can also be considered through emergence, which is described by emergent properties.

#### **Full Professor Andrei Osiptsov**

6.1 The list of publications includes one paper in a refereed journal (Q1, IF=12), which is a review paper, whereas all substantial novel results are published in conference proceedings only.

6.2 I might be coming from a different background which is too deterministic, I am accustomed to use first principles (conservation of mass, momentum and energy) to describe the motion of fluids and gases in technology applications, so for me the present work appears to be more descriptive than predictive. My key question: is it possible to use the proposed models to create new scientific knowledge, or they can only be used to describe the work done by others?

6.3 How does the decision quality chain (Fig. 23) help to improve the decision making process?

6.4 When we discuss emergent properties of a complex system in Chapter 3, what is the level of complexity of a mathematical problem to be solved? Is it the level of a weighted arithmetic average or something else?

#### **Response:**

6.1 This comment is under careful consideration, and the work on a Q1 paper presenting the whole proposed framework with a Case study 3 (architecture selection of the LNG transportation system) is in progress. There are two reasons for this:

a) Compared to petroleum engineering, the number of Q1-Q2 journals that publish on systems engineering topics is lower. Therefore, there are stricter requirements for what can be published in such journals. For example, IEEE System Journal claims to publish only on systems engineering topics devoted to the design of engineering systems of global significance. Thus, there is a stricter selection of research results that are appropriate for publishing in Q1-Q2 journals.

b) Dr. Alessandro Golkar, who played a great role in understanding the research topic, did his Ph.D. research under the supervision of Dr. Edward Crawley in MIT and published his paper on the thesis results only after the Ph.D. defense in 2012. This was taken as a good example to follow.

- 6.2 A new subsection 4.7 “Discussion on using CDMM-1 and CDMM-2 for creating new knowledge” in the “Discussion” section (from p. 129) was added to reply the raised question. There is no precise answer to this question, it is both “yes” and “no.” On the one hand, all elements of the proposed decision-making framework (STOEP, the emergence approach, CDMM-1, and CDMM-2) are developed and can be used only for descriptive study. On the other hand, all the elements of the proposed framework, including the decision-making models, allow adding modifications as they are very flexible. Adding modifications to STOEP, CDMM-1, and CDMM-2 allows obtaining new scientific data on models’ optimization, their efficiency, usability of new elements. Thus, new scientific knowledge is created, but it is limited.
- 6.3 A new subsection 4.8 “Discussion on the decision quality chain” in the “Discussion” section (from p. 129) was added to reply the raised question. The answer to it can be concluded from the book “Making good decisions” by Bratvold and Begg. The decision quality chain is the key part of the framework for evaluating the quality of decisions by Matheson and Matheson. This framework allows concluding, whether the taken decision was good (decision was consistent with its objectives, alternatives, and available information) or not. This knowledge allows improving the decision-making process.
- 6.4 Although the thesis is devoted to complex systems, the notion “complexity” is considered in it from the systems engineering perspective. Therefore, mathematical problems that are solved in Chapter 3 stay apart in their level of complexity from the notion “complexity” of complex systems. The general level of solved mathematical problems in the thesis represent the level of a weighted arithmetic average, which is demonstrated by formulas 1-3. This comment did not require any change of the thesis text, as given formulas already represent the level of complexity of mathematical problems to be solved.

### The list of changes made in the text after the additional revision (comment № 5.4)

- 1) p. 3: the sentence “It represents a schematic model that divides all systems emergent properties on strategy- and engineering-level properties and provides their link to systems values” was replaced by “It represents a schematic model that divides all systems emergent properties on strategy- and engineering-level properties and provides links to systems values.”
- 2) p. 3: the sentence “Finally, two decision-making models, which use the developed ontology and the proposed decision-making approach, were developed and tested in four case studies from the oil and gas industry” was replaced by “Finally, two decision-making models, which use the developed ontology and the proposed decision-making approach, were developed and tested on four case studies from the oil and gas industry.”
- 3) p. 5: the sentence “The last but not the least gratitude is expressed to the Head of Ph.D. studies in Skoltech Dr. Dmitry Artamonov...” was replaced by “The last but not the least gratitude is expressed to the Head of Ph.D. studies at Skoltech Dr. Dmitry Artamonov...”
- 4) p. 11: the sentence “The term definitions are analyzed in Chapter 2, but its primary explanation can be given through its related term of “systems emergence” on a clear example (Figure 1)” was replaced by “The definitions are analyzed in Chapter 2, but its primary explanation can be given through the related term “systems emergence” applied in an example (Figure 1).”
- 5) p. 13: the sentence “It may result in a worse understanding of decision-making methodology by all decision-makers that can include non-technical specialists (economists, lawyers, project managers, etc.)” was replaced by “It may result in a poor understanding of the decision-making methodology by all decision-makers, which can include non-technical specialists (economists, lawyers, project managers, etc.)”
- 6) p. 13-14: the sentence “This way, the decision-making approach and models developed in the thesis favor a good-level understanding of decision-making methodology by decision-makers, which aligns with the similar current-day tendency that appeared in companies and organizations” was replaced by “This way, the decision-making approach and models developed in the thesis favor a good-level of understanding of the decision-making methodology by decision-makers, which aligns with a similar current-day tendency that appeared in companies and organizations.”
- 7) p. 14: the sentence “According to Figure 2, the Cynefin framework represents five decision-making domains: right-hand domains of order (simple and complicated), left-hand domains of un-order (chaos and complex), and the central-field domain of disorder” was replaced by “According to Figure 2, the Cynefin framework represents five decision-making domains: right-hand domains of ordered (simple and complicated), left-hand domains of unordered (chaos and complex), and the central-field domain of disorder.”
- 8) p. 14: the sentence “The decision-making domain of the thesis, representing innovative complex engineering systems, is located on the boundary of complex and complicated domains, representing complex and complicated systems, respectively” was replaced by “The decision-making domain of the thesis, representing innovative complex engineering systems, is located on the boundary of the complex and complicated domains, representing complex and complicated systems, respectively.”
- 9) p. 14: the sentence “Interactions between systems elements in complicated systems are governed by fixed relationships and can be predicted using mathematics, e.g. simulated” was replaced by “Interactions between systems elements in complicated systems are governed by fixed relationships and can be predicted using mathematics.”
- 10) p. 14: the sentence “Opposite to them, interactions between systems elements in complex systems demonstrate self-organization, can not be predicted using mathematics, and need, for example, experiments for prediction” was replaced by “Opposite to them, interactions between systems elements in complex systems demonstrate self-organization, which cannot be predicted using mathematics, and need, for example, experiments for prediction.”
- 11) p. 15: the sentence “Thus, the research topic of the thesis is highly relevant nowadays due to its orientation on solving the current-day engineering problem of the development of more complex engineering systems, which are at the same time technological innovations” was replaced by “Thus, the research topic of the thesis is highly relevant nowadays due to its orientation on solving the current-day engineering problem concerning the development of more complex engineering systems, which are technological innovations.”

- 12) p. 15: the sentence “It correlates with the innovation policy for the strategic development of the Russian Federation, the global trend of the increasing complexity of engineering systems, the need to save energy resources, and the tendency of favoring a good-level understanding of decision-making methodology” was replaced by “It correlates with the innovation policy for the strategic development of the Russian Federation, the global trend of the increasing complexity of engineering systems, the need to save energy resources, and the tendency of favoring a good-level understanding of decision-making methodologies.”
- 13) p. 15: a comma was added in the following sentence: “For conciseness, the terms “complex system,” “concept,” “architecture,” “value,” “emergent property” are used in the text of the thesis assuming “complex engineering sys-tem,” “systems concept,” “systems architecture,” “systems value,” and “systems emergent property,” respectively.”
- 14) p. 15: the sentence “The dissertation’s research focus fell within systems engineering and systems analysis fields of knowledge, including the key aspects of complex systems design and touching on elements of the innovation theory (see Figure 3)” was replaced by “The dissertation’s research focus falls within the systems engineering and systems analysis fields of knowledge, including the key aspects of complex systems design and touching on elements of innovation theory (Figure 3).”
- 15) p. 16: the sentence “According to Figure 3, the research area restrained considered fields of knowledge to the four aforementioned disciplines” was replaced by “According to Figure 3, the focused research area considered the fields of knowledge of the four aforementioned disciplines.”
- 16) p. 16: the sentence “For design theory, the research was limited by complex systems and design decision making” was replaced by “For design theory, the research was limited to complex systems and design decision making.”
- 17) p. 16: the sentence “Systems analysis was focused on its aspects close to systems engineering and decision theory” was replaced by “Systems analysis was focused on its aspects close to systems engineering and decision theory.”
- 18) p. 16: the sentence “Systems engineering was chosen as the primary approach for the research due to its successful approbation for engineering complex systems by NASA, “Statoil” (currently “Equinor”), “Gazprom Neft,” and other companies and institutions” was replaced by “Systems engineering was chosen as the primary approach for the research due to its successful and extensive use for engineering complex systems design by NASA, “Statoil” (currently “Equinor”), “Gazprom Neft,” and other companies and institutions.”
- 19) p. 17: the sentence “Many researchers in systems engineering, systems analysis, and the design of new products raised the question of decision making in complex systems and how to improve it” was replaced by “Many researchers in systems engineering, systems analysis, and the design of new products raised questions about decision making in complex systems and how to improve it.”
- 20) p. 17: a comma was added in the following sentence: “In 1960, Simon developed a decision-making process-based model that still serves as the basis for most contemporary decision-making techniques.”
- 21) p. 17: the sentence “This model has been developed to the later decision-making models and techniques created by other researchers over time” was replaced by “This model has been developed based on the later decision-making models and techniques created by other researchers over time.”
- 22) p. 17: the sentence “However, the design stage, or decision problem structuring, remained the task of primary importance, as noted by Mintzberg et al. in 1976” was replaced by “However, the design stage, or decision problem structuring stage, remained a task of primary importance, as noted by Mintzberg et al. in 1976.”
- 23) p. 17: a comma was added in the following sentence: “In 1992, Keeney formulated two underlying philosophies for contemporary decision making: alternative-focused thinking (AFT) and value-focused thinking (VFT).”
- 24) p. 18: the sentence “The success of VFT, also called the value approach, was proved by the continuous application for design decision making of space missions and systems by NASA” was replaced by “The success of VFT, also called the value approach, was proven by its continuous application for design decision making of space missions and systems by NASA.”
- 25) p.19: the sentence “Development and approbation of a modified decision-making approach for good concept selection of innovative complex systems from systems engineering and systems analysis positions” was replaced by “Development and approbation of a modified decision-making approach for good concept selection of innovative complex systems from systems engineering and systems analysis perspectives.”
- 26) p. 20: the sentence “It represents an ontological model that uses systems thinking approach, unites strategic and engineering-level emergent properties, and is based on analyzing the semantics and

- relationships of emergent properties” was replaced by “It represents an ontological model that uses the systems thinking approach, unites strategic and engineering-level emergent properties, and is based on analyzing the semantics and relationships of emergent properties.”
- 27) p. 21: the sentence “According to the literature sources on systems engineering, systems thinking and emergent properties occur at the conceptual design of complex systems” was replaced by “According to the literature sources on systems engineering, systems thinking and emergent properties occur at the conceptual design stage of complex systems.”
  - 28) p. 21: the sentence “However, they are also applicable to complex systems at other design stages” was replaced by “However, they are also applicable to complex systems development at other design stages.”
  - 29) p. 21: the sentence “Therefore, the proposed in the thesis decision-making models can be applied to making design decisions at other design stages (not only those for concept selection), considering their further proper adaptation” was replaced by “Therefore, the proposed decision-making models can be applied to making design decisions at other design stages (not only those for concept selection), considering their further proper adaptation.”
  - 30) p. 22: the phrase “This type of methodology requires defining the research question that was formulated the following way...” was replaced by “This type of methodology requires defining a research question that was formulated the following way.”
  - 31) p. 25: the sentence “Clarification of the core research-related terms plays a significant role in understanding the current state of the art on design decision making in innovative complex systems” was replaced by “The clarification of the core research-related terms plays a significant role in understanding the current state of the art on design decision making in innovative complex systems.”
  - 32) p. 25: the sentence “Clarification starts by explaining the basic terms (system, concept, etc.), continues by clarifying more specific terms (decision, design decision making, etc.), and finishes by describing technological innovations (Figure 5)” was replaced by “The clarification starts by explaining the basic terms (system, concept, etc.), continues by clarifying more specific terms (e.g. design decision), and finishes by describing technological innovations (Figure 5).”
  - 33) p. 28: the sentence “Magee and de Weck, Volkova prepared informative overviews of the existing types of complex systems classifications” was replaced by “Magee and de Weck, and Volkova prepared informative overviews of the existing types of complex systems classifications.”
  - 34) p. 33: the sentence “Terms “design decision” and “design decision making” refer to decision making within the aspects of design theory” was replaced by “The terms “design decision” and “design decision making” refer to decision making within the aspects of design theory.”
  - 35) p. 33: the sentence “Supporting design decision-making techniques and tools facilitate increasing the quality of design decisions and consist of decision-making processes, models, and decision support instruments: decision support tools and DSSs” was replaced by “Supporting design decision-making techniques and tools facilitate the increase of the quality of design decisions and consist of decision-making processes, models, and decision support instruments.”
  - 36) p. 35: the sentence “In terms of economics, good concept selection potentially allows preserving more energy, financial and other resources than any other good design decision, which becomes especially critical in case of complex systems being technological innovations” was replaced by “In terms of economics, good concept selection potentially allows preserving more energy, financial and other resources than any other good design decision, which is especially critical in the case of complex systems based on technological innovations.”
  - 37) p. 35: the sentence “The core of innovation includes invention, which differs from innovation by the presence of economic value” was replaced by “The core of innovation includes an invention, which differs from innovation by the presence of an economic value.”
  - 38) p. 35: the sentence “Knyazeva generalized that innovation builds upon the novelty, which found its successful application” was replaced by “Knyazeva generalized that innovation builds upon a novelty, which found its successful application.”
  - 39) p. 35: the sentence “The existence of several closely related terms in the definition of innovation (new characteristics, novelty, and new knowledge) can confuse” was replaced by “The existence of several closely related terms in the definition of innovation (new characteristics, novelty, and new knowledge) can be confusing.”
  - 40) p. 36: the sentence “The primary division is the differentiation of innovations on those occurring in the engineering domain (technological) and society (social)” was replaced by “The primary division is the differentiation of innovations occurring in the engineering domain (technological) with those in society (social).”

- 41) p. 36: the set of sentences  
 “Radical technological innovations, also called basic, introduce principally new practical means or technologies that satisfy the needs of new customers. This type of innovation results in a paradigm shift like the invention of a transistor or a microprocessor... This type of innovation lies in modifying existing functionalities by increasing efficiency or reducing cost”  
 was replaced by  
 “Radical technological innovations, also called basic technological innovations, introduce principally new practical means or technologies that satisfy the needs of new customers. This type of innovation results in a paradigm shift like in the case of the invention of a transistor or that of a microprocessor... This type of innovation lies in modification of existing functionalities by increasing efficiency or reducing cost.”
- 42) p. 36: the sentence “Marquardt et al. gave the fact that the number of papers on disruptive innovations increased three times in 2008-2017, and the number of citations increased twice in 2014-2016” was replaced by “Marquardt et al. found that the number of papers on disruptive innovations increased three times from 2008 to 2017, and the number of citations increased twice in from 2014 until 2016.”
- 43) p. 36: the sentence “For the dissertation’s research, the division of innovations on radical and incremental, revealing radical-level and incremental-level innovativeness, respectively, is adopted due to its essence, clarity, and fundamentalism” was replaced by “For the dissertation’s research, the division of innovations in radical and incremental, revealing radical-level and incremental-level innovativeness, respectively, is adopted due to its essence, clarity, and fundamentalism.”
- 44) p. 37: the sentence “Radical-level innovativeness pays off in exploration research activities when new functionality and technological possibilities of future complex systems are searched” was replaced by “Radical-level innovativeness pays off in exploration research activities when new functionalities and technological possibilities of future complex systems are searched.”
- 45) p. 37: the sentence “Specific literature review reflects the descriptive study I stage of the dissertation’s research and highlights the state of the art of the research topic” was replaced by “The specific literature review reflects the descriptive study I stage of the dissertation’s research and highlights the state of the art of the research topic.”
- 46) p. 38: the sentence “An additional search was conducted via the Google Scholar and disserCat databases to find appropriate books and theses, respectively” was replaced by “An additional search was conducted via Google Scholar and disserCat databases to find appropriate books and theses, respectively.”
- 47) p. 38: the sentence “Additionally, an option of simply combining “decision” and “innovation” as keywords was attempted, which did not bring to any success due to an overwhelming majority of all publications on the combination of these keywords relating to the innovation theory and market decisions” was replaced by “Additionally, an option of simply combining “decision” and “innovation” as keywords was attempted, which did not result in any success, due to an overwhelming majority of all publications on the combination of these keywords relating to the innovation theory and market decisions.”
- 48) p. 38: the sentence “The dynamics of their publishing by the years is illustrated in Figure 8” was replaced by “The dynamics of their publishing by the years is illustrated in Figure 8.”
- 49) p. 39: the sentence “Therefore, the interest of researchers on the subject has been continuously growing since 1995” was replaced by “Therefore, the interest of researchers about the subject has been continuously growing since 1995.”
- 50) p. 41: the sentence “Non-rational approach assumes only the applicability of subjective evaluations” was replaced by “A non-rational approach assumes only the applicability of subjective evaluations.”
- 51) p. 42: the sentence “Prescriptive decision theory, also called normative, orients on how decision-makers should make decisions, explores decision-making logic and aims to achieve rational decisions” was replaced by “Prescriptive decision theory, also called normative, is oriented on how decision-makers should make decisions, explores decision-making logic and aims to achieve rational decisions.”
- 52) p. 43: the sentence “In 1992 Keeney formulated two underlying philosophies for decision making, also known as decision-making approaches: AFT and VFT, both absorbing systems thinking” was replaced by “In 1992, Keeney formulated two underlying philosophies for decision making, also known as decision-making approaches: AFT and VFT, both encompassing systems thinking.”
- 53) p. 43: the sentence “Its success was proved by the application for design decision making by NASA” was replaced by “Its success was proven by its application for design decision making at NASA.”

- 54) p. 43: the sentence “It serves as the basis for the subsequent adapted decision-making process and model, as shown below” was replaced by “It serves as a basis for the subsequent adapted decision-making process and model, as shown below.”
- 55) p. 44: the sentence “This process was met to be mentioned in the publications primarily devoted to systems engineering” was replaced by “This process was mentioned in the publications primarily devoted to systems engineering.”
- 56) p. 44: the sentence “The process finishes by evaluating alternatives against identified criteria using the selected tool and validating solutions against the problem statement, also called decision validation (steps 7-8)” was replaced by “The process finishes by evaluating alternatives against identified criteria using the selected tool and validating solutions against the problem statement, also called the decision validation (steps 7-8).”
- 57) p. 45: the sentence “The knowledge creation process, shown in Figure 10, actually represents one of possible decision-making processes based on the value approach” was replaced by “The knowledge creation process, shown in Figure 10, actually represents one of the possible decision-making processes based on the value approach.”
- 58) p. 45: the sentence “The knowledge creation process demonstrates, how Petetin et al. successfully adapted the generalized decision-making process for disruptive technological innovations, using the value approach” was replaced by “This knowledge creation process demonstrates, how Petetin et al. successfully adapted the generalized decision-making process for disruptive technological innovations, using the value approach.”
- 59) p. 45: the sentence “Its validity was proved by the successful application to making a design decision for technological innovation in one of the projects from the aerospace industry” was replaced by “Its validity was proven by the successful application to making a design decision for technological innovation in one of the projects from the aerospace industry.”
- 60) p. 46: the sentence “However, MCDM methods mostly require decisions to be fully rationalized, which is not the case of technological innovations, and are, therefore, rarely specifically used for design decision making in them” was replaced by “However, MCDM methods mostly require decisions to be fully rationalized, which is not the case of technological innovations, and are, therefore, rarely specifically used for design decision making in such cases.”
- 61) p. 46: two sentences “It then goes to problem and goals clarification, which assumes iterations by returning to problem definition. Further steps consequently lead to evaluating alter-natives linked by the inverse relationship with problem definition and chief executive” were replaced by “It then goes to problem and goals clarification, which assumes iterations by returning to the problem definition. Further steps lead to evaluating alternatives linked by the inverse relationship with the problem definition and the chief executive.”
- 62) p. 47-48: the sentence “Simon’s process historically became a background in decision making and decision support within systems engineering and is also applicable to design decision making in technological innovations” was replaced by “Simon’s process became a reference in decision making and decision support within systems engineering and is also applicable to design decision making in technological innovations.”
- 63) p. 48: a comma was added in the following sentence: “In 1960, Simon developed a decision-making process-based model that became the basis for most contemporary decision-making processes and models.”
- 64) p. 52: the sentence “All these tools can potentially be used to support design decision making in technological innovations, and their choice is a matter of preference of decision-makers” was replaced by “All these tools can potentially be used to support design decision making in technological innovations, and their choice is a matter of preference for decision-makers.”
- 65) p. 53: the sentence “There has been a rising interest of scientists and engineers in the last years in applying artificial intelligence technologies, such as machine learning and deep learning to improve decision support instrumentation” was replaced by “There has been a rising interest of scientists and engineers in the last years in applying artificial intelligence technologies, such as machine learning and deep learning to improve the decision support instrumentation.”
- 66) p. 54: the sentence “Solid proofs of validity and the majority of publications allow concluding that the value approach is nowadays the most successful decision-making approach” was replaced by “Proofs of validity and the majority of publications allow one to conclude that the value approach is nowadays the most successful decision-making approach.”

- 67) p. 55: the sentence “The clarification of all these terms facilitated understanding the theoretical fundamentals of the dissertation’s research and identifying the proper keywords for the subsequent literature search” was replaced by “The clarification of all these terms facilitated the understanding of the theoretical fundamentals of the dissertation’s research and the identification of the proper keywords for the subsequent literature search.”
- 68) p. 57: the sentence “STOEP is an ontological model drawn up on the basis of analyzing the semantics and relationships of emergent properties and plays the role of instrumentation” was replaced by “STOEP is an ontological model drawn up on the basis of analyzing the semantics and relationships of emergent properties and plays the role of an instrumentation.”
- 69) p. 61: the sentence “INCOSE provided an essential definition of emergent behavior as a behavior of a system that cannot be understood only considering the behavior of its separate entities” was replaced by “INCOSE provided an essential definition of emergent behavior as a behavior of a system that cannot be understood only by considering the behavior of its separate entities.”
- 70) p. 64: the sentence “Crawley et al. pay much attention to roles of benefit and cost in the notion of value” was replaced by “Crawley et al. pay much attention to the roles of benefit and cost in the notion of value.”
- 71) p. 66: the sentence “The current subsection starts with its formulation, proceeds to the formulation of the emergence approach, and finishes discussing the applicability of the approach” was replaced by “The current subsection starts with its formulation, proceeds to the formulation of the emergence approach, and finishes by discussing the applicability of the approach.”
- 72) p. 68: the sentence “The use of the notion of complementarity in application to innovative complex systems was inspired by two presentations given by Prof. Fortin” was replaced by “The use of the notion of complementarity in the application to innovative complex systems was inspired by two presentations given by Prof. Fortin.”
- 73) p. 72: two sentences “For example, in rock core description systems from the oil and gas industry, an increasing number of included techniques, representing complexity, separately brings low value. This way, it does not solve existing problems in the industry, consisting of low speed and low quality of rock core description” were replaced by “For example, in the rock core description systems from the oil and gas industry, an increasing number of included techniques, representing complexity, separately brings low value. This way, it does not solve existing problems in the industry, consisting of low speed and low quality of the rock core description.”
- 74) p. 75: the sentence “Its value for systems engineering and systems analysis consists of the possibility to consider the combination of innovativeness and complexity in innovative complex systems to improve design decision making in them” was replaced by “Its value for systems engineering and systems analysis consists of the possibility to consider the combination of innovativeness and complexity in innovative complex systems to improve design decision making for them.”
- 75) p. 76: the sentence “The emergence approach turned out to be a successful solution for design decision making in innovative complex systems, which was proved by applying it in case studies from the oil and gas industry (see Chapter 3)” was replaced by “The emergence approach turned out to be a successful solution for design decision making in innovative complex systems, which was proven by applying it in case studies from the oil and gas industry (see Chapter 3).”
- 76) p. 78: the sentence “The principle of complementarity given in this subsection uses research results by Prof. Dr. Clement Fortin and STG members” was replaced by “The principle of complementarity given in this subsection uses research results by Prof. Dr. Clement Fortin and the STG members.”
- 77) p. 84: the sentence “Thus, concept or architecture selection design decisions in innovative complex systems require support in mitigating the influence of uncertainty and ambiguity” was replaced by “Thus, concept or architecture selection design decisions in innovative complex systems require support to mitigate the influence of uncertainty and ambiguity.”
- 78) p. 88: the sentence “Both models were successfully tested in case studies from the oil and gas industry, as described in Chapter 3 of the current thesis” was replaced by “Both models were successfully tested on case studies from the oil and gas industry, as described in Chapter 3 of the current thesis.”
- 79) p. 90: the sentence “The presented in the subsection ontology, approach, and models were successfully tested in case studies from the oil and gas industry, which is described in Chapter 3” was replaced by “The presented in the subsection ontology, approach, and models were successfully tested on case studies from the oil and gas industry, which is described in Chapter 3.”
- 80) p. 91: the sentence “The first case study tested the possibility to apply STOEP separately as a decision support tool for concept selection of the hull envelope subsystem...” was replaced by “The first case

- study tested the possibility of applying STOEP separately as a decision support tool for concept selection of the hull envelope subsystem...”
- 81) p. 91: the sentence “ALTS is a complex system implemented by “Yamal LNG” company in the Arctic region of the Russian Federation” was replaced by “ALTS is a complex system implemented by the “Yamal LNG” company in the Arctic region of the Russian Federation.”
  - 82) p. 94: the sentence “In Case studies 2-4 author’s main collaborator was Prof. Dr. Clement Fortin” was replaced by “In Case studies 2-4, the author’s main collaborator was Prof. Clement Fortin.”
  - 83) p. 100: the sentence “According to Table 11, 12 emergent properties were identified in descriptive study II” was replaced by “According to Table 11, 12 emergent properties were identified in the descriptive study II.”
  - 84) p. 100: the sentence “It allowed using the ontology for numerical comparisons of the calculated decision values DV” was replaced by “It allowed using the ontology for the numerical comparisons of the calculated decision values DV.”
  - 85) p. 100: the sentence “Secondly, similar to descriptive study I, formula (1) with the same grading scales of its constituents was applied” was replaced by “Secondly, similar to the descriptive study I, formula (1) with the same grading scales of its constituents was applied.”
  - 86) p. 102: a comma was added in the following sentence: “In 2018, concept selection of ARCDS was performed using the value decision-making approach in the Skoltech Center for Hydrocarbon Recovery (descriptive study I).”
  - 87) p. 102: the sentence “Application of the emergence approach for concept selection of ARCDS allowed to save 1.5 months of the “Digital Petroleum” company’s resources (Appendix B)” was replaced by “The application of the emergence approach for concept selection of ARCDS allowed to save  $\approx$  1.5 months of the “Digital Petroleum” company’s resources (Appendix B).”
  - 88) p. 107: the sentence “STG members proposed ARCDS designers to apply the emergence approach for one more round of concept selection” was replaced by “The STG members proposed to the ARCDS designers to apply the emergence approach for concept selection of ARCDS.”
  - 89) p. 113: two sentences “Due to greater demands in energy resources of the Asian market compared to the European one, it can be assumed that 80% of LNG is intended to be transported to Asia through the Bering Strait and 20% to Europe. The amount of LNG for annual transportation was not specified in the decision problem statement as different values are given in the literature” were replaced by “Due to greater demands in energy resources of the Asian market compared to the European market, it can be assumed that 80% of LNG is intended to be transported to Asia through the Bering Strait and 20% to Europe. The amount of LNG for the annual transportation was not specified in the decision problem statement as different values are given in the literature.”
  - 90) p. 121: “Case study 4 was possible due to the significant support from Dr. Andrey Kazak, an expert in petroleum petrophysics (formerly in Skoltech)” was replaced by “Case study 4 was possible due to the significant support from Dr. Andrey Kazak, an expert in petroleum petrophysics (formerly at Skoltech)”
  - 91) p. 128: the sentence “Case studies 2 and 3 were conducted that tested the possibility to apply CDMM-1 for the realization of the emergence approach to design decision making” was replaced by “Case studies 2 and 3 were conducted that tested the possibility of applying CDMM-1 for the realization of the emergence approach to design decision making.”
  - 92) p. 128: “Case study 4 was conducted that tested the possibility to apply CDMM 2 for the realization of the emergence approach for concept selection of ILPS” was replaced by “Case study 4 was conducted that tested the possibility of applying CDMM 2 for the realization of the emergence approach for concept selection of ILPS.” To keep an appropriate construction of the text, the phrase “CDMM-2 revealed itself as an interesting solution...” was replaced by “CDMM-2 revealed itself as a solution...”
  - 93) p. 130: the sentence “Finally, CDMM-1 and CDMM-2 were developed and successfully tested in case studies from the oil and gas industry” was replaced by “Finally, CDMM-1 and CDMM-2 were developed and successfully tested on case studies from the oil and gas industry”
  - 94) p. 131: the sentence “It represents an ontological model that is based on analyzing the semantics and relationships of emergent properties, uses systems thinking approach, unites strategic and engineering-level emergent properties, and considers the link between emergent properties and values” was replaced by “It represents an ontological model that is based on analyzing the semantics and relationships of emergent properties, uses the systems thinking approach, unites strategic and engineering-level emergent properties, and considers the link between emergent properties and values.”
  - 95) p. 132: a comma was added in the following phrase: “During the research, the following tasks, constituting scientific novelties of the thesis, were fulfilled for the first time...”