Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Eldar Shakirov
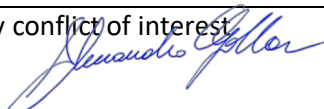
PhD Program: Engineering Systems

Title of Thesis: Integrated analysis of engineering and manufacturing change management in the additive manufacturing context: a simulation-based modeling framework

Supervisor: Professor Ighor Uzhinsky, Skoltech

Co-supervisors: Professor Clement Fortin, Skoltech; Professor A. John Hart, MIT

Name of the Reviewer:

I confirm the absence of any conflict of interest. (Alternatively, Reviewer can formulate a possible conflict)	**Date: 21-06-2021**

The purpose of this report is to obtain an independent review from the members of PhD defense Jury before the thesis defense. The members of PhD defense Jury are asked to submit signed copy of the report at least 30 days prior the thesis defense. The Reviewers are asked to bring a copy of the completed report to the thesis defense and to discuss the contents of each report with each other before the thesis defense.

If the reviewers have any queries about the thesis which they wish to raise in advance, please contact the Chair of the Jury.

Reviewer's Report

Reviewers report should contain the following items:

- Brief evaluation of the thesis quality and overall structure of the dissertation.
- The relevance of the topic of dissertation work to its actual content
- The relevance of the methods used in the dissertation
- The scientific significance of the results obtained and their compliance with the international level and current state of the art
- The relevance of the obtained results to applications (if applicable)
- The quality of publications

The summary of issues to be addressed before/during the thesis defense

I write this report in quality of IDC member of Eldar Shakirov, PhD candidate at Skoltech. This review is addressing the version of the thesis sent to me by email on May 7, 2021. This thesis document version consists of 6 chapters (+ bibliography and appendices) and 203 pages.

Brief evaluation of the thesis quality and overall structure of the dissertation

The thesis proposes an integrated change management approach for balancing the techno-econommic requirements between engineering and production, while considering the infusion of additive manufacturing-based product development approach. The further specification of the research objectives is done in Table 2.4 of the thesis, where research gaps are mapped to research objectives, which are further decomposed into research sub-questions.

The research questions presented are truly innovative – the introduction of additive manufacturing is a significant opportunity in product development, yet to be balanced with respect to the engineering and economic tradeoffs it induces. The thesis proposes an analytical framework enabling an accurate quantitative assessment of time and cost performance of an integrated change management process workflow, by proposing an Integrated Change Management reference process. While the approach has been comprehensively described in the document, a potential way to improve its understanding to the reader is the introduction of an approach diagram. In such a diagram, the approach would be decomposed into macro steps, with appropriate references to the sub-sections of chapter 4, which is presenting the approach. Such an approach is already present in the description of the discrete event simulation (DES) model, in Figure 4.4. This figure is very helpful in understanding how the simulation in the framework operates, with a specific decomposition into process steps. I recommend the same to be done at a higher level of abstraction (framework level) to improve the clarity of the manuscript.

The thesis is structured in six Chapters. The structure of the thesis is appropriate, and the thesis is generally very well written. It is recommended that the candidate checks once again the manuscript for occasional typos and English mistakes (example: 5.5 The context of ~~a~~ *the* use case → use case context). It is very much appreciated that the candidate offers a thorough analysis of his case study. He structures the work a series of 7 "studies", which is an easy to follow approach for understanding the advantages and the limitations of the proposed methodology.

The framework has been applied to a single case study of the design of an aeronautical pylon, also presented in Chapter 5. The case study is convincing and well structured. However, the case study is also difficult to grasp for non-experts of the aeronautical sector. In order to improve the clarity of the manuscript, I recommend the author to develop a simple "toy problem" (for instance, for which model calculations could be performed by hand), and discuss it.

The toy problem approach is very common in doctoral theses as a way to exemplify the application of the approach, by showing its implementation step by step, and bringing the reader deep down into the technicalities of the methodology. The development of a toy problem will also help the candidate to address one of the key limitations of the thesis, which is the lack of comprehensive validation. The candidate itself discusses the issue of validation as a limitation of the work. However, such a limitation could be overcome (albeit in part) through validation on a "toy problem" for which analytical results could be derived (by hand, or by simple spreadsheet calculations for example). Another key limitation of the thesis is the demonstration of the generalization of the approach. Ideally, the thesis would have had at least two case studies in two different sectors, in order to provide convincing evidence of its broad applicability in industrial engineering. Perhaps the author will not have time to do so during his thesis

process, but I highly recommend him to think at a new case study, perhaps in future work. A brief discussion of such opportunity of future work could perhaps be expanded in the text.

Despite the shortcomings here mentioned, the general impression is that the manuscript shows that Eldar has all the material required to successfully defend his doctoral thesis on July 15, 2021.

The relevance of the topic of dissertation work to its actual content
The topic of the thesis is highly relevant to industrial applications, as the use of additive manufacturing is certainly highly considered in a number of industries, including aeronautics, space, and automotive. The work presented by Eldar has practical relevance and could be further developed for actual usage in operations in an industrial context. Perhaps Eldar could think as well to develop the innovation component of his work, in order to unlock its commercialization value, for example through the development of a patent.

The relevance of the methods used in the dissertation.
The methodology developed by Eldar, as illustrated by his publications and doctoral thesis, is appropriate and relevant to the solution of the proposed problem. The proposed methodology is innovative, and demonstrated on a single industrial use case. The use case is convincing and demonstrated at a very high granularity. It shows how the proposed methodology could be applied at component level in the design process within industrial projects. This is certainly very interesting and worthwhile, and I am sure the work will find multiple opportunities for additional development.

The scientific significance of the results obtained and their compliance with the international level and current state of the art
The scientific relevance of the work of Eldar has been demonstrated by his publication activity. I believe Eldar will have an opportunity to publish at least one paper in a Q1 international journal based on the results of his work.

The relevance of the obtained results to applications (if applicable)
As discussed previously in this report, the results are industrially relevant and may give rise to innovation activity.

Quality of publications

The candidate presents four publications, including one in a Q2 journal (International Journal of Product Lifecycle Management), and three published conference proceedings.

The summary of issues to be addressed before/during the thesis defense

As discussed above:

- General approach diagram outlining steps
- "Toy problem" to demonstrate approach
- Validation of the approach potentially using toy problem or other means
- Discussion on generalization of results beyond industrial use case of aeronautical pylon

Provisional Recommendation

☒ *I recommend that the candidate should defend the thesis by means of a formal thesis defense*

☐ *I recommend that the candidate should defend the thesis by means of a formal thesis defense only after appropriate changes would be introduced in candidate's thesis according to the recommendations of the present report*

☐ *The thesis is not acceptable and I recommend that the candidate be exempt from the formal thesis defense*