Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 84 (2019) 374–379

www.elsevier.com/locate/procedia

29th CIRP Design 2019 (CIRP Design 2019)

Integrating Manufacturing Knowledge with Design Process to Improve Quality in the Aerospace Industry

Mohammed EL SOURI[a]*, , James GAO[a], and Clive SIMMONDS [b]

[a] University of Greenwich, School of Engineering, Chatham Maritime ME4 4TB, United Kingdom.
[b] Electronic Systems, BAE Systems, Rochester, Kent ME1 2XX, United Kingdom.

* Corresponding author. *E-mail address:* m.elsouri@gre.ac.uk

Abstract

There had been research efforts in the knowledge management and related disciplines devoted to integrating data and knowledge generated from manufacturing activities into the design process. Such efforts focused on approaches for enhancing engineering specifications and supplier related decision making in order to improve manufacturing quality through reducing defects. However, rarely did previous researchers address the 'Integration' aspect as part of a centrally-driven systematic workflow that enables collaborative knowledge capture between the internal design teams and manufacturing engineering teams firstly, and also with dispersed supplier teams. The industrial context of this research is discussed in this paper reflecting on the nature of the aerospace industry, which involves heavy reliance on information exchange to optimise designs on a day-to-day basis. This aspect had already been identified by many researchers to be under-addressed and a very significant challenge of collaborative design. The main aim of describing the context is to address the complexity involved in integrating manufacturing data generated internally first, and from suppliers second, within workflow context in order to to design a collaborative framework using knowledge management principles. The complexity also features aspects of product design and manufacturing specifically related to the the aerospace industry which tend to have exceptional functional specifications than other products from other industries. The implications of the proposed approach in the light of high value, low volume and high product lifecycle management challenges is also discussed. This paper also reports findings of an empirical investigation carried out with a leading UK based manufacturer of avionic systems with regards to manufacturing knowledge integration challenges related to improving the design of complex avionic systems, in order to enhance the design process for the business and improve the adaptation of a generic product design knowledge base. The purpose of it is to enable more rich data towards information driven design to improve manufacturing quality through defect reduction strategies and techniques.

Peer-review under responsibility of the scientific committee of the CIRP Design Conference 2019.

Keywords: Knowledge Management; System Integration; Design for Manufacturing; Collaborative Design

1. Introduction

Investment for productivity has now become an essential part of the UK's industrial strategy with a key focus on efficiency, according to government policies, and industry experts' opinion [1]. However, it was reported by the House of Commons [2] that manufacturing only accounted for just over 10% of UK's economy in 2017, significantly less than neighboring countries in Europe (i.e., Germany 20%, Italy 16%) due to relatively high costs in production. Many underlying causes for these high costs are due to products that have become significantly more complex and more resource demanding. To remain competitive with these economic pressures, industries have to reduce the amounts of resources consumed in the design and manufacturing activities, through more innovative and smarter solutions that have abilities to reduce the non-value adding costs accumulated from product lifecycle disruptions, such as failures, defects, scrappages,

2212-8271 © 2019 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the scientific committee of the CIRP Design Conference 2019.
10.1016/j.procir.2019.04.179

rework and related quality management activities [3]. This is more so the case for products of the aerospace industry as they are highly specialised, safety critical, engineered systems that require a huge resource of knowledge diffusion and expertise accessability throughout all lifecycle stages, i.e., design conceptualisation, engineering, manufacturing, supply chain, and other industry specific requirements.

For the past two decades, there had been a number of approaches developed to respond to some of these product lifecycle challenges in the concurrent engineering paradigm, which resulted in new developments of collaboration enhancing frameworks and tools mostly within internal multidisciplinary areas without much focus given on cross-supplier knowledge acquisition, communications and learning dimensions. In other words, enabling a more closely-synchronised integration mechanism of manufacturing knowledge from both internal manufacturing systems (an teams) and supplier manufacturing systems (and their teams) within the research related to improving collaboration in the design process for the aerospace industry remains limited [4].

The demand for integrating supply chain information networks remains problematic due to access related issues. This challenge currently contributes to overall manufacturing costs and management inefficiencies as a result of the trade-off caused. This include problems of supplier systems used in manufacturing activities firstly; being isolated, secondly; their data being locally as well as regionally scattered, and thirdly; a lack of structuring and linkages of the information related to defects and failures caused by suppliers' manufacturing or designs, mostly on the externally sourced parts and sub-assemblies [5] which tends to be a large proportion of most aerospace manufacturers.

This paper provides an overview of some of the reported techniques used to improve collaboration especially for applications involving the use of manufacturing knowledge and its integration with the design process for complex products requiring internally and externally manufactured parts. This is followed by an outline of the current integration challenges found out with the industrial collaborator and supported by the findings of some existing literature. More detailed analysis of this aspect of the investigation had been reported previously in [6] and in more detail in [7]. A proposed mechanism of integration is discussed and validated followed by development of a collaborative solution to allow workflows between designers, manufacturing engineers, and suppliers' within their design process.

The works of this research were carried out within our industrial collaborator's site, BAE System (Rochester, UK), an aerospace manufacturing company in the Southeast of England. They facilitated this research over the duration of 3 years with a committee of stakeholders including managers, engineers, and technologists, which resulted in the introduction of some principles of knowledge management that had been utilized to develop a solution that aimed to integrate manufacturing knowledge in the design process through enabling collaborative workflows through an Open Source tool that can be used by manufacturing engineers, related supply chain teams and design engineers within the design process for New Product Introduction (NPI). The collaborating company were also involved in its evaluation, further details in 5. Discussions, conclusions and further work section of this paper.

2. Overview of Related Research

According to Sassanelli et al [8], service systems that have some abilities to enable the use of knowledge from manufacturing activities into other processes in the product's lifecycle has had limited development in the early stages of the design process or NPI activities. On the other hand, other researchers identified that there is a lack of data management approaches for improving the transfer of knowledge between manufacturing and design in complex industry setting due to limitations in the development of system interoperability – an approach used to improve the relationships between information management software tools using like common linguistic identities to enable better flow of information. An example is, Wang, et al.'s work, [9] that developed a holistic tool that integrated knowledge based on collective intelligence to improve process innovation using semantic relationships from multiple ICT tools used in lifecycle management. Furthermore, Chungoora, et al., [10], as well as some of Palmer, et al.'s work [11] who also used semantic relationships to develop approaches to improve overall communications of ICT systems using interoperability protocols, in a more global manufacturing setting, proving that interoperability of cross-functional teams in design and manufacturing using different ICT tools can be achieved to a high degree of autonomy. Other researchers like Szejka, et al., [12] and Panetto, et al., [13] highlighted the effects of interoperability on future smart factories as well as the importance of eliminating knowledge exchange system barriers as a step in the right direction towards improving information flows.

However, it is important to clarify that the work mentioned above, did not address interoperability using knowledge management principles within aerospace engineering domain. This would need a much more robust classification of product data models (to correspond to product complexity) as well as shortcomings in workflow developments that would allow more knowledge acquisition, sharing and dissemination as opposed to allowing systems to interconnect in better ways.

The issue related to identifying the types of data that could be useful in preventing defects had rarely featured researchers whome were able to provide a structured means of enabling the use of it, integrating multiple teams (design, manufacturing and the supply chain) through collaborative workflow design, and interweaved into the design process itself toward enabling product design optimisation and functional improvement.

In alternative approaches, other researchers in the concurrent engineering paradigm bypassed the challenges of integrating knowledge in product lifecycle management (PLM) systems through interoperability by focusing on primitive formations of collaborative networks. A wide research community began exploring how new types of information system platforms that don't have to integrate with existing platforms, can be designed and developed to improve the transfer of knowledge between different teams working outside the governance of PLM systems (where interoperability is mainly applied). This has recently paved the way for a more

'Open Source' type of approaches to information exchange for collaborative teams involved. For example, Zammit, et al., [14] explored how collaboration-based knowledge sharing tools could be designed to improve complex product testing processes by enhancing the communications (format of media) happening between the different teams collaborating using Social Media platforms. Similarly, Evans, et al., [15], explored how Web technology can be used to improve collaborations between different people within NPI activities using Open Source Web platforms that offer value adding functionalities compared to rigid PLM systems. In addition, there were several developments in data and information modelling that have improved the design of knowledge feedback methods to also improve knowledge reuse independent of the governing frameworks in place (such as CAD, PLM, and other similar service systems). For example, the works of Cochrane, et al., [16], Baxter, et al., [17], and Madrid, et al., [18], developed linkages from different processes in manufacturing stages to support common configuration models of design data to improve knowledge retrieval regardless of where the data behind the model is manifested. However, the referenced works here have had very limited applications and may have not been explored enough in literature in regards to the design of the integration mechanisms to be used for integrating knowledge from manufacturing into the design process. Especially to improve product design aspects within high value low volume aerospace manufacturing context and its related supply chain complexities.

2.1. Main Contribution

As valid as these attempts are to enhance the integration of knowledge and information across multi-dispersed activities and teams, the systematic defect-preventative approach to improve collaboration within the internal design teams, manufacturing engineers, and suppliers, to improve product design in aerospace context had not been fully addressed in the concurrent engineering and complex systems manufacturing disciplines. Similarly, from an industry practice point of view, there still remains a heavy reliance on extensive defect-reactive based information exchange and face to face communications to optimize designs on a day-to-day basis in the manufacturing stages, with very minimal impact in the early design stage, largely due to the lack of a systematic integrated framework and tool that could be embedded into the design process in NPI to facilitate effective collaboration through the integration of manufacturing knowledge there. This research paper goes further than existing literature by applying some of the theoretical standpoints and approaches highlighted in existing research to a real world industrial context to further identify integration barriers from practice, as well as assess the feasibility of some of these approaches for businesses to gain insight into a real case study carried out using industrial context influenced and evaluated by stakeholders amongst the collaborating company.

Furthermore, most research and industry solutions still lack the integration of supplier data and manufacturing data that contain knowledge particularly related to manufacturing defects that can be used to elicit new design solutions in response, within the design process of complex high value low volume context. Typically collaborative workflows have been researched in this industry to enhance general knowledge sharing dynamics, however, the current methods and tools used for manufacturing data informed decision making lack technological extensions that are able to use real time data generated particularly from defect occurrences and associated information within manufacturing activities to improve its utilization and effectiveness of collaboration (and specifically integration mechanisms into the design process), particularly for the aerospace industry.

3. Industry Investigation

This research was carried out in collaboration with BAE Systems, Electronic Systems, UK, aiming to address the limitations found in the current operations in order to integrate and facilitate the use of manufacturing knowledge related to defects from companies' existing sources in the product lifecycle management system, and provide a new type of collaboration framework and tool to manage design improvements and decision making within the design process itself.

An empirical investigation was carried out at the collaborating company using three types of data collection methods: Semi-structured interviews with 15 decision makers involved in the scope of this research, observational studies across 4 production lines to identify the issues surrounding data and information access, sharing and re-use, and twenty discussion sessions with the industrial advisory committee (a group of seven key stakeholders in the project consisting of mainly design, supply chain and manufacturing personnel) lasting an hour each in order to validate the industrial findings, and formulate the design of the framework and tool towards the research aim.

3.1. Summary of Key Findings

It was found that the data, information and knowledge held within the company's systems are although rich in content, but lack mechanisms that could reduce its very large size and extensiveness to something more focused, measurable and targeted (based on product or process improvements). It was also found that most personnel in the business felt that with the amount and discrete nature of the data, and its various tools used to manage it, it is not always clear on how to structure the variety in ways that would enable its integration into the design process and inform design decisions made for NPI through knowledge reuse.

In addition, the observation identified that a substantial amount of time is often required to be able to access, acquire, re-structure and reuse any kind of historic manufacturing data or information towards improving new designs which could be very resource demanding. The stakeholders were in agreement that a systematic approach is needed in order to make use of it and integrate it into the design process which could fill a gap in enabling improved collaboration across design, manufacturing and supply chain personnel.

4. Integrating Manufacturing Knowledge within the Design Process

As mentioned in the key findings, the ability to link manufacturing knowledge generated from high impacting design defects into the design process had not been properly addressed in both academic and industry research to enable a more robust systematic approach of collaborative framework between manufacturing, supply chain and design personnel. The proposed framework which is reported in this research paper mainly details the key aspects of its development towards achieving an integrated nature of product design using manufacturing knowledge linkages into the design process utilized at the collaborating company. Furthermore, a set of real life data generated from manufacturing systems related to design defects were acquired from 4 manufactured systems over a duration of twelve months. The initial data and information acquired was in the region of five hundred values initially, thirty of which were targeted to be used to populate the developed ICT tool based on the framework. This was carried out in order to evaluate the framework and the resulting tool, in their effectiveness of improving collaboration firstly, and integrating the knowledge from manufacturing into the design process secondly.

4.1. Manufacturing Data and Information Acquisition

The proposed framework aimed to acquire the datasets from the current PLM framework. The data had been acquired through multiple meetings with data specialist personnel at the collaborating company and extracted, centralised and used for analysis. The data acquired can be seen in Fig. 1:

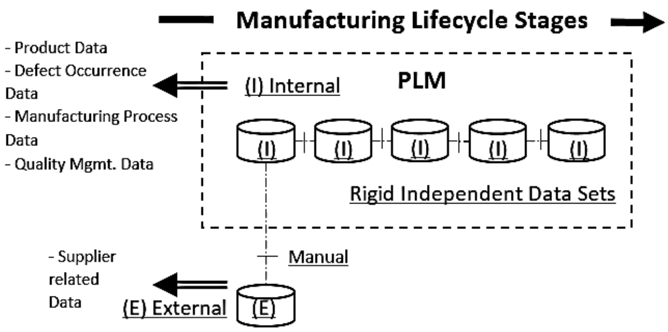

Fig. 1. Showing the types of data and information acquired from manufacturing activities (manufacturing lifecycle stages)

The framework links the various databases using an association mapping technique. The external sources of data were proposed to be acquired and linked with the aid of quality management personnel through establishing which supplier reports with defects occurring were on the selected products reviewed.

4.2. Integration in the Design Process

In order to facilitate data accessibility, and generate new knowledge, multiple components towards the framework had been designed as represented in Fig. 2.

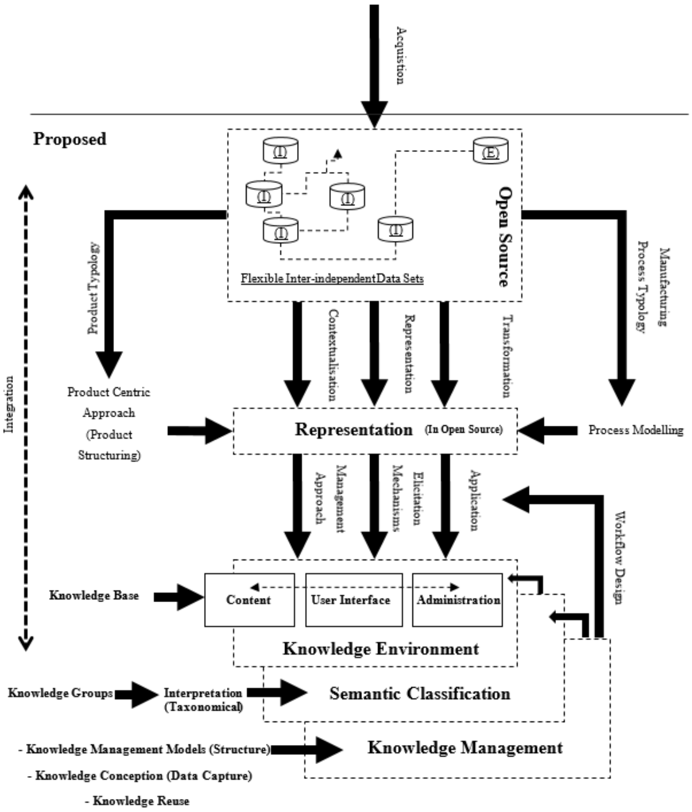

Fig. 2. Knowledge management framework used to integrate manufacturing knowledge into the design process.

The principles are shown in each element of the framework. After acquiring the data, the transformation, representation and contextualization can be achieved through creating a view of the manufacturing knowledge in accordance to the target product. The manufacturing knowledge can then by filtered based on the manufacturing process view – giving design engineers, suppliers and manufacturing engineers the ability to navigate appropriate types of knowledge being pursued. In NPI activities it is not always clearly defined in the creative stages. However, to utilize the most effective way to integrate usable manufacturing knowledge in that special stage, a semantic classification was used based on knowledge groups. The ability to access manufacturing knowledge using terms relevant to the users intention can be achieved through groups classified using populated linguistic interpretations (using case studies with the stakeholders) such as electronic components, mechanical components as a general example, or more specifically, 'root causes' of 'short circuit defect' in ' 'Printed Circuit Board design' as a more detailed example. The manufacturing knowledge management incorporated several knowledge structures, to capture data in the first instance of use, and to retrieve knowledge in a similar way by accessing the knowledge structures (and the populated data) by design or manufacturing cases. Last but not least, the framework has been designed and implemented in Open Source platform (Drupal 7) in order to allow remote access, and integrate all aspects of the framework effortlessly and seamlessly to enable flexible inter-independent data sets by multiple users (engineers, manufacturing personnel and supply chain personnel) allowing collaboration without restriction to any adapted PLM systems that may be in place.

From an organizational learning point of view, there are many opportunities that would arise from expanding the applications with similar domain context to include accessibility to the knowledge base created as a result of integration of the three key players identified into the design process. However, often the knowledge base is overlooked in its usability aspect. Our research fundamentally enables the integration of data generated in isolation independently into the design process using workflow mechanisms that in effect, enables the acquired data and information to form knowledge items through the use of knowledge classification terminologies related to product structure, and manufacturing structure too. The contribution in this research context, is an additional type of structure related to defect knowledge, where a linkage is formed from the data that aimed to capture.

4.3. Development of Knowledge Management Tool

The framework was implemented in Drupal 7, which is an Open Source content management tool for development. The knowledge structures, capture forms, taxonomical (knowledge type) groups were modeled. Furthermore, content types were created, and 30 data values related to 4 products were populated to demonstrate the functionality behind the framework.

Furthermore, the framework practically allows the development of the collaborative framework through multiple scenario models also resulting from discussions with the key stakeholders. Fig. 3 shows the infrastructural design for 3 main types of users, i.e., Design Engineers, Manufacturing Engineers, and Suppliers to make use of the collaboration framework using a portal.

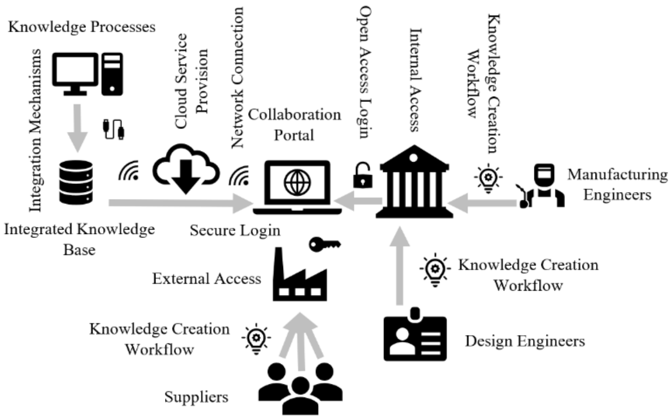

Fig. 3. Implementation of the collaborative framework.

The capability is indicated as part of the workflow for each key player that would facilitate knowledge creation. For example, the manufacturing engineer can use it to report a defect on a product that a design engineer would have preset its product data model configuration in order to monitor it. Similarly, the design engineer can access defects and related information to generate new knowledge regarding a design principle to avoid it, and reuse it in NPI detailed engineering stages. Alternatively, the supplier can log in to the system and review reported defects and related information on parts they've supplied in order to create new knowledge of corrective actions that could improve the manufacturing and assembly of their parts in future projects.

The knowledge processes involve capturing and centralizing of the data facilitated through the workflows into product, process, and defect knowledge terms and linked to the various populated data and information values. This effectively allows the knowledge base to be created, and facilitated through provision of knowledge access using searchability functions provided by the open source tool as usable modules. This was tested based on product data models and process data models and worked effectively to locate the item of interest based on knowledge terms that would describe a defect.

4.4. Evaluation

There are two aspects aimed to evaluate the proposed framework and implemented tool. The first is about the implications regarding the collaboration effectiveness. The second aspect is in regards to how well does the framework integrate knowledge from manufacturing into the design process. Three key stakeholders (design for manufacturing, technical supply chain, and mechanical engineering management) took part in using the proposed framework through the functional tool developed. The concept was very well received with all users agreeing that the collaboration is certainly enhanced in the way this solution had been designed. However, although the integration of manufacturing knowledge was achieved to a certain extent, the perceived value of adaptation of such tool into the design process would require a further test in NPI to validate and planned to be completed in later stages of this research.

5. Discussions, Conclusions and Further Work

Remarkably the gap addressed in this research had recently been discussed in Schildt's work, [19]. Their research explicitly stated that companies from now on, need to begin managing their external boundaries (to include partnering with suppliers and enabling knowledge flows between each other) as the direction to move towards. However, Schildt proposed the added value that the use of data mining algorithms can bring as a source of significant organisational advantage with some views of knowledge elements to be integrated into the design process, beyond the typical material, geometry and physical performance optimisation approaches. This confirms to a certain extent that by opening the boundaries up to facilitate more knowledge flows using organisational data management, and knowledge management approaches in order to keep up with the growing demands of managing complexity between internal and external functions or third party suppliers can help address similar challenges.

The move from traditional PLM systems to managing isolated activities within manufacturing industry to "cyber-physical-social connected or service oriented manufacturing paradigm" as stated by researchers like Jiang et al, [20] and Meissner and Kotsemir [21] had been proven through this research to promise some added value. Through the development of knowledge management frameworks and implemented as functional tools, many businesses could overcome similar challenges related to high value low volume manufacturing that this research tackled.

On the other hand, the full capability of such frameworks had not been explored in this research. It is important to recognise that although integrating manufacturing knowledge in the design process could aid manufacturing engineers, design engineers, and suppliers in collaborating towards preventative approaches to defects, and data-informed decision making in NPI activities, the motivation to use such system by any of these beneficiaries are not clear. Arguably, it would add additional processes to the design process which is complex in nature, and would add further information reliance to make decisions.

This research did carry out the design and development of case study examples to be used in the framework under a controlled scientific approach, but more work would be needed to validate the accuracy of the data, information, and potential new knowledge generated through using the framework principles proposed.

As further work related to this research, an exploratory study is required to confirm the data usefulness performance, not just collaborative workflow utilization, or design optimisation, as although these are beneficial to any organization – the use of such data to inform NPI activities decision making is required.

The main limitation of the approach is the amount of time it may take to populate a full spectrum of taxonomical identifications in the various knowledge structures proposed, and using it to a high level of search return performance. In order to overcome this challenge, a trial run of the tool is required with multiple intermediate evaluative studies to add, subtract, enhance or develop further functionalities to meet industry requirements not fully addressed yet in our research.

Companies, especially operating in the aerospace industry should also investigate the capability of migration into new innovative Open Sourced tools. This would be a substantial business decision that would have IT security implications and would need to be addressed, as it is not covered so far in research related to this area.

Acknowledgements

This project was funded by the UK Engineering and Physical Science Research Council (ESPRC) Grant: EP/L50544/1 and BAE Systems. The authors would like to thank all the personnel of BAE Systems (Rochester, UK) involved in the investigation for their support and collaboration. Also thanks to the supervision and administrative teams at University of Greenwich for facilitating our research.

References

[1] Deloitte. Impact of Brexit on the manufacturing industry: Managing through uncertainty. Deloitte NWE LLP, London, UK, 2017a.

[2] Rhodes C, Manufacturing. statistics and policy. House of Commons UK 2017.

[3] Okechukwu C, Uchendu O, Ndubuisi C, Okpala C. An Evaluation of Actual Costs of Rework and Scrap in Manufacturing Industry. Journal of Multidisciplinary Engineering Science and Technology 2015; 2: 4 p. 612-618.

[4] Ebikake O E, Sassanelli C, Terzi S. PSS design through Design for Supply Chain: State of the art review. Procedia CIRP 2018.

[5] Agrahri H, Ahmed F, Verma V K, Purohit J K. Benifits of implement big data driven supply chain managment: an ISM based model. International Journal of Engineering Science and Computing 2017; 7: 5 p. 11426-11431.

[6] El Souri M, Gao J, Owodunni O, Simmonds C, Martin N. Improving Design for Manufacturing Implementation in Knowledge Intensive Collaborative Environments: An Analysis of Organisational Factors in Aerospace Manufacturing. Proceedings of International Conference of the IEEE Technology and Engineering Management Society 2017.

[7] El Souri M, Gao J, Simmonds C, Martin N. A Structured Approach to Defect Data Management for Improving Design for Manufacturing Implementation in Aerospace Manufacturing. Int. J. of Product Lifecycle Management 2017; 10: 4 p. 282-300.

[8] Sassanelli C, Pezzotta G, Piralo F, Terzi S, Rossi M. Design for Product Service Supportability approach: A state of the art to foster Product Service System design. Procedia CIRP 2016; 47 p. 192-197.

[9] Wang G, Hu Y, Tian X, Geng J, Hu G, Zhang M. An Integrated Open Approach to Capturing Systemic Knowledge for Manufacturing Process Innovation Based on Collective Intellligence. Applied Sciences 2018; 8: 3 p. 340.

[10] Chungoora N, Young R, Gunendran G, Palmer C, Zulkarnain U, Anjum N, Cutting-Decelle A, Harding J, Case K. A model-driven ontology approach for manufacturing system interoperability and knowledge sharing. Computers in Industry 2013; 64: 4 p. 392-401.

[11] Palmer C, Urwin E N, Young R, Marilungo E. A reference ontology approach to support global product-service production. International Journal of Product Lifecycle Management 2017; 10: 1 p. 86-106.

[12] Szejka A L, Canciglieri Jr O, Panetto H, Loures R R, Aubry A. Semantic interoperability for integrated product development process: a systematic litereture review. International Journal of Production Research 2017; 55: 22 p. 6691-6709.

[13] Panetto H, Zdravkovic M, Jardim-Goncalves R, Romero D, Cecil J, Mezgar I. New perspectives for the future of interoperable enterprise systems. Computers in Industry 2016; 79 p. 47-63.

[14] Zammit J, Gao J, Evans R. Development of a knowledge sharing framework for improving the testing processes in global product development. International Journal of Product Lifecycle Management 2016; 9: 1 p. 1-18.

[15] Evans R D, Gao J X, Martin N, Simmonds C. Exploring the benefits of using enterprise 2.0 tools to facilitate collaboration during product development. International Journal of Product Lifecycle Management 2015; 8: 3 p. 233-252.

[16] Cochrane S, Young R, Case K, Harding J, Gao J, Dani S, Baxter D. Knowledge reuse in manfuacturability analysis. Robotics and Computer-Integrated Manufacturing 2008; 24:4 p. 508-513.

[17] Baxter D, Gao J, Case K, Harding J, Young B, Cochrane S, Dani S. An engineer design knowledge reuse methodology using process modelling. Research in Engineering Design 2007; 18: 1 p. 37-48.

[18] Madrid J, Vallhagen J, Soderberg R, Warmefjord K. Enabling reuse of inspection data to support robust design: a case in aerospace industry. *Procedia CIRP 2016; 43 p. 41-46.*

[19] Schildt H. Big data and organisational design - the brave new world of algorithmic management and computer augmented transparency. Innovation Organization and Management 2017; 19: 1 p. 23-30.

[20] Jian P, Ding K, Leng J. Towards a cyber-physical-social-connected and service-oriented manufacturing paradigm: Social Manufacturing. Manufacturing Letters 2016; 7 p. 15-21.

[21] Meissner D, Kotsemir M. Conceptualising the innovation process towards the active innovation paradigm - trends and outlook. Journal of Innovation and Entrepreneurship 2016; 5: 14 p. 1-18.