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A multidisciplinary implementation methodology for knowledge based engineering: KNOMAD

Richard Curran [a,*], Wim J.C. Verhagen [a], Michel J.L. van Tooren [b], Ton. H. van der Laan [c]

[a] Air Transport and Operations, Delft University of Technology (TUD), The Netherlands
[b] Systems Engineering and Aircraft Design, TUD, The Netherlands
[c] Stork Fokker AESP B.V., The Netherlands

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ABSTRACT

Existing knowledge-based engineering methodologies offer opportunities for improvement, as the multidisciplinary character of engineering design is not well implemented and as the current methodologies are not optimally substantiated. To better address the integration of multidisciplinary engineering knowledge within a knowledge based engineering (KBE) framework, the KNOMAD methodology has been devised. KNOMAD stands for Knowledge Nurture for Optimal Multidisciplinary Analysis and Design and is a methodology for the analytical utilization, development and evolution of multi-disciplinary engineering knowledge within the design and production realms. The KNOMAD acronym can also be used to highlight KNOMAD's formalized process of: (K)nowledge capture; (N)ormalisation; (O)rganisation; (M)odeling; (A)nalysis; and (D)elivery. These implementation steps are taken and repeated as part of the knowledge life cycle and in this context KNOMAD nurtures the whole Knowledge Management across that life cycle. The main contribution of the paper is to highlight the development of the KNOMAD methodology and to substantiate its individual steps with sufficient detail to support the application of KNOMAD in practice. A discipline-specific case study shows the potential of the KNOMAD methodology.

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1. Introduction

Many projects within the aerospace sector have the challenging objectives of meeting difficult production cost and rate targets for the future, as well as addressing environmental economic and environmental performance requirements for future products. An important enabler in this respect is to be able to carry out full optimisation and integration, for example in application to the design and manufacture of aerospace structures as presented later in the paper – including rapid and automated assembly of structures and systems. Consequently, established concurrent engineering paradigms have the potential to be implemented within a software environment to achieve a more automated design process. Full integration and optimisation will require the early and continuous use of knowledge-based engineering (KBE) solutions that must be integrated over the various design domains. In particular, objectives and constraints from a multidisciplinary viewpoint are viable candidates for research and KBE implementation, as the inclusion of multidisciplinary knowledge and subsequent optimization based on multidisciplinary knowledge has great potential to reduce design and production costs by executing the design 'first time right'. However, one stumbling block on the road towards wider adoption of KBE solutions is that they are often not very well suited to represent and re-use their embedded knowledge, while existing Knowledge Management (KM) solutions fail to properly interface with KBE applications to iteratively transfer essential knowledge for use in the KBE routines. To overcome this, research programmes are being carried out to investigate and develop technologies necessary for design, development and validation in the production environment (Castagne et al., 2008).

An underlying issue in KBE adoption and a significant cause of the stumbling block mentioned above is the lack of a sufficiently developed, mature KBE development methodology. In particular, the multidisciplinary nature of design and the means to represent, use and re-use the required multidisciplinary knowledge are not sufficiently embedded within proposed KBE methodologies, which is an issue that will be explored in more detail in the theoretical context. The aim of this paper is to address the integration of multidisciplinary knowledge within an knowledge-based engineering framework by formalisation into a methodology known as KNOMAD. Knowledge Nurture for Optimal Multidisciplinary Analysis and Design (KNOMAD) is the proposed methodology for the analytical utilisation, development and evolution of multidisci-

* Corresponding author. Address: Delft University of Technology, Faculty of Aerospace Engineering, Chair of Air Transport & Operations, Kluyverweg 1, 2629 HS Delft, The Netherlands. Tel.: +31 (0)1527 88288; fax: +31 (0)1527 82062.
E-mail address: R.Curran@tudelft.nl (R. Curran).
URL: http://www.lr.tudelft.nl/amo (R. Curran).

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plinary knowledge within design through a KBE framework. It will be presented in detail in this paper and will be tentatively validated using a case study.

The structure of the following sections reflects the aspects mentioned above. First, the research will be defined in more detail by discussing the research question, objective and method. Subsequently, associated literature will be reviewed to assess the current state of the art as a context for the research objectives. This includes a discussion of knowledge itself before specifically addressing the topic of knowledge-based engineering. Relevant KBE methodologies are briefly reviewed, leading to a set of requirements that should be met by an improved KBE methodology. After this theoretical context, the KNOMAD methodology is introduced. First, the general features of KNOMAD are discussed, followed by a more detailed description of the individual methodology steps. Subsequently, a case study is identified and performed to provide initial validation of the KNOMAD methodology. The case study is comprised of an implementation of aerospace manufacturing knowledge into a knowledge-based engineering application, the output of which is subsequently used for manufacturing performance analysis and results delivery. Finally, initial conclusions are drawn with respect to the validity and applicability of the KNOMAD methodology. To wrap up, some future work is briefly discussed.

2. Research definition

The perspective that has unfolded in the introduction regarding the adoption of knowledge-based engineering and its attendant methodologies has prompted the following research question:

Is it possible to develop a multidisciplinary knowledge integration framework that can facilitate the flow of multidisciplinary knowledge from experts and experience domains for use in the informal/formalized analysis tool domain for truly integrated design and production engineering?

The rationale for this research question is addressed in more detail at the end of Section 3. The main research objective of this paper is formulated as follows:

To establish and test a knowledge-based engineering methodology that will facilitate the capture, formalisation and use of multidisciplinary knowledge within a knowledge-based engineering framework.

Following from the research question, the main research hypothesis to be tested is:

H_1 = *A knowledge-based engineering methodology can be successfully used to facilitate the effective exploitation of multidisciplinary knowledge to achieve truly integrated design and production engineering.*

Keywords in this hypothesis are ‘successfully’, ‘effective’ and ‘integrated’. Any KBE methodology can be used to facilitate the exploitation of knowledge to support design engineering; however, the newly proposed methodology will have to contribute towards the successful use of multidisciplinary knowledge within a problem that ties together the design and production domains. Furthermore, the effectivity of the methodology is determined by its compliance with methodology requirements (see Section 3) while retaining simplicity and practicability. Thus, contrary to the general scientific method and compliant with the engineering requirements of this research, the ‘experiment’ (use case) to test the hypothesis is set up to positively confirm the hypothesis. This complies with the research context, as the work presented in this paper is being carried out as part of a research programme with a major aircraft producer in order to investigate and develop technologies necessary for design, development and validation that properly integrate multidisciplinary objectives and constraints.

To achieve the research objective and to properly answer the research question and associated hypothesis, a dedicated methodology (see Section 4) has been devised (Curran, Verhagen, Van der Laan, and Van Tooren, 2009). This methodology requires validation effort, which is achieved through the application of the methodology on an available use-case study that considered the manufacturing implications of an aircraft moveable on design (see Section 5).

3. Theoretical context

Increasing organizational and supply chain complexity, accelerating technical change and impending retirement or loss of company employees are frequently mentioned drivers for companies to move towards the adoption of knowledge-based systems (Ammar-Khodja & Bernard, 2008; Hackbarth, 1998). Knowledge-based systems use knowledge management methodologies and techniques to capture, store and use knowledge from various sources in order to be able to meet business objectives and requirements. This is reflected in the following definition of knowledge management (Ammar-Khodja & Bernard, 2008): “Knowledge management is a systematic, organized, explicit and deliberate ongoing process of creating, disseminating, applying, renewing and updating intellectual and knowledge-based assets of the organization to achieve organizational objectives”. In general, knowledge-based systems are set up to achieve one or more of the following objectives (Ammar-Khodja & Bernard, 2008):

- *Knowledge capitalization*: Learning from the past by knowledge retention and re-use.
- *Project accompaniment*: Learning from present activities by knowledge sharing and exchange.
- *Innovation*: Moving towards future benefits by leveraging organizational knowledge assets.
- *Cost reductions*: Achieving cost reductions through ‘first-time right’ adoption enabled by knowledge sharing.

Most knowledge-based systems using knowledge management methods and techniques are confronted by a number of challenges. These challenges are related to the type of knowledge that must be addressed. Many knowledge type taxonomies exist (an excellent overview of knowledge taxonomies is provided by Alavi & Leidner, 2001). However, Nonaka’s explication (Nonaka, 1994) of the epistemological dimension of organizational knowledge creation is most relevant in the context of this article. This dimension is split into explicit and tacit knowledge. Explicit knowledge refers to “articulated, codified knowledge that is communicated in symbolic or natural language form (e.g. reports, manuals)” (Alavi & Leidner, 2001), while tacit knowledge refers to an individual’s mental models (mental maps, beliefs, paradigms, viewpoints) and concrete know-how, crafts and skills that apply in a certain context (Nonaka, 1994). Knowledge capture from explicit sources is complicated by the sheer amount of codified material that has to be analysed and processed in order to retrieve the desired knowledge. Furthermore, explicit sources often do not capture the tacit assumptions and decision trade-offs that underlie the captured, explicit knowledge. Knowledge capture from tacit sources has different challenges: difficulties in explicating implicit knowledge, difficulties in retrieving truly useful knowledge and lack of engagement on the part of the tacit knowledge sources (e.g. experts) (Kitamura, Kashiwase, Fuse, & Mizoguchi, 2004). Any knowledge-based application under development will require an investment of time and effort to retrieve the necessary explicit

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