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EDITORIAL

Guest editorial

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Most artefacts, products and complex systems are designed by modification of prior designs to reduce the complexity of the development process and the risk inherent in product development. Even designs that appear at first to be completely new are often combinations of pre-existing components and technologies. Innovation is often focussed on specific components or systems as companies aim to reuse as much as possible, maximising the benefits they gain from minimising changes to the product. Yet changes to existing products and systems are an integral part of the life cycle of all designed products and systems. Designs are upgraded to meet evolving customer needs. New versions are generated to address the requirements of specific customers groups and incorporate new ideas for new markets, to improve performance, cost and lifecycle properties and to eradicate problems with earlier designs or those arising during the design and verification process. In each of these cases some parts or sub-systems of the products remain constant while others are modified. In carrying out these changes companies are anxious to avoid unnecessary knock-on effects to other parts of the products, especially those that are already frozen. Targeted engineering change is an opportunity for companies to adapt and innovate; and managing and controlling changes is a means of reducing design effort and cost. Engineering change is however also often the response to problems with the product or its product process. The process of carrying out changes is similar across different firms regardless of the cause, but carried out by different participants in the change process and with different attitudes.

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In spite of the critical role that engineering change plays in all product and system design projects, academic research has been slow to recognise it significance, and research has only taken off in the last few years. This special issue of the journal Research in Engineering Design collects papers on the state of the art of change research in engineering design. One of the phenomena that is of particular interest in this special issue is that of change propagation where one change generates another change and so forth. Research in this area attempts to first qualitatively describe the reasons for engineering changes, then moves to quantitative description of the phenomenon, and finally to a predictive and prescriptive capability.

Papers for this special issue were first invited in Spring of 2010 with a due date of October 1, 2010 with revised papers due in mid-2011 and final papers accepted in 2012. A total of 12 papers were submitted to the special issue. Each paper was reviewed by at least three reviewers and a recommendation based on these reviews was prepared by the guest editors. All these recommendations including the reviews themselves were monitored by the editor-in-chief to make sure that the regular standards of the journal are enforced. In order to ensure this further, papers co-authored by guest editors were reviewed blindly with respect to those editors. Five papers were selected from 12 submissions. Traditionally change research had concentrated on the product development phase of complex engineering products. This special issue broadens the scope to capital goods, very complex and expensive products such as power plants, radar systems or battle ships, which are one-off products or produced in very small numbers to diverse specifications. One paper also addresses specifically the production phase where changes are often carried out in response to errors rather than to meet new requirements or open up new markets as during the earlier phases addressed in the other papers.

The papers presented in this special issue cover empirical studies of change in industry and the development of tools and methods with industrial applications; they are briefly summarized as follows:

1. Alex Alblas and Jasper Veldman of Twente University in the Netherlands provided their empirical insights on the design of very complex products designed in very small numbers in a paper titled *Managing design variety, process variety and engineering change: a case study of two capital good firm*s. Within a family of capital goods, small numbers of individualized products are delivered to each customer, and consequently, the underlying generic design of each family is continuously under revision during delivery of products. They found that the two case study companies had different ways of (i) managing generic design information, (ii) isolating large engineering changes, (iii) managing process variety, and (iv) designing and executing engineering change processes; as well as different strategies of handling changes. One company operated an open product delivery strategy with informal engineering change processes, while the other company focused on prevention of engineering changes based on design standards and use of formal engineering change procedures. The authors propose a framework relating product delivery strategy and engineering change to design variety and the processes with which this is handled to help managers (i) analyze existing configurations of product delivery strategies, product and process designs and engineering change management, and (ii) reconfigure any of these elements according to a 'misfit' derived from the framework.

2. Changes during the manufacturing phase is the main topic of *Reasons for Change Propagation: A Case Study in an Automotive OEM* by Prabhu Shankar, Beshoy Morkos and Joshua Summers from Clemson University. The first author spent 8 months as an intern in the department dealing with change requests in an automotive company and had access to their change records. The paper focuses on identifying the reasons for change propagation during the production phase of the product life cycle and analyzed the effects of changes on the wider organization. They inferred that 32.4 % of the total changes are due to propagated changes such as inventory issues, manufacturing issues, and design error rectification. The majority of reasons for these propagated changes include document error rectification such as bill of material (BOM) errors, drawing errors, incorrect introduction dates in engineering change notices (ECN) and design error rectification such as design limitations. The reasons for the changes are identified using archival analysis through which it is found that 77.0 % of changes are due to internal reasons while 23.0 % are external. The paper concludes that nearly one-third of time spent by the engineers can be reduced by developing appropriate controls during the change release process.

3. In a paper titled *Multilayer Network Model for Analysis and Management of Change Propagation* Michael Pasqual and Olivier de Weck of MIT present an integrative framework for modeling and visualizing change propagation as a multi-layered phenomenon, including the product layer, change layer, and social layer. The model constitutes a holistic, data-driven approach to the analysis and management of change propagation. A baseline repository of tools and metrics is developed for the analysis and management of change propagation using the model. The repository includes a few novel tools and metrics, most notably the Engineer Change Propagation Index (Engineer-CPI) and Propagation Directness (PD), as well as others already existing in the literature. As such, the multilayer network model unifies previous research on change propagation in a comprehensive paradigm. A case study of a large technical program, which managed over 41,000 change requests over 8 years, is employed to demonstrate the model's practical utility. The case study also explores the program's social layer and discovers a correspondence between the propagation effects of an engineer's work and factors such as his/her organizational role and the context of his/her assignments.

4. Change propagation is also the subject matter of A *Method to Assess the Effects of Engineering Change Propagation* by Edwin Koh, Nicholas Caldwell and P John Clarkson from the EDC in Cambridge. This paper links changes to product requirements by combining the House of Quality (HoQ) and the Change Prediction Method (CPM) to model the performance of different change options during the design and development of complex products. This extends the CPM component-to-component analysis to address situations where a simple change in requirements might result in immediate change to a number of components and subsequent change to many more. This enables them to select between different change alternatives that would all address the same requirement for change. The method was applied to the design of a jet engine fan during a case study with an aerospace company.

5. *Developing a parameter linkage-based method for searching change propagation paths* by Gui-Jiang Duan and Fan Yang goes deeper in understanding the mechanisms through which change is propagated. The paper developed a method to search for change propagation paths based on product models from the parameter linkage perspective, through which the propagation mechanism of changes is analyzed. The authors identified two types of linkages: fundamental linkages, which are determined by physical laws and are intrinsic relationships between parameters, and constraint linkages, which designers artificially impose on the design for the purpose of part assembly, interface matching, performance guarantee or function combination. The paper argues that change

propagation is an alternate process of influence diffusion and change routing. A case study presented in this paper indicates that this method can provide support for the searching and optimal selection of change propagation paths.

In summary we believe that this special issue of RIED on engineering change marks the beginning of a journey. The engineering design community is becoming increasingly aware of the mismatch between the amount of attention paid to "green field" versus "brown field" design. The majority of academic research and teaching literature assumes a clean sheet or de novo design. The majority of design in industry on the other hand is based on evolving future generations of existing designs via engineering changes. Therefore we encourage the community to consider *engineering change* as a worthy and fruitful area of research within the broader considerations of engineering design and systems engineering. This is essential to build a better world with artefacts and systems that are sustainable, usable and better adapted to the needs of future generations.