THE DIGITAL FOOTPRINT OF ENGINEERING DESIGN PROJECTS: SENSORS FOR PROJECT HEALTH MONITORING

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1. The paradigm shift

When compared to the practices of 1950 the engineering design process has undergone a transformative change. In particular, the scale of engineering projects is an order of magnitude greater, the complexity of the artefacts being designed has increased dramatically, and the toolchains employed are almost all digital and far more advanced in terms of analytical capability than classical techniques used in the 50s. For example, the design of the Boeing 787 Dreamliner involved more than 153,000 employees in 70 countries, R&D in 43 countries,13,000 suppliers, 300,000 parts designed in 3D in CATIA and a PDM system that saw between 75,000-100,000 accesses a week (Briggs, 2012). While the aforementioned dimensions of the engineering process have undergone dramatic change, the overall process and project management methodologies have remained largely unaltered, with the plan-driven and phase-gated approaches described by VDI221 (Jänsch & Birkhofer, 2006) and NASA (Briggs, 2003) back in the 1950s and 60s respectively providing the basis for most industrial processes. Although it is self-evident from the global advances in technology and products that the engineering process has, in general, been effectively undertaken; many large engineering projects (civil, aerospace, automotive and pharmaceuticals) experience significant problems in terms of their execution. These include, for example, technical, process, people and contractual issues, which have led to major cost overruns. High profile examples of major cost overruns are the development of the Airbus A380 (2-year overrun and 2 billion euro overspend (Anon, 2009)) and the Boeing Dreamliner (2+ year overrun and $10 billion overspend (Drew, 2009)). It might appear that such major cost overruns are one-offs, however, the cost implications arising from overruns on engineering projects has been evaluated by the US National Science Foundation who reported an estimated total value of delay and cost overruns of $150M/day for the US Department of Defence alone (NSF, 2010).

2. Engineering Project Health Monitoring (ePHM)

As previously stated, digital tools are ubiquitously used in modern engineering. For example, in the design and construction of a building project spanning 5 years, hundreds of engineers will contribute generating in excess of 100,000+ emails and 15,000 reports and presentations, creating more than 5,000 computer models and representations and holding over 2,000 meetings (Watson, 2012). These digital tools all produce what is referred to herein as a *digital footprint.* This footprint represents the output of a significant proportion of engineering and project related work, and includes a record of all changes to the physical, content and structural attributes of all digital objects including *communications* (email and social media), *records* (reports, presentations and minutes) and *representations* (CAD models, FE models, CFD models, code modules etc.). Correspondingly, these changes are the embodiment of the activities of the engineers, which consequentially presents an opportunity to monitor engineering project activity. This concept can be considered analogous to condition motoring approaches such as Integrated Vehicle Health Management (Jennions, 2011) where systems are monitored in real-time, through changes detected in the operating conditions and components.

3. Sensors for ePHM

In order to investigate the potential of using the digital footprint as the basis for sensors for health monitoring of engineering design projects a major UK funded research project commenced in 2014. To date, research has focussed on investigating potential sensors and the inferencing capability that can be generated from automated analysis of the three strands of the digital footprint - *communications, representations* and *repo*rts. To date we have shown that it is possible to:

1. Model using Sigmoid functions the evolution of CAD part and assembly files and predict their time to completion.
2. Through analysis of co-occurrence of file edits reveal previously hidden structural and functional dependencies between parts.
3. Through co-word analyses of reports monitor and establish the changing product structure.
4. Through content analysis of project briefs evaluate the likely complexity of a new project based on historical cases.
5. Through sequence analysis of the workflow of historical projects using Markov chains to monitor the complexity level of a project.
6. Through content analysis of communications monitor the levels of problem-solving, management intervention and information requests.
7. Through topic analysis of communications identify those topics that are core to the project and those that are isolated - i.e. the relative attention to topics by the team members.
8. Through measures derived from topic analysis monitor diffusion of information through the team and reveal topics that are likely to be issues.
9. Through content analysis of reports and presentations compare and contrast relative attention of team members to the requirement / specification.
10. Through analysis of user behaviour (style of email) monitor the composition and effectiveness of the community - w.r.t. norms.
11. Through information transmission patterns determine informal team structure and hierarchy.

4. Outlook

Work to date has revealed that it is possible to use the *digital footprint* as the basis for sensors to monitor aspects of engineering projects and to do so in a meaningful manner, such as to assist in early warning of issues, evaluate team and process performance and reveal gaps/risks in project focus. While the relative success of the application of sensors to each class of digital object has been widely reported by the project team a number of challenges remain. The first concerns the overall framework for monitoring engineering projects from the digital footprint i.e. the features of, or activities within, a project that are impactful to its performance or of interest to stakeholders e.g. project managers. The second concerns the integration of the three strands of digital object and sensing of their interrelationships. The third challenge concerns the form of visualisations to use and the process of user-interaction - i.e. to perform root-cause analysis or to evaluate the impact of an intervention made, for example, by the project manager. The research project has two years remaining and it is these three aspects that are currently being investigated.

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