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SUPPORTING ENGINEERING DESIGN COMMUNICATION THROUGH A SOCIAL MEDIA TOOL – INSIGHTS FOR ENGINEERING PROJECT MANAGEMENT

James A. Gopsill, Hamish C. McAlpine, Ben J. Hicks

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1. Introduction

Engineering activities are *"fundamentally socio-technical"* where communication is an intrinsic and essential part of the process [Törlind and Larsson, 2002, Perry and Sanderson, 1998, Robertson, 1997, Alavi and Leidner, 2001, Badke- Schaub and Frankenberger, 1999, Clarkson and Eckert, 2005]. In this paper, Engineering Design Communication (EDC) is defined as the communications that pertain to the development of the product [Gopsill et al., 2013a,b] and engineers can typically spend in the region of 40-60% of their time communicating with one another [Tenopir and King, 2004, Hertzum and Pejtersen, 2000]. A high proportion of this (69% as recorded by Handel and Herbsleb [2002]) is what is colloquially termed '*water-cooler conversations*', as it is informal and is a quick exchange of knowledge and information between engineers [Larsson et al., 2002, Herbsleb and Mockus, 2003, Poile et al., 2009]. Engineers often use this as a means of '*filling in the gaps*' left by formal processes and documentation [Brown and Duguid, 2000], as well as maintaining awareness of project progress [Clarkson and Eckert, 2005, p. 20].

It has been highlighted that the volume of EDC is indicative of progress being made within a project as well as successful product development [Liebowitz and Wright, 1999, Griffin and Hauser, 1992, Dougherty, 1987]. This is in addition to playing a key role in reducing 'needless' uncertainty as it aids the sending of the right information at the right time to the right engineers [Adler, 1995, Daft and Lengel, 1986, Court et al., 1997]. Considering communication as the sharing of knowledge, interviews by Johnstone et al. [2009] discuss how engineers see that better information and knowledge management is key to better decision-making. Although numerous benefits have been associated with effective EDC, there has been little prescriptive research that has looked at supporting EDC through the development of a supportive tool [Tenopir and King, 2004, Clarkson and Eckert, 2005, Sonnenwald, 1996]. Rather, past prescriptive research has looked at the application of off-the-shelf communication technologies [Höllta, 2011, Törlind and Larsson, 2002].

It is currently the case that E-Mail is the main means for EDC, especially when teams become more distributed both spatially and temporally [Gopsill et al., 2013a, Herbsleb and Mockus, 2003]. Yet, research highlights that the functionality of E-Mail does not provide suitable support for EDC. For example, Chiu [2002] discusses how the current distributed communication tools used within engineering (E-Mail, Face-to-Face and Telephone) do not provide the interaction required by EDC, and Popolov et al. [2000] raise the issue of E-Mails inability to cope with collaborative discussions. Further, Orlikowski et al. [1995] & Eppler and Mengis [2004] question the suitability of E-Mail based upon the case that there is often a need for intervention and guidance on its appropriate use and

governance. Also, Dabbish and Kraut [2006] mention that engineers commonly have limitations on personal E-Mail storage and this may lead to potentially useful information for both the engineer and project management being lost through deletion. Allen [2000] mentions that E-Mail simply lacks the richness in terms of capturing the context and ability to associate it to the artefact of interest. It is also important to note that almost all EDCs revolve around an artefact[1] of the product [Eckert and Boujut, 2003, Carlile, 2002, Hicks et al., 2008].

Gopsill et al. [2013c] reveals that the functionality present within many Social Media (SM) tools could provide the environment in which distributed EDC can be supported more effectively and in turn meet the recommendations on improving communication outlined by Maier et al. [2011]. For example, Törlind and Larsson [2002] express the need for the tool to be lightweight and SM tools have been described as such [Whittaker et al., 1997, Zhao and Rosson, 2009, Brzozowski, 2009]. However, to apply SM effectively in the given context a number of requirements have to be met by the tool (see Gopsill et al. [2013b,c]). In doing so, such a tool would look to better support engineers' work as well as providing opportunities for supporting project management through the analysis of the communications stored.

This paper briefly describes such a tool, called PartBook, which has been specifically designed to support EDC and has been used by a Formula Student engineering team for a period of almost 3 months. The paper then presents some initial insights from the study in terms of how the tool impacted engineering work and how the analysis of the SM content of the tool could aid project management by potentially monitoring aspects of its '*health*'.

2. PartBook

PartBook[2] is a SM tool that has been designed specifically to support EDC through the implementation of a SM framework developed by Gopsill et al. [2013c, 2012]. Greater detail of PartBook's functionality and how it has been built to support EDC is provided by Gopsill et al. [2013b]. For the

Figure 1: Communication Process within PartBook

purpose of this paper, a brief overview of the process of the communication is described from an engineers' perspective. PartBook follows a four stage communication process; **Creation**, **Response**, **Conclusion** and **Hindsight** (Figure 1). In addition to this, there is **Awareness**, which is aimed at providing the functionality to ensure engineers are made aware of communications of potential interest. Each step is now discussed.
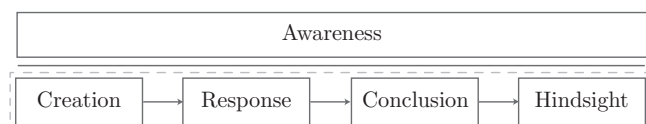
2.1 Creation of a Communication

The creation of a communication within PartBook has four steps that need to be completed (Figure 2). Step one of creating a communication requires the engineer to upload an image of the artefact to which the communication is pertaining. The role of the image is to provide a 'temporal snapshot' of the artefact at the time the engineer wishes to initiate the communication. This enables participating engineers to further understand the engineering context surrounding the communication. In addition, Partbook enables the engineer to provide the URL/real-world location of the artefact (e.g. prototype stored in cabinet X). The URL/real-world location enables quick access to the artefact.

[1] Examples include, CAD, CFD, Report, Prototypes, Calculations and Simulation Results
[2] http://www.part-book.com

Figure 2: Creating a Communication within PartBook

2

Moving to step two, the engineer is required to tag the communication with respect to the type of artefact (for example, a CAD file) and the '*focal* point' on the artefact (for example, Error Message). Again, this is building the engineering context that surrounds the communication and also enables the aggregation and filtering of communications based on these dimensions.

Step three is where the engineer types their statement. There is a 250-character limit to maintain conciseness and thereby prevent 'waffle' Perry and Sanderson [1998]. The appropriate size of an engineering message is still to be tested but has been set at 250-character as it is argued that engineering terminology typically contains more characters yet the principle is to have a similar formulation of the message seen in the 160-character limited SMS and Twitter messages. The engineer is required to select the type of communication they wish to have (for example, idea, clarification or decision). This plays an important role as it determines the type of responses that participating engineers can make and focuses the communication towards a limited number of possible outcomes.

Finally, step four provides the opportunity for the engineer to align the communication against the wider engineering working environment[3]. The main role of these tags is for search & retrieval, and to be used by the Awareness part of the communication process, which is discussed later. Once completed, the engineer can click 'Create' and this generates the communication within PartBook whereby engineers are able to respond to it.

2.2 Response(s) to a Communication

Once created, the engineers are able to access and respond to the communication from the within tool. Figure 3 demonstrates the multi-threaded functionality of the PartBook tool and this enables engineers to present various perspectives concurrently as well as enabling the divergence and convergence of ideas/discussions. This is a key issue with current tools such as E-Mail that PartBook is attempting to address. Engineers can select one or more elements against which their response will be associated. Again, the response is character limited and the engineer is required to select the type of response that they are making (for example, expressing an opinion or based on experience) and this enables other participating engineers to understand '*where they are coming from*'. The engineers are also able to add supplementary artefacts through the upload of an image, which might for example, show the effect of changes they have made to an artefact (e.g. showing the code that fixes a CAD error). The communication remains within this stage until the originating engineer determines that it has reached its conclusion.
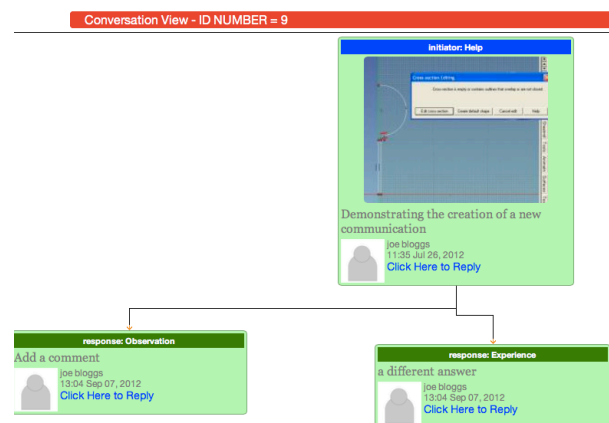

Figure 3: Responding to a Communication within PartBook

2.3 Conclusion of a Communication

The originating engineer determines whether the communication has reached its conclusion (Figure 4). The engineer is required to select the type of conclusion that has been reached (for example, problem solved) as well as providing a final comment detailing the result of the communication. They are also able to provide a final image of the artefact, which could be used to record the consequence(s) of the communication on the artefact (e.g. the modified CAD drawing). By concluding the communication, the engineer
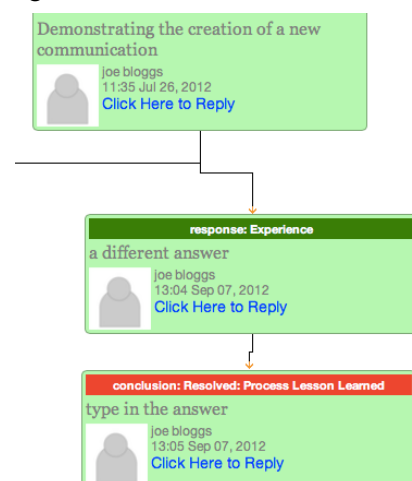

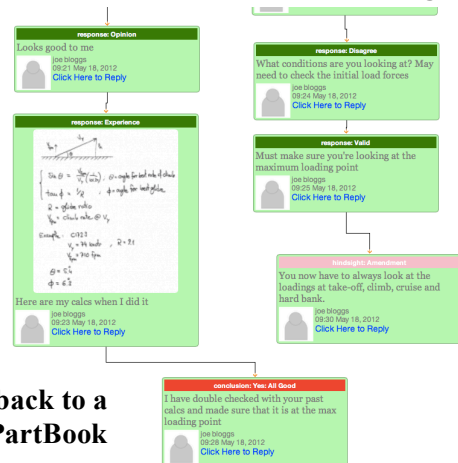**Figure 4: Concluding a Communication within PartBook**

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[3] These include project, activity, product, part, concept, feature and lifecycle stage.

effectively moves it from the current use state to an archived re-use state. This leads to the **Hindsight** stage.

2.4 Hindsight of a Communication

The communication is now in an archive re-use state and **Hindsight** enables engineers to place comments and refer back to past communications. Examples could be to highlight redundancy, best practice and/or make amendments (Figure 5). As with the previous stages, the engineer is required to direct these comments to particular elements of the communication and highlight the type of hindsight being made, as well as making their comment.

Figure 5: Referring back to a Communication within PartBook

2.5 Awareness of Communications

Throughout the communication process, PartBook provides functionality that is aimed at ensuring the *right* engineers are made aware of communications to which they could potentially contribute. This functionality comes in the form of tags that can be applied within any textual element (referred to as #tags). The engineers are able to notify one another through the use of @(Joe Bloggs) for example, thereby supporting the use of the engineers' social knowledge to send the communications to the *right* engineers. There are also a number of #tags that enable the grouping of communication for personal bookmarking, task and expert groups. Engineers have the opportunity to #tag other communications allow the sharing of rationale and enabling traceability of communications that influence other communications. The final aspect is the ability to take advantage of all the tags being used within the system so that engineers are able to generate so called '*interests*'. An *interest* is a selection of tags chosen by the engineer and this enables the customisation of the communication feed they see. The aim is to present the *right* communications to the *right* engineers.
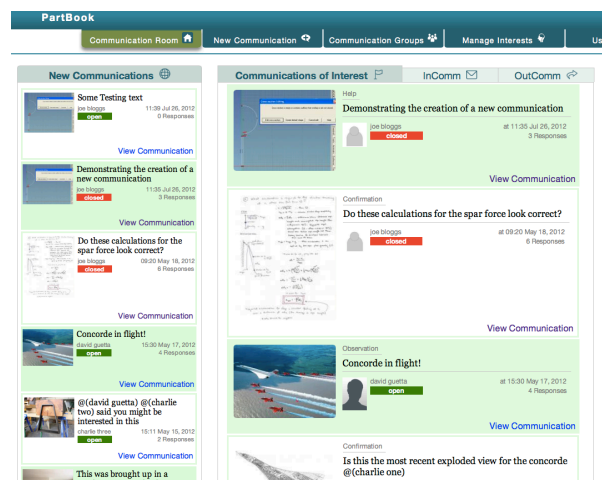

Figure 6: Making engineers aware of communications within PartBook

3 The Study

PartBook has been introduced into a Formula Student (FS)[4] project at the University of Bath (known as Team Bath Racing) whereby 30 students are tasked with the design of a race car (Figure 7) to compete against other universities within the country and across the world[5]. Each year Team Bath Racing starts afresh and designs a new car. It is the largest engineering project to occur at the University of Bath and is a highly multi-disciplinary and collaborative project, involving students undertaking various

Figure 7: Formula Student Car (source: Team Bath Racing)

[4] Formula SAE in America
[5] http://teambathracing.com

4

engineering courses such as automotive, aerospace, electrical, manufacturing and mechanical.

The aim of the study is to look at the effects of introducing a SM tool designed to support engineering communication into an engineering project, validate the requirements to support engineering communication that this tool has been built upon, and evaluate the usability of the tool. This is to be assessed through the capture of activity and communications within the SM tool and E- Mail, and through feedback from surveys of the user group.

The dataset was generated over 11 weeks of design and development, which consists of approximately 450 communications. The tool was introduced to the team in week one through a presentation and demonstration of the tools functionality by the author. This was the only training they had by the author. Weekly meetings were held with the author and the team to discuss the tools functionality and to answer any issues they may have alongside any additional one-to-one training if the users wished. There were no requirements to use the tool and it was viewed as an additional tool alongside Face-to-Face, E-Mail, FaceBook, Telephone & SMS communications that were also used. The functionality of the tool has remained a constant throughout these weeks with only issues (i.e. bugs) to be fixed.

4. Initial Insights

This section presents and discusses some initial insights from the 11 weeks of E-Mail and PartBook activity captured during the FS project in relation to how it has affected Engineering Work and the potential metrics that could be used to aid Engineering Project Management.

4.1 Effect on Engineering Work

Figure 8 shows the instances of communications in both PartBook and E-Mail for each week. Original E-Mails and creation of PartBook communications are the only ones that have been taken into account (i.e not replies/forwards). It can be seen that the contribution of E-Mails to the volume of computer-mediated communication was initially much higher than PartBook. Yet, by week three/four the relative contribution of PartBook had increased significantly and it appears that an equilibrium is reached between the two tools of approximately one third E-Mails to two-thirds PartBook Communications. Further the total number of communications averages approximately of 60 per week. It is argued that the uptake of PartBook took longer due to it being a new tool that the engineers are unfamiliar with. It could also be the case that the first few weeks were spent setting up and organising the project (i.e. Project Management communications) and therefore, the volume of EDCs, which is PartBook's key function, is less during those first few weeks. The key insight from this result is that despite having an additional method by which they could communicate, the actual communication workload of the engineers remains largely unaffected.

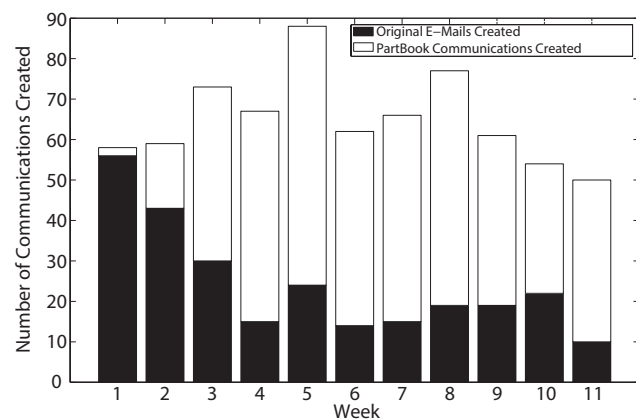Figure 9 shows box plots for weeks 6-11 of the time spent creating a communication.

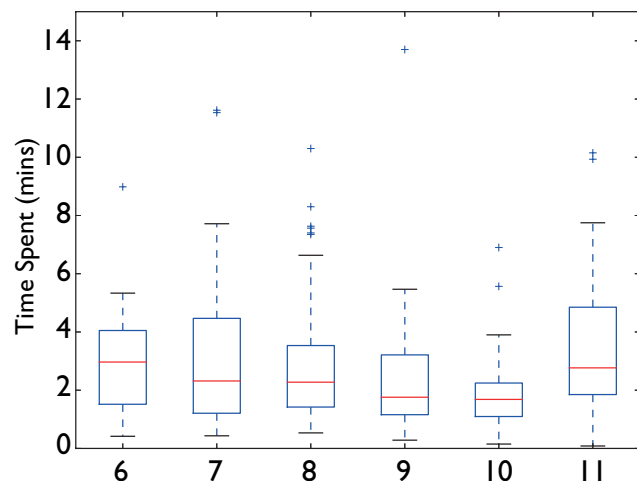**Figure 8: Instances of Communication in E-Mail and PartBook**

Figure 9: Time taken to create a communication within PartBook

5

This has been calculated by taking a timestamp upon the user going to the '*create a communication*' screen and a timestamp when the user clicks the 'create' function. Issues with the timestamps led to data for weeks 1-5 being unusable. However, it can be seen that the creation of a communication often takes within the region of 2-4 minutes although there are a number of outliers that reach 10 minutes. The box plots are fairly consistent over the eleven weeks with the majority of the communications taking between 2-4 minutes. This consistency suggests that the engineers became instantly familiar with the generation of a communication within the tool. Feedback from the team suggested that these were cases when an individual would start the '*creating communication process*' before having the image of the record available to them. Thus, this extra time was where they created the image to upload to the tool. Even though, the fact remains that it took a relatively short time to create the communications within PartBook especially when one considers that the average length of an original E-Mail (i.e. not a reply or forward) for the team consisted of 118 words on average and with a typical speed of 19 words per minute for composition, this leads to an average creation time for an e-mail to be around six minutes [Karat et al., 1999]. The key insight from this is that the time taken to create an Engineering Design Communication is actually reduced when using a Social Media tool that has been built specifically to support that type of communication.

The final aspect that has been considered with respect to Engineering Work is the effect of the tool on the collaborative nature of the engineers. Figure 10 provides a visual depiction of the communication network generated by both tools. Each node is representative of an engineer with the size determined by the number of connections to that node (degree). It can be seen that E-Mail (a) appears to have a few highly connected engineers, whilst the level of connectedness is more evenly distributed in PartBook (b). This is further shown by the average degree values of 8 and 23 respectively. Although, it is noted that E-Mail was the method used to communicate with people outside of the engineering team and that does influence the result as they would not be connected to all the engineers within the team. Even though, the magnitude of difference between the two levels of degree does suggest that a Social Media tool has the potential to provide a more collaborative method of communication within a team.
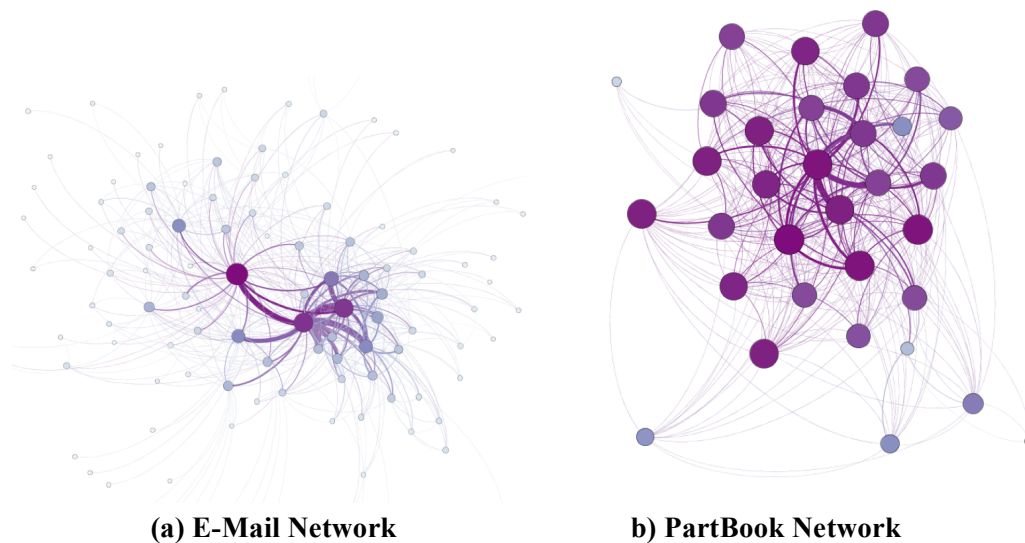

(a) E-Mail Network   b) PartBook Network

Figure 10: Network of Communications generated from E-Mail (left) and PartBook (right)

4.2 Potential Support for Engineering Project Management

Figure 11 provides an insight into the typical length in terms of number of replies for the various purposes of communications used within PartBook as well as showing the average number of people involved in these communications. The box plots show that there are distinct differences in the distributions between the various purposes of communication. For example, idea shows a high number of responses whilst action contains very little. Decision and confirmation both have the majority of the communications with a low number of replies but also have a positive skew showing that there are a minority of responses in the region of 10-15. This may be of potential interest to Engineering Project

Management as it may indicate levels of agreement upon particular subjects and possible areas of uncertainty. Figure 12 shows changes in the instances of various purposes of communication across the duration of the study. Firstly, it is clear that differences can be seen between the various purposes of communication and that some appear to coincide with events in the project schedule. Thus, it presents the opportunity for patterns to be identified that could be of potential use to - Engineering Project Management in understanding how the project is developing and further confirms past research showing that this may be the case [Wasiak, 2010]. There is a high-level of idea generation at the conceptual design phase and the number of instances drop considerably as the project reaches the design freeze milestone. This potentially shows the convergence of a solution. Noting that there is likely association between the two features, if one were to have a number of these events, it may be possible to associate the outcome of the 'design freeze' to the pattern in idea generation. Therefore,

Figure 11: The number of replies and the average number of engineers involved in the various purposes of communication

Figure 12: The instances of various purposes of communication across the duration of the study

the shape of the instances of idea generation before the 'design freeze' meeting could provide a useful indicator to whether the team has considered the entirety of the solution space (to their knowledge) and are converging on a solution. Engineering Project Management could use such information to provide intervention if and when required. One example may be altering the dates of review meetings to better coincide with the completion of work.

Figures 13 show the potential for differentiating engineers within an engineering project based upon their communications in relation to purpose, response types and against the engineering record that the communication is related to. Looking at Figure 13 it can be seen that both engineer 1 & 2 generate the most Information Requests whilst engineers 3 & 4 start the most discussions. Then there are engineers 2, 3 & 4 who have presented the most number of ideas. It is difficult to draw any conclusions from this directly, although it is argued that this may relate to the role, personality, expertise and/or capability of the engineers involved. The key point is that one engineer can be differentiated from another based on
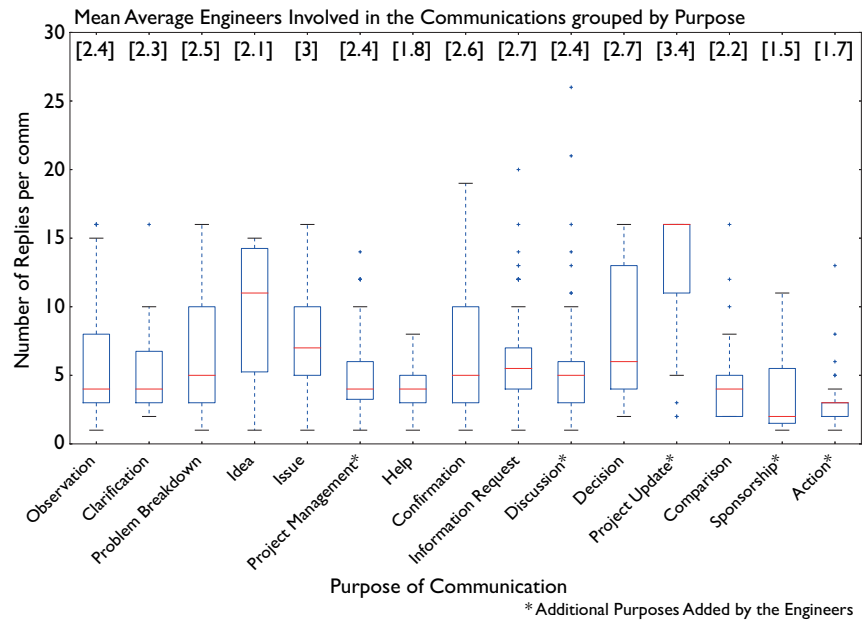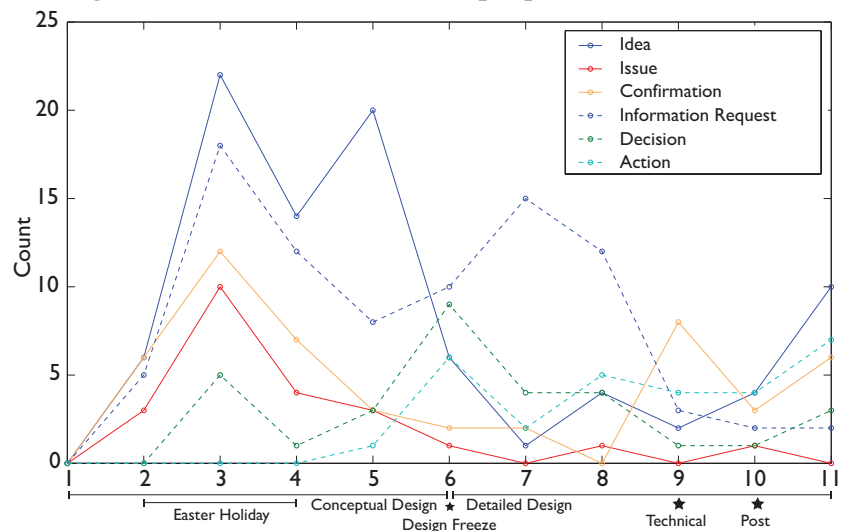
7

this dimension. This can also be said for the types of reply an engineer typically makes. For example, engineer 9 can be seen to make many opinion based statements independent of the purpose the communication whilst engineer 1 makes opinion statements to information requests and discussion statements in discussion communications rather than opinion statements.
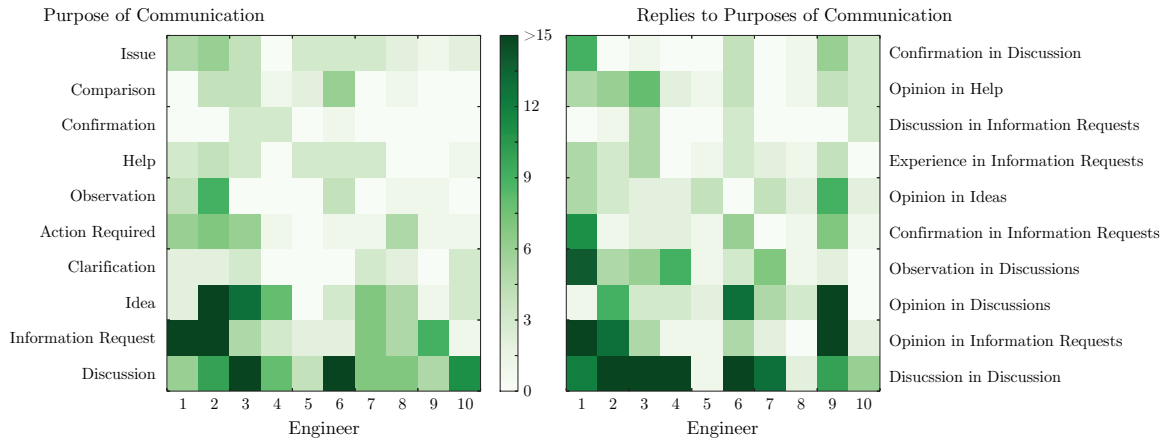

Figure 13: Potential Identification of Knowledgeable Engineers through the Purposes of Communication and their Response Types

Figure 14 provides a bipartite graph that relates the engineers to the artefacts with the weighted edges representing the number of communications with respect to the engineer and artefact. Again, the size of the node is dependent of the degree of that node. The figure clearly demonstrates that there are key members for each type of engineering record. Engineer 20 is highly associated with CAD, for example. This is the same for engineer 10 and Sponsorship. Engineer 11 is highly related to both CFD and Aero Design. Such a view on the engineering project has the potential to highlight the knowledgeable/key influential engineers on the various facets of the project. It can also distinguish potential integrators or engineers with a wider breadth of knowledge such as engineer 24 & 13. Such information could be used to automatically assess engineers' skill sets, enable appropriate Engineering Work to be sent to the right engineers and as a monitor of collaboration activities between various departments.
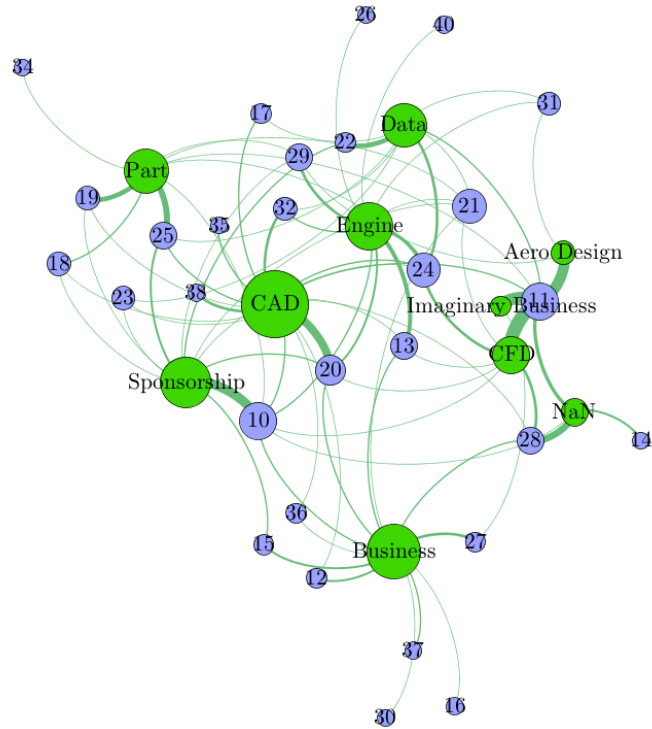

Figure 14: Potential identification of knowledgeable engineers through the digital objects they converse about

5. Conclusion

This paper has discussed the importance of Engineering Design Communication within Engineering Design as a means to share knowledge, maintain project awareness and reduce 'needless uncertainty'. Although fundamental to Engineering Work, E-Mail is still used as the distributed means for Engineering Design Communication despite its limitations in appropriately supporting it. This has led to the authors developing a Social Media tool that meets the requirements for supporting Engineering Design Communication [Gopsill et al. 2013c].

This paper has briefly described such a tool, called PartBook, which has been specifically designed to support EDC and has been used by a Formula Student engineering team for a period of almost 3 months. The paper then presents some initial insights from the study in terms of how the tool impacted engineering work and how the analysis of the SM content of the tool could aid project management by potentially monitoring aspects of its '*health*'.

These are as follows:

- The overall communication workload between the engineers remained largely unaffected by having an additional method through which they could communicate.
- The time taken to create an Engineering Design Communication is reduced (compared to e-mail) when using a Social Media tool that has been built specifically to support that type of communication.
- A Social Media tool that has been built specifically to support that type of Engineering Design Communication has the potential to provide a more collaborative method of communication.
- Levels of normality can be defined for various purposes of communication and deviation may indicate an area of potential interest for the Project Management Team.
- The levels of various purposes of communication over time may indicate current stage of the project.
- Engineers can be differentiated from one another based on purpose of communication, replies to communications and artefacts that are discussed, potentially leading to knowledgeable engineers being identified.

Acknowledgements

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Corresponding Author: Dr. James A. Gopsill, Research Associate, J.A.Gopsill@bristol.ac.uk

University of Bristol, Department of Mechanical Engineering, Queens Building, Bristol, UK