

COMPUTATIONAL TEAM DYNAMICS AND CREATIVE TENSION BALANCE INDEX IN NEW PRODUCT DEVELOPMENT TEAMS

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ABSTRACT

Teamwork is an extremely effective pedagogical tool in engineering education. New Product Development (NPD) has been an effective strategy of companies to streamline and bring innovative products and solutions to customers. Thus, Engineering curriculum in many schools, some collaboratively with business schools, have brought NPD at graduate level. Teamwork is invariably used during instruction where students work in teams to come up with new products and solutions. They need to be creative as a group and generate a breadth of ideas and innovative solutions. They also need to be very efficient in their teamwork and work cohesively. These two distinctive traits of the teams for have and manage ideational creativity and effective teamworking introduce different creative tensions in the team members – ideational conflicts and tensions thereof, and relational conflicts and interpersonal tensions thereof. Teams that foster and effectively manage these creative tensions are successful and teams that are not, show poor team performance. In this paper we explore the network structural analysis of these tensions and propose a Creative Tension Balance (CTB) index along the lines of Degree of Balance in social networks that has the potential to highlight the successful (and unsuccessful) NPD teams. Team's emails are analysed to generate the social networks for analysis. CTB index is computed, and this is used to correlate to the overall NPD team performance. It is found to capture the signatures of high and low performing teams.

Keywords: New product development, NPD teams, team creativity, social network analysis, structural balance

1 INTRODUCTION

Across industries one of the ways to be and remain innovative is through the introduction of new products. Companies place a lot of emphasis on New Product Development (NPD) and the company's very survival and competitive advantage lies in the success and effectiveness of their NPD. This imposes a lot of emphasis and pressure on the teams to be creative, innovative, and effective. The superimposition of the conflicting requirements on the team in terms of them being creative as a group, which translates to their discussions being more diverse and having more breadth in terms of ideas and topics / content, and at the same time the team members being on the same page and working very closely for an effective and efficient teamwork to develop the product and prototype impacts the team dynamics significantly. This divergence and convergence phenomenon of NPD process has been studied with respect to design documents and email communication by other researchers from this group [4]. The study conducted, discussed and presented here however focuses on the effects and impact of such a divergent / convergent (in a semantic coherence sense) phenomenon on the team dynamics over the entire NPD process and a metric that captures these creative tensions and their balance in the team. In this study team communication is analysed and patterns of team interaction that manifests in terms of team dynamics are identified. The different tensions (interpersonal tensions) that arise out of this divergent-convergent phenomenon / requirement among the team members and the spread of these tensions among the team is captured and analysed through a social network analysis technique called Structural Balance. A measure of this residual creative tension balance in the team, Creative Tension Balance (CTB) index, along the lines of structural balance, is proposed and this index is then associated with the team performance and team reflections to identify the signatures of high performing and low performing teams and explore the potential of this index to be a team creativity metric.

2 BACKGROUND AND LITERATURE REVIEW

There is a whole body of research on various aspects that contribute towards understanding the factors affecting New Product Development success and its effectiveness. Effectiveness research has focused on various aspects of NPD effectiveness and the factors influencing them. Wind and Mahajan [12] provide a good status of NPD research, the broader context of it, and the issues related to managing NPD in organisations. Creativity is consistently mentioned as a key ingredient and component of NPD in the literature [11][12]. There are three areas of research and literature that is relevant here: Teamwork and Team Dynamics, Team communication and Interaction, and Group Creativity.

Poole et al., [7] synthesise over 50 years of theoretical advances in *Small Group Research* from various disciplines into a set of NINE general theoretical perspectives. Yang and Tang in [14] take a social network perspective to show the team structure and team performance in Information Systems teams. Team climate is often cited when it comes to creativity in teams. Isaksen and Lauer [5] go on to define the nine dimensions of climate that support creativity. The concepts of Idea time, Idea support, Debate, and Conflict from these dimensions are the themes that are drawn upon in this research.

Morrisette [6] was one of the earliest to investigate the group tension and its correlation to group effectiveness. His work also defines a metric of identifying the balance of these tensions in the group, structural balance and degree of structural balance. The work of Morrisette is extensively used in this research and is used as a basis for extending it to characterise the creative tensions in teams and an index is defined and hypothesised to capture the signatures of successful and creative NPD teams and serve as a metric. Wortham [13] did extensive research and presented an analytic framework based on Social Network Analysis (SNA) to analyse computer-mediated communication in small groups. Agogino et al., [1] triangulated research from different methods and artifacts of NPD teams to identify indicators of successful teams. They analysed design sketches, email communication, and design documents using LSA (Latent Semantic Analysis) for coherence and shared understanding.

Team communication and interaction has been researched for quite a while and different techniques used to analyse the interactions including social network analysis (SNA) are found in the research literature. The research track that we outline here is mostly of team interaction where communication is the media of interaction. Of particular interest is the structural balance techniques of SNA as applied to communication within teams and their effects on the receiver. There was a lot of interest in SNA techniques and structural balance as a metric to capture various psychological aspects of interactions and their impact in the mid to late sixties [6][10]. As computer-mediated communication became more prevalent, the techniques of SNA applied to study team communication were explored further and can be seen in the many research literature [13][3]. [13] is comprehensive research that provides an analytical framework based on social network analysis to analyse computer-mediated communication in small groups. Generic SNA techniques and how to convert communication data into SNA representable data is also clearly laid out.

Team communication especially those that are based on content of communication does reflect the relationships between members quite accurately. Gorman [3] provides a semi-automatic measurement from team communication using Latent Semantic Analysis (LSA) and sequence analysis to analyse cognition. They consider the content and quantity of communication as well as flow of communication as a method of analysing team interaction. They have shown that LSA can be successful in assessing teams for communication content-based analysis. [2] describes and details the Latent Semantic Analysis and Indexing.

The connection of NPD to creativity and research on this angle of NPD can really be traced back to 1999 [8] where he outlined two dimensions of creativity, level and style, and studied effective NPD leaders from this angle. Later research started focusing more on the factors that influence team creativity, the activities that cause / generate / encourage creativity in teams like brainstorming, debate, the differences between them, the effects of these on team members and the influence of that effect (resulting as tensions, stress etc.) on team creativity and team dynamics. The value of deliberation and criticism in team creativity is very important to NPD teams.

3 DATASETS, PROCESSING, AND METHODOLOGY

3.1 Datasets

The dataset used in this research comprises of team communication in the form of emails between team members of New Product Development teams. The NPD teams are student teams from multiple semesters of the same course ME 290P / BA 290A – Managing New Product Development, which is a

graduate level course offered at UC Berkeley School of Engineering and Haas School of Business. This course is offered jointly by Haas School of Business, College of Engineering, School of Information Systems & Management, and the California College of Arts at San Francisco. 11 of these NPD teams of this course from one semester and 12 teams of another semester were chosen for this study. All the teams in this study comprised of four or five members. Teams that used email as their primary mode of communication are considered for this research. The course is project-based wherein the students work in teams towards a semester long project. Students work in small teams of four or five members. Teams are multi-disciplinary and students from these different disciplines aim to join forces on small product development teams to identify a user need and come up with a product solution to address the need. They then go through the new product development process in detail to develop the concept into a fully working prototype and gain valuable knowledge and experience along the way.

3.2 Data Processing and Analysis

3.2.1 Team Communication Content-based Social Network Analysis

Traditional Social Network Analysis (SNA) mostly uses frequency of communication as a means of measuring the interaction between actors. As in this small team setting, emails are addressed to a common listserv email address and the content of an email are meant for multiple team members, the content of communication is used rather than the frequency. The content of communication is analysed using the Latent Semantic Analysis (LSA). Topic segmentation and clustering are done on the LSA vector subspace and the actual content measure of each of the emails is then computed. This content measure of email is used to determine the content-based interaction with other members and aggregating it over all the emails exchanged to arrive at the total level of interaction of a member with another team member is computed. Tabulating these scores between the members gets the adjacency matrix used to arrive at the social network graph.

3.2.2 Social Network Adjacency Matrix (AM) and Tie-Strength

After levels of interaction between members are arrived at based on the content of email communication, a matrix is generated specifying these levels of interaction as matrix cell values. The cell values a_{ij} of the matrix corresponding to the i th row and j th column of the matrix and represent a_{ij} = interaction between member i and member j . This matrix is termed as Adjacency Matrix of the network of the team. Each team will thus have a separate adjacency matrix. Adjacency matrices of all the teams are computed. For visual representation of the network graph, the adjacency matrix is transformed into a symmetric matrix with average interaction strength representing tie-strength between the members. In another research paper, [9] have outlined the methodology to arrive at visual representation of these team interactions using this social network analysis and tie-strengths. In these visual representations, the thickness of the line between the nodes is proportionate to the tie-strength between the members represented by the nodes.

3.2.3 Dichotomised Adjacency Matrix (DAM)

Social network analysis provides many techniques to transform the network adjacency matrices to amplify stronger interaction arcs and attenuate weaker interaction arcs, thus providing a sharper interaction diagram for the team. One such analysis technique is the dichotomisation of the adjacency matrix of the team. This dichotomisation is a technique wherein every cell value of the matrix is compared with a given average value and if the cell value is higher than the average, it replaces it with a 1 and for cells that have a cell value lower than the average value it is replaced with a cell value of 0. Thus, the new dichotomised adjacency matrix would just contain arcs between members who have more than the average level of interaction and would drop those interaction arcs for those where the level of interaction is lower than the average. Density of the social network provides a good metric for the average interaction level or average tie-strength of the team's network and this value is used in the dichotomisation of the adjacency matrix. This Dichotomised Adjacency Matrix (DAM) is computed for each of the teams from considered in this study.

3.2.4 Structural Balance Computation – Degree of Balance

A transformation of the adjacency matrix is used as the base matrix for identifying cycles and semi-cycles which are the basis for balance computation. This transformed matrix is one whose values are from the set $\{+, 0, -\}$. Each of the cell values from the original adjacency matrix is used and compared with the network density (Δ) value. If the original adjacency matrix cell value is greater than Δ then the

value in the cell of the transformed matrix is '+'. If it is less than Δ , then the value in the transformed matrix cell is '-' and '0' if it is exactly equal in value to the network density value Δ . A slightly different transformation matrix is used for the degree of structural balance and for this the transformation matrix has numbers instead of just signs and '0'. Network Density (Δ) value again is used as the transformation parameter. From the cell values of the adjacency matrix the value of the transformed matrix cell is computed. The new cell value is just the value that is greater or lesser than the Δ value. So, values will be signed real numbers. This matrix is called the Degree-Structural-Balance Matrix.

The cycles and semi-cycles of the team's social network are listed in the same way as explained earlier. The cycle / semi-cycle strength is computed as the algebraic product of the cycle's arcs taken from the Degree-Structural-Balance matrix. Morrissette's degree of balance is one of the popular degrees of balance and is computed as per the equation (1) below:

Morrissette's Degree of Balance of a Graph.

$$b(G) = \frac{\sum_{k=1}^r p\sigma Z_k}{\sum_{k=1}^r |\sigma Z_k|} \quad (1)$$

3.2.5 Creative Tension Balance (CTB) Index Computation

Creative Tension Balance index measures the residual and interpersonal creative tensions in teams. Creative Tension Balance Index is essentially a function of the Residual Creative Tension (RCT) and the Interaction Factor (IF). The value of CTB index is computed for every team as per the formula.

The Creative Tension Balance Index (CTB) is given by the equation (2) below.

$$CTB = [1.0 - (RCT * q_1 + IF * q_2)] \quad (2)$$

where q_1 and q_2 and weight constants that combine the two factors. For four member teams, $q_1 = 1.0$, $q_2 = 0.2$ and for five member teams $q_1 = 0.7$, $q_2 = 0.3$.

4 RESULTS AND DISCUSSIONS

The Creative Tension Balance (CTB) index computed for all teams are correlated with the team performance in the semester as assessed through their final semester numeric grade and the grade categories. The correlations first measure through a Pearson's correlation metric whether there is a correlation in the list of values of CTB and team grade numbers. Then the correlations look into the ability of the CTB metric to correlate to the top performing and lowest performing teams. These correlations are presented in this section.

We first present the results of correlation of Creative Tension Balance with the team grade. The results are presented in table 1 for all the teams. At the end of the table the Pearson's product moment correlation coefficient, r , between the Creative Tension Balance and the team grades is computed and the value displayed. Pearson's product moment correlation coefficient between two array of numbers is given by the equation (3) below.

$$r = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 \sum (y - \bar{y})^2}} \quad (3)$$

The values of r range between -1.0 and +1.0 indicating the linear relation between the two arrays. The table also shows the computed T-Test probability associated with Student's T-Test for 1-tailed distribution and the type of T-Test being two-sample unequal variance (heteroscedastic). This aids in arriving at the statistical confidence measure of the correlation value computed. The T-Test probability and the statistical probability measures are also shown in the table.

Table 1. Correlations of Creative Tension Balance (CTB) with Team Grades (Performance).
Green boxes indicate highest performing team in the class and orange-coloured boxes indicate lowest performing team in the class

Team	Grade	Creative Tension Balance (CTB)
A	115	0.33
B	117	0.38
C	107	0.54
D	90	0.05
E	115	0.40
F	109	0.44
G	120	0.67
H	115	0.10
I	108	0.42
J	115	0.52
K	106	0.09
L	85	0.49
M	85	0.40
N	90	0.41
O	90	0.48
P	85	0.56
Q	90	0.54
R	90	0.40
S	85	0.39
T	85	0.38
U	85	0.24
V	90	0.45
W	95	0.64
	Pearson Correlation	0.564278782
	Statistical Confidence Measure	p < 0.001

5 DISCUSSIONS & CONCLUSIONS

We have shown here through a social network analysis of the NPD teams and standard network analysis techniques of structural balance a means of extending the degree of balance to include the effects of team dynamics, patterns of interaction and residual creative tensions to arrive at an integrated index called the Creative Tension Balance (CTB) index. This paper provides the specification and definition of Creative Tension Balance index that characterises the balance of ideational and relational tensions in teams.

The Creative Tension Balance metric is associated with the student team's final overall grade. The two semesters grading differed a bit and teams L through W had mostly an overall low, medium, and high grade levels only. However, in both the semesters, the best performing team was announced and the teams having a lot of issues in terms of the various measures were provided feedback. The Creative Tension Balance index is able to clearly point the high performing teams and also highlight the lowest performing teams consistently. The overall correlation coefficient, however, is just a 0.56 as the spread of the grades between teams in one of the semesters was quite low. The ability to capture the signatures of high and low performing teams using the Creative Tension Balance can clearly be seen.

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