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Requirement Volatility Metrics as an Assessment Instrument for Design Team Performance Prediction*

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Predicting and assessing student team performance in design projects presents a host of challenges. Most involve turning qualitative interpretations into quantitative assessments. This challenge is simplified when all student teams are working on the same project. Establishing a relative performance metric based on the top and bottom performers simplifies the task. However, in classes where the projects are diverse and/or sponsored by outside industry representatives the challenge is increased. In classes where formalized requirement documentation exists, requirement volatility (change over time) can be used to simplify student team performance assessment, as well as serving as a predictor of future performance on the project. In an analysis based on project requirement documents from the graduate design class at Stanford, ME210, requirement volatility metrics proved to have surprising power as a predictor of student design team performance. Tracked over time, the metric predicted of team rank-order performance. This document will summarize a method for volatility measurement and the results of our initial analysis.

CONTEXT

COURSE ME210 'Team-Based Design Development with Corporate Partners' is a graduate level design class which focuses the students' efforts on real-world design problems generated from the challenges facing the corporate partners of the class. Over the nine-month duration of the class, students bid on projects, formulate formalized requirements, generate prototypes, document the effort, and present milestone results to the corporate sponsors. Averaging between 10–15 different projects a year, it is difficult to predict the success of the teams. Given the diversity of the projects, it is also challenging to make assessments of the team performance relative to each other. Each project has its own innate issues and unique circumstances. For the students this creates an enriched environment in which they experience the victories and defeats of many diverse projects beyond the focused efforts of their own.

Making assessment of student performance is a significant challenge when you have groups of students working on the same design problem. This challenge is compounded when each group has a vastly different project. Often the true performance of the design team is not known till the delivery of the final prototype. In the life of ME210 there have been stellar teams fail terrifically and mediocre teams succeed heroically. Research by Ade Madabunge has indicated that current and future performance of design teams can be assessed based on an analysis of the number of unique noun phrases in the project design documentation. A complex and time-consuming analysis, the technique does not lend itself to regular assessment of student performance though does provide a metric of unique concepts generated by the design team.

REQUIREMENT VOLATILITY

Requirement volatility has a marked effect on the deliverables of any product development effort. Gause and Weinburg explain that false assumptions not corrected in the requirements development phase may cost 40 to 1000 times more to remedy after the product has already been fielded. A survey of 133 defense system program managers cited requirement changes as responsible for annual cost growth of 2.71% and responsible for 11.9% of the total schedule slip that occurs over the procurement cycle [5]. The effects of requirement volatility in the real world can also be felt in the academic reality. Leveraging off Mabogunje's work with the design documentation, other relationships between team performance and information documented about the team and their efforts in the formalized design documentation were sought. Analysis of design documentation from

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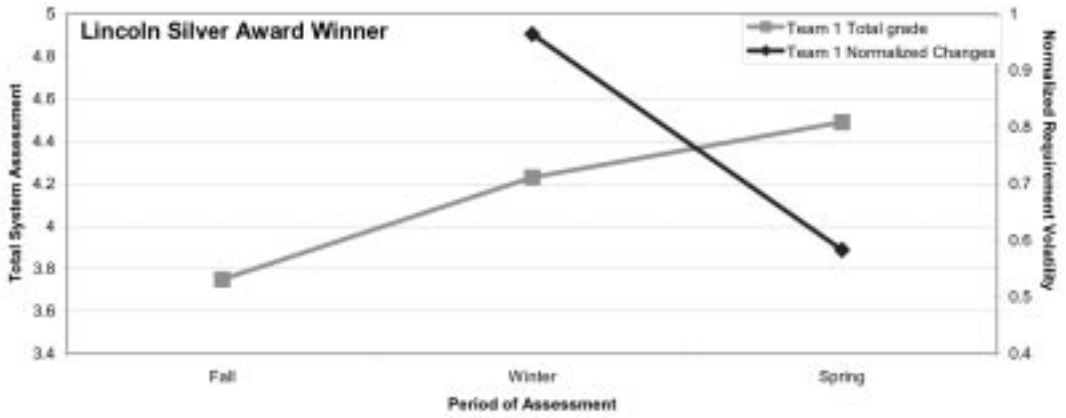

Fig 1. Team 1 performance as compared to normalized requirement volatility.

ME210 has indicated certain relationships between team performance and the volatility of the requirements documented in the formalized requirements.

From the archive of ME 210 data at Stanford, three teams from the same academic year were chosen at random for detailed study. The students are required at the end of each grading period to publish a Design Requirements Document (DRD) that details the status of the product development. For each team, the system requirements were extracted for all three grading periods, Fall, Winter, and Spring. Once extracted, comparisons were made between the different editions of the DRD, paying special attention to modifications in the requirement set from period to period. Modifications were grouped into three categories, changes in existing requirements, creation of new requirements, and redundant allocations of requirements. Number of modifications was normalized for fair comparison between the different teams. Once the requirement data was analyzed, performance data was collected.

ANALYTICAL RESULTS

The graphs (Figs 1, 2, 3) depict the analytical results of each of the selected teams' volatility analysis. Additionally their overall performance for each quarter is also noted. Finally the team's performance in the Lincoln Arc Welding design competition is displayed. The results of this competition are included in this study as a third-party objective assessment of the student team performance.

Notice that Team 2 had the most success in managing their requirements. This proved to have a positive effect on their performance as indicate by both their grades and their performance in the Lincoln Arc Welding Contest. Team 1 successfully improved their management of their project requirements as the development matured, resulting in improved performance in the final semester. Team 3 lacked successful requirement management. Although their performance improved throughout the project, their overall performance was significantly lower than Team 1 and Team 2. Samples of requirement volatility made through the development efforts can be used to assess the progress of the students as well as make assessments as to their future performance.

IMPLEMENTATION

Valid for design teams that develop formalized requirements, the requirement volatility metric can be extracted from design documentation. It is

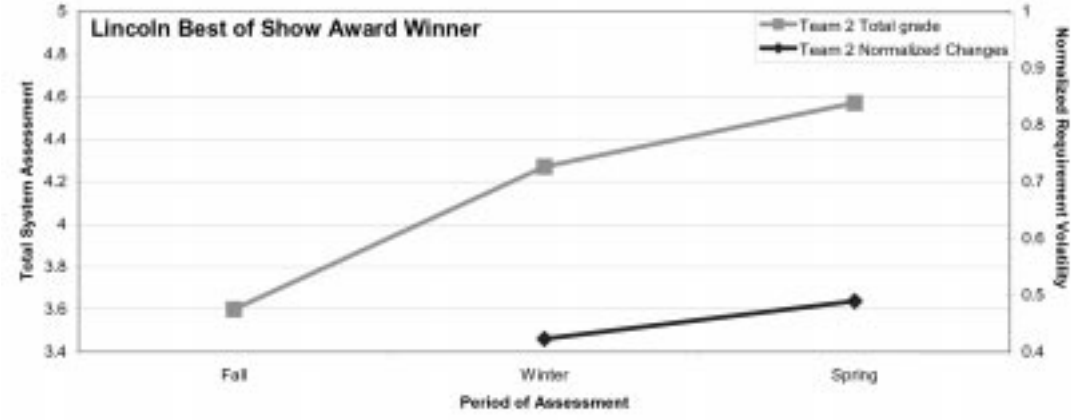

Fig 2. Team 2 performance as compared to normalized requirement volatility.

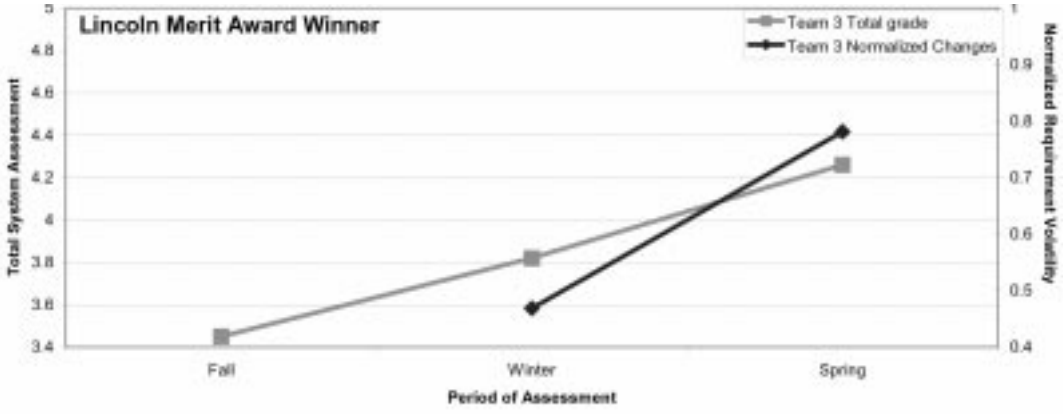

Fig 3. Team 3 performance as compared to normalized requirement volatility.

important to note that the use of such a metric should be limited to qualitative assessment rather than for grading of the students; otherwise the students can modify their documents so as to maximize their grades as opposed to having a true assessment of the design team's progress. This is similar to the dilemma surrounding Schoedinger's cat. Any attempt to open the box to assess the state of the cat would find it dead, regardless of the actual state prior to assessment. The same fear holds true here, in how assessing the students' grades in this fashion will affect their performance.

For curricula that make use of requirement tracking tools, such as DOORS, the task of extracting such metric is greatly simplified. Otherwise a simple spreadsheet of requirements can be used to track the student progress along the way. Critical to the use of this method is a formalized record of requirements so that an accurate representation of volatility can be made.

FUTURE WORK

In the near future, an exhaustive survey of ME210 project materials will be undertaken to test the applicability of these methods. Using the five-plus years of data to support the maturation of the model, the method will be used to support assessment of student progress in the senior capstone design class at the United States Air Force Academy.

REFERENCES

1. N. Cross, *Engineering Design Methods: Strategies for Product Design*, John Wiley and Sons Ltd., Chichester, UK, 1989, 1994.
2. J. M. Feland, M. L. Nowak, L. J. Leifer, Cost-performance management through knowledge reuse in large-scale defense projects—vision and proposed system architecture, *Proc. Design Reuse*, *EDC 98*, Brunel University, 1998.
3. D. C. Gause and G. M. Weinberg, *Exploring Requirements: Quality before Design*, Dorsethouse Pub., New York, NY, 1989.
4. A. Mabogunje and L. J. Leifer, Noun phrases as surrogates for measuring early phases of the mechanical design process, *Proc. 9th Int. Conf. Design Theory and Methodology*, ASME, Sacramento, California, 1997.
5. E. Rebentisch, *Preliminary Observations on Program Instability*, White Paper LEAN 96–03, Lean Aerospace Initiative Working Paper, Massachusetts Institute of Technology, 1996.
6. http://me210.stanford.edu (ME210 Web Site)
7. http://sll.stanford.edu (Stanford Learning Lab Web Site)

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