Configuration Management Instructional Material for Engineering and Management Students

Michael Leonard, Nagraj Balakrishnan, Judith McKnew
Clemson University

Abstract

This paper documents interim results of a NSF–CCLI funded project to develop innovative educational materials in Configuration Management (CM) for use as a module in regularly scheduled courses in engineering and management. CM is a methodology for identifying the components of a continuously evolving product and its associated production system, to control changes to these components and to maintain integrity and traceability throughout the system life cycle. CM provides a means to insure effective and efficient engineering and management reviews, costing, and adoption for approved product and process changes. Doing CM well can have a significant influence on reducing costs and improving productivity.

Although professional development programs are available to provide corporate managers with an understanding of CM, there is little coverage of CM in typical engineering and management courses in universities. This may partially be the result of limited CM educational resources for faculty use. For that reason, we have prepared a CM Overview Module and Instructor's Guide to be used in a one-to-two week segment of engineering or management courses. The contents of the educational sessions, outside readings, and recommended homework and project assignments are described in this presentation. Also discussed is the use of pre- and post-testing, and the use of an skilled teaching-effectiveness-and-innovation observer, to evaluate the effectiveness of, and make enhancements to, the CM instructional sessions and materials.

I. Introduction

Configuration management is a significant concern for any manufacturer. As a typical product progresses from prototype design to initial unit manufacture and then through the later stages in its life cycle, the number of changes made to that product in terms of refinements to component parts, part suppliers used, assembly methods employed, testing protocols applied, and maintenance procedures recommended can be very large. Configuration management is an organized method for engineering documentation control which provides a systematic approach to selecting product related information to be maintained, and provides structure and speed to the formal review, costing, approval and adoption of changes. In other words, "Configuration management is the discipline of identifying the components of a continuously evolving system (taking into account relevant system interfaces) for the purpose of controlling changes to these components and maintaining integrity and traceability throughout the system life cycle [1]."

Configuration management (CM) is a software-driven approach to the task of coordinating an enormous quantity of detailed information. Properly implemented, CM provides, in a nearly paperless environment, the ability to plan, identify, control and account for the status of a product's configuration and its logistic support at any point in time, the ability to insure appropriate review and approval processes are followed in processing proposed changes, and the ability to forecast the costs of change [2].

CM is used routinely in the defense and aerospace industries, and there are a numerous commercial software systems that support these applications. While there is also considerable commercial software designed to support more general manufacturing implementations of CM, these systems have not been widely adopted across the manufacturing sector. In most manufacturing firms, particularly small and mid-sized organizations, the myriad details of product design and manufacture are typically handled, stored and accessed on an ad-hoc basis by a few indispensable individuals. Unfortunately, informal systems are prone to error, which at the very least waste resources and can sometimes be life-threatening to consumers.

Why are CM systems not yet widely implemented in the general manufacturing sector? Certainly professional development education programs are available to provide corporate managers and operating personnel with an understanding of the benefits of CM and the key steps in implementing these systems. For example, the Institute of Configuration Management, established in 1981 and headquartered in Scottsdale, Arizona, offers a comprehensive array of coursework in configuration management.

However, within university academic environments, there is little or no coverage of CM in the typical baccalaureate-level engineering or management coursework. Indeed, the authors of this paper know of no examples of regularly offered undergraduate coursework which provides more that a brief overview of CM. In part, this lack of coverage may be the result of limited educational materials for faculty members to use as resources. Academic journals provide references to CM under topics such as quality-assurance and management of design, but there are very few textbooks that are explicitly dedicated to CM [3]. Moreover, since commercially available CM software is expensive and not quickly adaptable to student use with personal computers and/or a university network server, it is also very difficult to demonstrate the operation of CM systems in an academic setting. Thus, today's engineering and management graduates do not leave their universities with an understanding of CM, its benefits, and how such systems operate.

When one of today's graduate enters the workforce in defense or the aerospace industry, where CM is present by mandate or by tradition, he or she is likely to soon be educated by colleagues in the benefits of CM and be able to function in this environment relatively quickly, particularly if the graduate attends professional development courses. However, if the graduate of a current engineering or management program enters a typical manufacturing environment, where CM is not a part of the culture, he or she is all but certain not to lead a move to, and perhaps not even to be an advocate of, introducing a CM system. Hence, the cycle of missing benefits from failure to employ CM continues.

Currently, there is no provision or demand in either engineering or management curricula for introducing a full course in CM. As with any new topic, it is important to generate sufficient awareness and interest among students in order to make a course in CM a viable course offering. To do this, a carefully planned CM instructional module could be developed and placed in production control and/or quality engineering required coursework in industrial engineering. Similarly, courses in operations management and/or information systems, which are typically required in management curricula, would be natural vehicles for the presentation of this CM module.

The authors of this paper proposed to the Course, Curriculum, and Laboratory Improvement Program of the National Science Foundation (NSF) Division of Undergraduate Education, a proof of concept project to develop CM educational materials. Specifically, we sought funding to develop and introduce a CM Overview Module and accompanying Teacher's Guide for use as part of regularly-scheduled courses in engineering and business curricula. NSF funded our project in May, 2000, and our work on the project began in June 2000.

II. The CM Overview Module

The CM Overview Module provides 1-2 weeks of college-level coursework. The module is modeled on material presented in the few reference texts that provide significant discussions on CM topics, and on material developed by the Institute of Configuration Management. As such, the module introduces students to CM and its various components. The module also includes material illustrating how commercially available CM software is used in change control.

The educational materials in the Overview Module have been developed with eight specific educational objectives in mind. These objectives specify that, at the end of the CM Overview module, students will be able to

- Correctly use selected CM terminology including: engineering change requests, engineering change orders, field change orders, configuration item, vault, approved document, controlled document, functional baseline, allocated baseline, developmental baseline, product baseline, revision levels and effectivities, interchangeable, traceable, and continuous improvement;

- Describe the consequences of trying to function (in a manufacturing, service or software environment) without the use of CM (and clear, concise and valid documentation);

- Explain why the product or process is considered the proof of the documentation;

- Describe how basic information about products and processes is communicated (via bills of material, blueprints, specifications, operation sheets, process charts and flow diagrams);

- Explain why change is necessary and inevitable, and why continuous improvement is critical to the future competitiveness and survival of the organization;

- Explain how to apply CM principles facilitate continuous improvement;

- Explain why changes apply to documents, not physical items, why physical items and/or processes must conform to the documents; and

- Analyze the elements of a successful CM implementation including: physical item hierarchies and linkages, administrative hierarchy and linkage, development programs and work breakdown structures, flow down of requirements, document validation, integrated databases, and database audits.

To help students achieve these learning objectives, the authors have prepared as set of CM instructional materials. These materials include a four-chapter Readings in Configuration Management, a set of PowerPoint© lecture notes highlighting key points in the Readings, a CM Overview Module Teachers Guide, CM case studies, and pre- and post-module evaluation instruments.

The chapters of the Readings in CM include:

- *An Introduction to CM.* Several example problems are used to illustrate the importance of CM and the results a firm can hope to achieve by implementing CM. Also discussed are typical industry practices in firms that do not have good CM and how poor CM practices result in high costs, wastage, etc.

- *Identification and Documentation.* This chapter examines the product development life cycle and the role of CM can play in insuring that products and processes consistently conform to specifications. Product and process documentation, configuration items, and baselines are examined in some detail.

- *Change Control and Management.* The role of CM in change control and change management is examined in light of the motivations for ongoing product change, and the types of changes that may need to be considered. Relationships between CM and continuous improvement are also explored.

- *Status Accounting, Audits, and ISO 9000.* Processes used to record and report information needed for management of product characteristics, and evaluations used to ascertain product compliance to specifications are examined. Also discussed are relationships between CM and ISO 9000.

In order to give students, some of whom may have little or no work experience, a deeper appreciation of the importance of CM, the module presentation includes example problems and cases in which students consider/play the roles of employees of different departments of a manufacturing firm. These example problems and cases are used to illustrate the chaos that could potentially develop when a firm makes product and/or process change decisions in a non-coordinated manner, and the benefits resulting from a CM oriented approach. A demonstration of the use of CM software is also employed to illustrate how computer systems can monitor progress of a request for product change as it moves though a typical organization.

The CM Overview Module Teacher's Guide provides an annotated bibliography documenting sources for material presented in the CM Overview Module, and a reading list on CM-related topics. The guide also describes possible supplemental reading and project assignments for engineering and business students.

III. Evaluation of the CM Overview Module

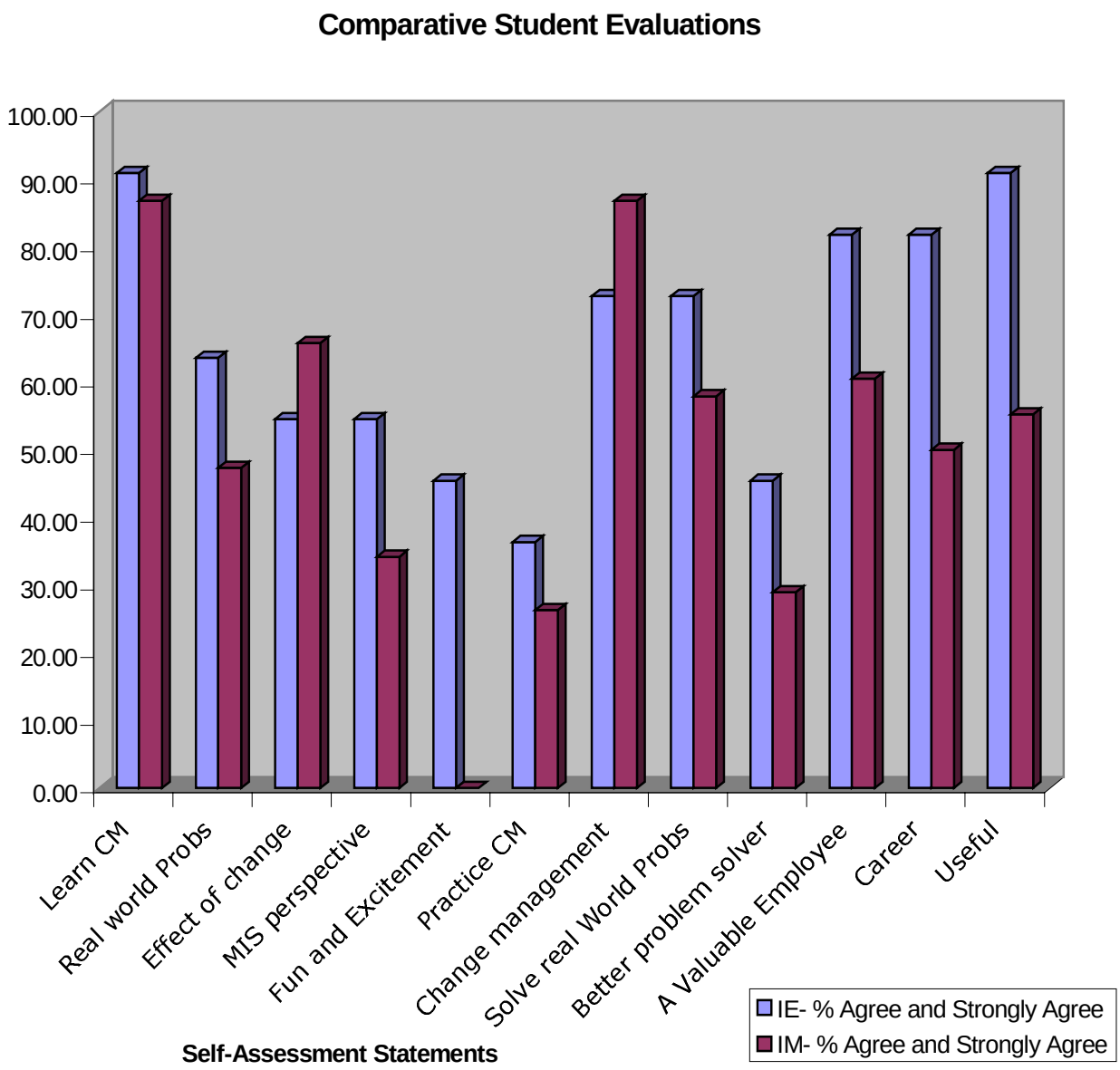
The CM Overview Module was presented to one class of 11 engineering students and one class of 37 management students on the Clemson University campus during the Fall 2000 semester. The classes selected for module delivery were a required senior-level industrial engineering course in production planning and control and a required junior-level course in management information systems. In the industrial engineering class, the module was covered in 5 fifty-minute class periods; while in management, the module was presented in 3 seventy-five minute classes.

The effectiveness of this first module delivery was assessed in several ways. A pre-module evaluation and post-module quiz (counted as a part of the course grade) were used to evaluate student learning about CM principles. In addition, three homework assignments on applications of CM to local industries were collected and graded. At the end of the module, each student completed a self-assessment addressing what the student learned about CM and how the module could be improved. Finally, the Director of the Clemson University Office of Teaching Effectiveness and Innovation sat in on one class session of both the engineering and the management offerings of the CM module to assess the effectiveness of subject material delivery. At the end of the sessions where she visited, she asked the instructors to leave the classroom, and she talked with the students about their understanding of module learning objectives, their views about the importance of CM, and their thoughts about how this material might be useful in their careers.

The pre-module evaluation and post-module quiz data collected from the first round of CM Overview Module delivery showed measurable changes in knowledge about CM. Mean pretest scores were 6.71 for engineering students, and 6.43 for management students [on a 9-point scale where 6 indicated "some" understanding of the need to manage documentation and change control processes, and 9 indicated "a good" understanding these information management issues]. Post-module quiz scores were 89.6% for engineering students and 90.3% for management students.

Homework assignments were graded on the same 9-point scale used for the pre-module evaluation. Mean homework assignment scores for engineering students were 7.78, and 7,89 for management students.

The post-module student evaluation included self-assessment sections on knowledge, motivation, problem solving skills and general information where the student was asked to respond to statements with either "strongly disagree," "disagree," "neither agree or disagree," "agree," or "strongly agree." A display of the "agree" and "strongly agree" responses for both engineering (IE) and management (IM) students is presented below:



A summary of the observations made by the students interviewed by the Director of the Office of Teaching Effectiveness and Innovation during the Fall 2000 offerings of the CM Overview Module included the following comments:

Strengths:

- Case studies most helpful to our learning
- Combination of the excellent handout packet, which allows us to learn from the outlines or the text, and the lecture
- Strong on the "why" and "what" of CM.
- Module and its materials are well organized
- Demonstrations are very important to our learning
- Materials are aimed at our level

Weaknesses

- Not designed to suit how we learn. Too much lecture. We learn better by examples, cases, simulations, and other forms of hands-on experience.
- Material presented is too abstract with not nearly enough focus on how to do CM in a corporate setting.
- Too many lengthy, complicated definitions for simple concepts
- Module rushes thought material because there is too much information for the short time allowed. We don't feel free to ask questions.

Suggested Improvements

- Less lecture and more cases, simulations, and other forms of hands-on learning
- More in-depth treatment of CM with a greater focus on how to do CM and make good CM decisions in a corporate setting. Make the module longer.
- Give more examples/cases of companies that use CM

IV. Next Steps in the Development of the CM Overview Module

At the time of the writing of this paper in December 2000, the authors have begun to make changes to the CM Overview Module in advance of a second presentation of the material to the students in an industrial engineering and a management class during the Spring 2001 semester. Planned revisions include a reduction in the amount of lecture materials presented in the module sessions and increased use of examples. Likely additional examples include disassembly of two or three frequently used products, examination of their component parts, and discussions about what changes might be made to the parts and how they should be evaluated and controlled throughout the life cycles of the products.

Following the second offerings and subsequent revisions of the CM Overview Module during the upcoming semester, the authors will turn to the important issue of disseminating their work to interested colleagues at other universities. A Clemson University CM web site will be developed to serve as:

- *an information distribution site*. The web site will serve as a convenient location for placing orders for the CM Overview Module and CM Overview Module Teacher's Guide
- *a source of updated CM course material*. As the overview module is refined each semester, it will be updated on the web page for easy distribution.
- *a link to other CM web sites*. The web site will serve as a one-stop source for academic literature in CM.

Finally, it is anticipated that the proof of concept project will be successful in demonstrating the value of CM instructional materials for undergraduate engineering and management students, and the appropriateness of the approach to module development employed by the project team. If so, the project team will propose to the NSF that funding be provided for the development of CM engineering, business, and laboratory modules. These three modules and supporting teacher's guides, in conjunction with the CM overview module materials developed in the proof

of concept project will provide the basis for a semester-long interdisciplinary elective course in CM. We anticipate that that the second stage CM instructional materials development and testing activities will be jointly conducted by a project team with members from Clemson University and the Arizona State University.

V. Conclusions

This paper has described the development of a CM Overview Module to help faculty in engineering and management meet and important educational need of their undergraduate students. Through this NSF funded CCLI project, the authors have worked to accomplish the following objectives:

1. development and evaluation of the instructional module, including a set of Readings in CM, PowerPoint© slides, example problems, case studies, and other supporting instructional materials incorporating effective educational practices and pedagogies;
2. development of a CM Overview Teacher's Guide for current and future engineering and management faculty members providing insights on the operation of CM systems and effective ways to teach students this information;
3. dissemination of CM Overview Module instructional materials to promote the effective implementation of these materials in institutions across the United States.

By way of its dissemination efforts, the authors will make available and encourage the use of the CM educational materials by engineering and management colleagues across the nation. Progress to date gives strong evidence that these three objectives will be accomplished during the 2001 calendar year.

Acknowledgement

The authors gratefully acknowledge the financial support for the development of the CM Overview Module provided by the National Science Foundation Grant Number DUE-9952277.

Bibliography

1. British Standard 6488. Code of Practice for Configuration Management of Computer-Based Systems. British Standards Institute (1984)
2. Monahan, R. *Engineering Documentation Control Practices and Procedures*. New York: Marcel Dekker (1995).
3. Fowler, A. Models and Applications of Configuration Management. *Omega*. Vol. 21, No. 4, pp. 425-431 (1993).

MICHAEL LEONARD
Michael Leonard is Professor of Industrial Engineering and currently Interim Chair of the Department of Industrial

Engineering at Clemson University. Dr. Leonard holds Bachelors, Masters, and Doctoral degrees in Industrial Engineering, and his research specialties include scheduling, performance assessment, and information and healthcare delivery systems. He is a Fellow of the Institute of Industrial Engineers, and a registered Professional Engineer in Missouri and South Carolina. Dr. Leonard currently serves as a Representative Director on the Accreditation Board for Engineering and Technology.

NAGRAJ BALAKRISHNAN
Nagraj (Raju) Balakrishnan, Professor of Management at Clemson University, teaches courses in Management Science, Business Statistics, and Operations Management. His current research focuses on job and tool scheduling, capacity allocation models, and problems related to the interface between manufacturing and marketing. His articles have been published in leading academic journals such as *Decision Sciences, Production and Operations Management, European Journal of Operational Research, IIE Transactions, Networks*, and *Computers & Operations Research*. Dr. Balakrishnan serves on the editorial boards of *Production and Operations Management* and *Computers & Operations Research*.

JUDITH McKNEW
Judith McKnew is a Lecturer in Management at Clemson University. Dr. McKnew holds a Bachelors degree in Construction Science, Masters degree in Industrial Management, and a Doctorate in Industrial Engineering. She has done research in the areas of manufacturing and simulation, and teaches in the areas of operations research and management, and statistics.