

## A Graduate Course in Agile Manufacturing

Rakesh Nagi

Department of Industrial Engineering, State University of New York at Buffalo

**Abstract** In face of recent global competition, a significant paradigm -- *agile manufacturing* -- is emerging, where multiple firms cooperate under flexible virtual enterprise structures. To address manufacturing education needs to promote and understand agile manufacturing concepts, a unique graduate level course is being offered at the Department of Industrial Engineering, SUNY-Buffalo. This graduate level course covers topics, enabling techniques/technologies, and case projects in agile manufacturing. It provides a core set of fundamental tools, example applications and open research topics. The objective is to expose participants to agile manufacturing issues, and enable them to creatively synthesize and apply the tools covered to open research problems. It blends quantitative and qualitative material, from multiple disciplines of industrial, manufacturing and management engineering. The specific objectives of this paper are to discuss the design and experiences of this course. Further, it is our desire to share the motivation behind the relevance of such a course, and some of the challenges in designing and offering it. We would also like to propose some possible directions in which academia could focus so that a skilled and empowered manufacturing profession base can be created.

### 1 Introduction

Markets for industrial goods have been fragmenting and changing rapidly. The reasons that have brought about this unpredictable change, but one which has almost become a way of life, are the constantly changing customer demands, broader product ranges, shorter model lifetimes, production to order in arbitrary lot-sizes, and technological innovations. To be competitive and thrive in such a dynamic environment a manufacturing firm must be capable of rapid adjustment in order to reduce the overall design-to-delivery time for customer-valued quality products. The necessity for swift recurrent changes has led to adoption of concepts like horizontal partnerships, cross-functional work teams, concurrent engineering, Just In Time (JIT), Total Quality Management (TQM), and lean production into a singular concept called Agile Manufacturing<sup>1</sup>. It is believed that an efficient way to satisfy market needs is for a company to collaborate with qualified partners with the necessary physical resources and capabilities. This collaboration is viewed as virtual company formation, which leads to smooth flow of product, process and business-related information across company boundaries.

Central to the ability to form joint ventures is the deployment of advanced information technologies and the development of highly nimble organizational structures to support highly skilled, knowledgeable and empowered people<sup>4</sup>. While research projects are currently addressing the first need, the significance of the future manufacturing education activities should be aimed at the creation of that skilled and knowledgeable professional workforce. It is quite clear that agile practices are significantly different from the traditional paradigms. There currently exists a pressing need to promote empowerment of people to form information networks and to communicate as peers of a non-hierarchical/decentralized and responsive scheme.



Undoubtedly, success of agile competition in practice will depend on “an agile education system” that will impart the right skills, knowledge, and motivation to participants. With these objectives in mind, and to address manufacturing education needs to promote and understand agile manufacturing concepts, a unique graduate level course is being offered at the Department of Industrial Engineering, SUNY-Buffalo. The objective is to provide young manufacturing engineers with core competencies in both manufacturing and information technology, and the creative integration of the two to accomplish an agile industry.

In this paper we discuss the curriculum design and experiences of this course. In a more general sense, it is our desire to share the motivation behind the relevance of such a course, and some of the challenges in designing and offering it. We would also like to propose some possible directions in which academia could focus attention so that a skilled and empowered manufacturing profession base can be created for the future. The remainder of this paper is organized as follows. In Section 2, we further discuss the background that makes agile and information-based manufacturing a necessity. In Section 3, the curriculum of the course is presented in detail. Section 4 is devoted to the course project work. Section 5 presents the use of software and Internet to enhance the activities of this course. Finally, in Section 6 we conclude with our remarks.

## 2 Background

The following discussion of the literature focuses on Agile Manufacturing, and Information Technology for Manufacturing, both of which are relevant to future directions in manufacturing and our graduate course.

Agile Manufacturing is a nascent concept, and therefore, an extensive background on its success is unavailable. The Agile Manufacturing Enterprise Forum (AMEF), Iacocca Institute of Lehigh University is an industry-supported organization created to disseminate the ideas contained in *21st Century Manufacturing Enterprise Strategy* report, and to increase the pace and scope of agile competition. AMEF has organized national conferences, made congressional appearances, and created an industry review board to monitor progress. Agile Infrastructure for Manufacturing Systems is an industry collaborative effort to build directly on DARPA-funded research to create an agile infrastructure, promote conversion/dual-use, and finally evolve to a full-scale Factory America Net prototype. The initial focus is on shop-floor integration for precision machining. In future it will encompass enterprise-wide functions, and other domains like electronic assembly<sup>7</sup>.

The Agile Aerospace Manufacturing Research Center at the UT Arlington is conducting research on agile business practices, process identification and characterization, and enabling technologies. The Manufacturing Research Program at the U of Illinois at Urbana-Campaign is developing computer integrated manufacturing and machine tool systems. The Electronic Agile Manufacturing Research Institute at RPI is focusing on electronics product realization in distributed manufacturing environments using improved information infrastructures/architectures. A project on "Optimal Selection of Partners in Agile Manufacturing," has recently been completed at the University of Maryland; University at Buffalo, Westinghouse, Martin Marietta, and NIST were partners<sup>5</sup>. The system developed evaluates a candidate design with respect to the capabilities of candidate partners and selects the optimal set of partners considering product cost, cycle time, and quality. The focus is on feasibility and manufacturability of electromechanical parts. Design-for-manufacture data: PDES/STEP product models, GT codes, process data, and manufacturing plant data, are employed in partner synthesis, using object-oriented technology.

At the education side, AMEF is a recognized Industry Forum for spreading the word of agility and enabling the transition process for industries. They propose creation of training programs to prepare people to excel in agile environments, from hourly workers to the senior executives. Numerous training programs are being offered by for-profit companies in areas that pertain to the use of their (usually software) products towards agility. For instance, STEPTools, Inc. offers training courses in their products like ST-Developer and



ST-Acis. And, due to the increased need for such education in the lack of formal university programs, specialized consulting agencies offer short-courses: e.g., RPI's staff offers a course in EXPRESS.

While the on-going work is serving the industrial community, there is also a need to start education at the college level. We are not aware of specific courses that are being offered in agile manufacturing at this time, although we are hopeful that the National Science Foundation's Engineering Research Centers will be soon offering courses and developing study material.

Regarding Information Technology for Manufacturing, at the request of National Science Foundation, the National Research Council's Computer Science and Telecom Board and Manufacturing Studies Board formed a committee in April 1993. The committee of 16 individuals from academia and industry was charged with determining the computer science and engineering research need to support advanced manufacturing.

In recognizing the needs of manufacturing industry in achieving high product quality, low cost, efficient performance and timely production to market, the committee focused on: (i) articulating a vision of Information Technology (IT)-enabled manufacturing in the 21st century, (ii) identifying the obstacles to achieving the vision, and (iii) identifying research topics that address the obstacles. The report identifies the potential of IT in manufacturing as being able to provide the tools to help enterprises achieve many critical goals including: (i) Rapid shifts in production from one product to another, (ii) Faster delivery of products to customers, (iii) Improved utilization of capital and human resources, etc. In summary, the study has three key findings:

- Modern manufacturing has an increasing need to rely on IT in decision making. Timely information is needed at both shop floor and executive levels. Basic science of engineering principles should not be overlooked.
- Current IT is inadequate to support manufacturing in the 21st century. Although scattered efforts have been made, a total integration is absent. The need for open architecture and standards in IT is significant to prevent serious penalties from closed and proprietary manufacturing practice in the global economy.
- Using IT to its full potential also requires addressing many "soft" non-technical issues. That is, IT as a technology in itself would not make a significant change to the manufacturing industry unless compatible supporting business, managerial and personnel functions are simultaneously developed.

The emerging Agile Manufacturing paradigm and the studies by national organizations on research and education in advanced and IT-based manufacturing are compelling. Thus, the nation's manufacturing engineering educational system has to respond to these insistent needs.

### 3 Course Curriculum

In this section, we discuss the curriculum design of the graduate level agile manufacturing course being offered at the University at Buffalo. The course does not use a specific text largely because a suitable one is yet unavailable. The major references relevant to this course and the course outline are available on the Internet (<http://www.acsu.buffalo.edu/~nagi/courses/500.html>). The various topics covered are presented below.

#### 3.1 Introduction to Agile Manufacturing

An introduction to Agile Manufacturing is the first and essential step in this course. This helps paint the background on which the remaining course finds its setting. The introduction is very broad in nature and begins with characterizing the *Environment* as fragmenting, competitive, dynamic, highly customized, and wherein there is a strong need to reduce time from designing to delivery. *Agile Manufacturing* is briefly presented as a means to accomplish success in the above environment. The introduction continues with a historical perspective on *manufacturing paradigms* and reasons for the recent shift to the agility paradigm.



The next step is detailing the *basis of agile manufacturing*: the two parallel (defense and commercial) infrastructures left behind by 30 years of cold war, each with distinct technologies, processes, and business practices, and the need for an evolutionary plan for a unified industrial base (i.e., dual-use). Rapid advances in computer and transportation technologies are demonstrated as the basis for this change. We summarize the introduction by formal definitions: “Agility is characterized by cooperativeness, by the rapid production of high quality, customized goods, by a knowledgeable and empowered work-force, and by an information infrastructure that links computers, marketeers, engineers, and robotics in a unified electronic web<sup>6</sup>.”

### 3.2 Case Project Study

The introduction to agile manufacturing is on “high-level” concepts. Thus, to provide the audience with a concrete understanding of tangible project work with specific research tasks, a recent two-year funded project on Optimal Selection of Partners in Agile Manufacturing<sup>5</sup> is discussed. This work develops a decision support system for flexible synthesis of multi-enterprise partnerships to rapidly respond to market opportunities. The proposed methodology is based on conducting product design evaluation (manufacturing complexity, cost and quality), and on matching designs with the manufacturing capabilities of prospective partners considered for a joint venture. Thereafter, a list of qualified manufacturers is established, and an optimal set of partners is selected. The system architecture is shown in Fig. 1. After discussing the overall project, two specific topics are considered in detail (see § 3.2.1 and 3.2.2). Later students have to critique this project as a case study.

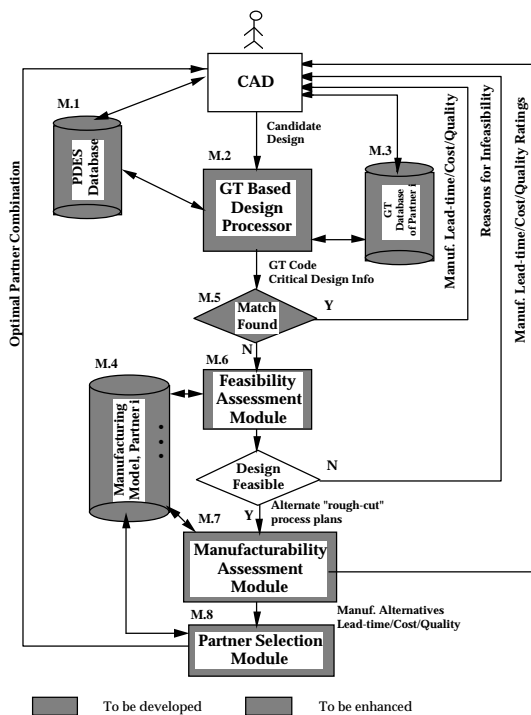


Fig. 1: System Architecture for OSPAM<sup>5</sup>

#### Key project and module issues:

1. Representation of product designs in the PDES standard (*PDES/STEP Draft 4.0*), and Group Technology (GT) codes (see modules M.1 and M.3 in Fig. 1). GT coding from the product information model is automated (module M.2).
2. Representation of the manufacturing capabilities of each manufacturing partner, including part cost and quality performance related attributes (see module M.4).
3. Product feasibility assessment (M.6) and manufacturability rating (M.7), based on: (i) the standard product design representations (PDES model and GT code), and (ii) either existing similar designs (M.5) or matching with manufacturing partner profiles.
4. A decision scheme to select the best manufacturing partners from the alternatives created in step 3 above (module M.8). Decision criteria include overall manufacturing and transportation costs, cycle times and product quality.

#### 3.2.1 Automated Retrieval and Ranking of Similar Parts in Agile Manufacturing

In an agile enterprise set-up where manufacturing partners share product related data to come-up with new and customized products at minimal lead-times, Iyer and Nagi<sup>3</sup> propose identifying existing parts that are

similar, in one or many characteristics, to a new part at the design stage. The underlying procedure is based on the principles of Group Technology (GT), and on the definition of the neighborhood of similarity. A two-step procedure is proposed: (1) A search procedure, which acquires and processes the designer's search intent to retrieve similar parts. (2) A sorting procedure, which ranks these parts in order of their similarity to the candidate part. A software system using object-oriented technology demonstrates the implementation.

### **3.2.2 Optimal Partner Selection for Virtual Enterprises in Agile Manufacturing**

Selecting manufacturing partners for a virtual enterprise in the new emerging world of agile manufacturing is beset with the complexity and dynamics of the market, driven by customer needs, and is inherently subjective. The optimal choice of collaborating companies is governed by cost, quality, responsiveness, delivery and other business concerns. Gupta and Nagi<sup>2</sup> develop a flexible partner selection scheme. The framework: (1) employs a Fuzzy-AHP approach to compute attribute preferences, (2) acquires linguistically, needs of the specific business initiative, and systematically modifies attribute preferences, (3) performs a search among alternative manufacturing companies to identify and rank a small number of efficient solutions, and (4) recommends an optimal solution while providing a decision aid for human decision making.

### **3.3 Back to Basics**

The audience in such a course may be varied (as was for this offering), and therefore, a uniform background in manufacturing maybe too much to expect. To bring everyone to a common basis, and with an objective to revise the essentials, the fundamentals in a number of topics are covered. The recent course offering covered the following topics: (1) Manufacturing Processes, (2) Product Design Representations, (3) Product Design Process, (4) Feature Extraction, (5) Process Planning, (6) Measurement and Representation of Quality, (7) Sourcing and Vendor Selection, (8) Supply-Chain Management, (9) Manufacturing Resources Planning Systems (MRP), (10) Information needs in Manufacturing, (11) Organizational Structures, and (12) Optimization Problems and Procedures. A number of activities to supplement each lecture can make these interesting. For example, along with the lecture on manufacturing processes, a tour to the college machine shop can be organized, and along with product design representations, a video tape on STEP model from USPro, Inc. can be shown. In the particular course offering, these topics were prepared and presented by the students.

### **3.4 Function Modeling with IDEF0**

During the 1970s, the US Air Force Program for Integrated Computer Aided Manufacturing (ICAM) developed a series of techniques known as IDEF (ICAM Definition) for functional modeling (IDEF0), information modeling (IDEF1 and its extended version IDEF1X), dynamic models to capture the time-varying behavior of systems (IDEF2), process flow modeling (IDEF3), etc. Currently, IDEF0 and IDEF1X techniques are widely used in the government, industrial and commercial sectors, supporting modeling efforts for a wide range of enterprise and application domains. The National Institute of Standards and Technology has developed Federal Information Processing Standards (FIPS) for these techniques. Due to the popularity of these tools in various sectors, especially defense and their contractors, they are believed to be important for the future workforce. Some academic programs in Computer Integrated Manufacturing as well as Project Management have recently been incorporating an promoting the use of these techniques. However, our graduates are still largely under-prepared in such system modeling tools.

A course in Agile Manufacturing is a natural place for such techniques to be covered. It is a little difficult to develop materials for instruction on these topics because their coverage in most texts is not in-depth.



An instructor can rely on the FIPS publications (183 for IDEF0, and 184 for IDEF1X) for developing instructional materials. In the recent offering of this course, in-class examples, assignments and examination questions on IDEF0 allowed students to develop mastery on application of this technique. It is further possible to enhance appreciation for this technique by the use of software applications for IDEF0 modeling (see § 5).

### 3.5 Information Modeling

Since agile manufacturing is information-based, information modeling is an essential topic of this course. Information models enable a formal description of types of ideas, facts and processes and which provide an explicit set of interpretation rules. A number of graphical information modeling techniques like Entity-Relationship, EXPRESS-G, IDEF1X, NIAM (Nijssen's Information Analysis Method), OMT (Object Modeling Technique) and Shlaer-Mellor, and lexical techniques like DAPLEX, EXPRESS, GEM and SQL (Structured Query Language) are available. After a brief introduction of IDEF1X and OMT, we considered EXPRESS and EXPRESS-G<sup>9</sup> in detail. These methods were chosen because: (i) they collectively offer advantages of both graphical and lexical tools in a consistent manner, and (ii) they are probably the most popular tools for manufacturing information modeling, e.g., STEP model for product data uses EXPRESS or ISO-10303-11 (which is an international standard). Finally, a wealth of product, process and resource information models are available in EXPRESS.

### 3.6 Client-Server and Network Technologies

Designing and implementation of an information system on a computer platform can be enabled using the traditional centralized multi-user architecture, or the more recent client-server architecture. Client/Server architecture is an application design approach that results in the decomposition of an information system into a small number of server functions, executing on one or more hardware platforms. These provide commonly used services to a larger number of distributed client functions that perform more than narrowly defined work in reliance on the common services provided by the server function. Several good texts are available in this topic.

### 3.7 Petri-Nets

Petri-Nets<sup>8</sup> are bipartite graphs with places representing conditions and transitions representing operations. They are not only powerful as a modeling tool, but their qualitative and quantitative properties are particularly rich. This makes Petri-Nets a powerful modeling, simulation as well as system analysis tool. Petri-Nets have become very popular in the modeling and control of Flexible Manufacturing Systems (FMS) in recent years. We believe that this is also a powerful tool that must be covered in the classroom for manufacturing education.

## 4 Project Work

Students performed term projects on various topics in Agile Manufacturing. These projects are built upon agile manufacturing concepts and fundamental tools introduced during the course. This was a motivated group of participants who also brought into these projects expertise from other topical areas and summaries from extensive literature reading. Some of these projects were:

- Quantitative (Game Theoretic) Methods to (Dis)Prove Cooperative Competition
- A Variance-Based Vendor Evaluation Model for Agile Manufacturing
- Virtual Enterprise Scheduling and Project Management in Agile Manufacturing
- Process Information Representation using EXPRESS and Information Integration



- Organizational Models in Agile Manufacturing
- Virtual Company or Virtual Enterprise Formation

Projects of this type allow the participants to creatively apply some of the tools covered during the course to new problems in agile manufacturing. It also helps them learn from each other, and lay the foundations of their graduate research. Based on the informal feedback from students we have found this to be particularly beneficial.

## **5 Desired Facilities and Software**

### **5.1 Educational Software**

A variety of software are helpful in providing participants with hands-on application to a number of concepts covered in the classroom. In addition, these can be very helpful in the course project work and agile manufacturing research. Examples of software are:

- CAD tools (Microstation, Autocad, IDEAS, etc.) and Acis to STEP translators
- IDEF0 (Triunc Software, Dayton, OH; Meta Software, Cambridge, MA; KBS, College Station, TX)
- Steptools ST-EXPRESS, ST-Developer, ST-Acis (STEPTools, Inc. Troy, NY).
- Petri-Net modeling software.

### **5.2 Role of the World-Wide-Web in Education**

Agile Manufacturing is a rapidly developing concept and current findings have not taken shape as formal educational materials. However, the World-Wide-Web (or Internet) is proving to be an important repository where recent information and educational material can be readily found. Due to the emphasis on information technology in this course, it is appropriate to have the students spend some time on the Internet. Further, the instructor can also place essential course readings on his or her homepages so that students can browse and download this information at their convenience.

The following are some sites that students visited extensively during this course:

- National Institute of Standards and Technology. <http://www.nist.gov>
- National Product Data Exchange Resource Center (NIST). <http://elib.cme.nist.gov/pub/nipde/>
- Steptools, Inc. <http://www.steptools.com>
- National Industrial Information Infrastructure Protocols. <http://www.niiip.org>
- PDES, Inc. <http://www.scra.org/pdesinc.html>
- Rennselaer Polytechnic Institute. <http://www.rdrp.rpi.edu>

## **6. Conclusions**

This paper addressed an important education need within manufacturing engineering as a consequence of recent changes in global competition and emerging manufacturing paradigms. To promote the understanding of agile, virtual and information-based manufacturing, we discuss a recent graduate course offered at SUNY-Buffalo's Industrial Engineering Department. The curriculum design of such a course is challenging due to: (i) the lack of formal educational material and ready-to-use texts, (ii) expensive software that are essential to supplement course lectures with hands-on training, (iii) evolving state of the field itself, and (iv) broad set of fundamentals and mature understanding required of the participants, among others.



Despite these, we propose a course that attempts to overcome some of these difficulties, and promote graduate research in emerging information-based manufacturing topics. The most important curriculum components of this course are: (i) the introduction to basic concepts and motivation for agile manufacturing, (ii) basics and fundamentals in design, process planning and manufacturing, (iii) specific function and information modeling tools, (iv) case study projects, and (v) creative project work. In the recent offering we positioned the case study projects (item (iv)) early in the course. In retrospect, we feel that it would be better placed mid-way through the course, and after discussing the basics (item (ii)). Further, by imposing some prerequisites to this course, a more uniform and mature audience can be generated.

Future manufacturing educational activities should be aimed at developing study and course material for such courses. Virtual reality-based course material is currently being developed at Rennselaer Polytechnic Institute, and we hope that other similar efforts for formal texts will be pursued soon. We are even more convinced that, given a proper level of detail, a similar course can also be offered as an elective at the undergraduate level.

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