Enhancing Manufacturing Process Education via Computer Simulation and Visualization

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Acharya joined RMU in Spring 2005 after serving 15 years in the Software Industry. With US Airways, Acharya was responsible for creating a conceptual design for a Data Warehouse which would integrate the different data servers the company used. With i2 Technologies he led the work on i2's Data Mining product "Knowledge Discover Framework" and at CEERD (Thailand) he was the product manager of three energy software products (MEDEE-S/ENV, EFOM/ENV and DBA-VOID) which were/are used in Asian and European countries by both governmental and non-governmental organizations. Acharya has a M.Eng. in Computer Technology and a D.Eng. in Computer Science and Information Management with a concentration in knowledge discovery, both from the Asian Institute of Technology in Thailand. His teaching involvement and research interest are in the area of Software Engineering education, Software Verification & Validation, Data Mining, Neural Networks, and Enterprise Resource Planning. He also has interest in Learning Objectives based Education Material Design and Development. Acharya is a co-author of "Discrete Mathematics Applications for Information Systems Professionals- 2nd Ed., Prentice Hall". He is a member of Nepal Engineering Association and is also a member of ASEE, and ACM. Acharya is a recipient of the "Mahendra Vidya Bhusak" a prestigious medal awarded by His Majesty the King of Nepal for academic excellence. He is a member of the Program Committee of WMSCI, MEI, and CCCT and is also a Member of the Editorial Advisory Board of the Journal of Systemics, Cybernetics and Informatics of the International Institute of Informatics and Systemics. Acharya was the Principal Investigator of the 2007 HP grant for Higher Education at RMU. In 2013 Acharya received a National Science Foundation Grant for developing course materials through an industry-academia partnership in the area of Software Verification and Validation.

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Abstract

Industrially significant metal manufacturing processes such as melting, casting, rolling, forging, machining, and forming are multi-stage, complex processes that are labor, time, and capital intensive. Mathematical modeling of these processes provides a theoretical framework for understanding the process variables and their effects on productivity and quality. However it is usually difficult to provide the students with hands-on experience of experimentation with process parameters to arrive at optical process design. In order to solve this problem, interdisciplinary student projects were undertaken at author's institution to develop computer simulation tools that would facilitate process visualization, experimentation, exploration, design and optimization.

The first system described in this paper is the visualization of metal ingot production schedule in an industrial setting that provides a basis for interactive decisions. A metal ingot casting is simulated by designing the abstract machine models to visualize capacity and loading of the production schedule. The graphical user interface is created to visualize the schedule according to the specific characteristics of the machines. The application of computer tools may also be extended to support other important functionalities such as tracking availability of raw materials, projection of inventory due to production overage, as well as critical business analysis. The students thus are exposed to the comprehensive process analysis. Another example of process simulation presented in this paper is the design and analysis of flexible rolling technology in industrial processing of C – Mn and Low C - microalloyed steels. Process simulation tools designed by the students allow new process sequences to be generated by breaking down existing process routes in to key elements and then by recombining them to generate novel alternative and more efficient hot processing sequences. This enables the identification of an optimal process sequence for specified steel compositions that also satisfies simultaneous design criteria such as process feasibility and property maximization.

It is proposed that incorporation of such computer simulation tools in the pedagogy would be highly effective to enhancing and enriching undergraduate manufacturing education.

1. Introduction

Manufacturing and mechanical engineering curricula typically include one or more courses where the students are introduced to industrially significant, primary manufacturing process such as casting, rolling, forging, forming, and welding. Such processes are best taught in a hands-on manner using lab scale equipment or via industrial visits. While such lab activities are important for student's understanding of the subject matter they are both expensive and cumbersome. In order that the students achieve the most benefits from hands-on lab exercises, they must therefore be well prepared prior to conducting the hands-on activities. In this regards, this paper proposes that the computer simulation tools offer a wonderful opportunity to enhance the teaching – learning process. The paper describes a couple of process simulation and visualization tools developed by the students at the authors' institution as part of their project work.

Over the past three decades a number of computer based expert systems have been developed around the world for a more efficient solution of manufacturing problems in several areas such as diagnostic, design, planning, scheduling, process control, and quality control within the iron and steel industry [1, 2]. More recent research focus has been on the application of Artificial Intelligence (AI) to the hot rolling of the steel [3,4]. The primary objective of steel rolling to obtain the desired shape has been augmented by the need to produce steel products with a range of desired properties such as strength, toughness, weldability, and formability at low overall cost. Going further upstream in primary processing industry, the optimization of metal ingot casting schedules presents significant challenges as market needs change rapidly. In this case, production planning decisions must be made quickly to be responsive to the market. Quite often judgments need to be made when objectives and constraints are not even readily quantifiable. In order to avoid knee-jerk response to the merging situation, it is important that response is evaluated using appropriate tools such as an information system. The information system should then be able to visually present production plan with its capacity and load, allowing human interaction to make changes while showing the ramifications by immediate feedback [5, 6, 7]. The human planner would thus be able to promise a delivery based on the available production capacity without causing problems in other areas of production scheduling.

The complex task of process visualization of both casting and downstream rolling using computer programming and modeling was undertaken as interdisciplinary student projects. The work was supervised by manufacturing and computer faculty and implemented in Visual C++. The paper will demonstrate this approach where the students developed process visualization tools as part of their manufacturing engineering curriculum.

2. Ingot Casting System

Production planning is known to be an extremely difficult task due to rapidly changing market needs, a high degree of complex logistics involved, and therefore the use of the right tool will make the job easier and may result in higher efficiency and higher profits [8]. The production planning problem of metal ingots casting is addressed in the system presented in the present work. The solution strategy is based on an analysis of the bottle neck of the assembly line [9], where the melting furnace and the heating oven have been identified as the production machines casing bottleneck. The system approach is based on visualizing the production capacity and load on the schedule of these machines. An interactive load graph is designed to visualize the effect of production capacity and load on the production scheduling of these machines. Using the interactive load graph the planner can then interact with the production schedule and make changes manually, while relevant information about the impact of the changes may be shown immediately through visual feedback.

The user interface design is the most important aspect of system visualization. In metal ingot casting, the bill of materials is relatively simple: for each alloy, the bill of materials specifies the proportion of ingredients to be mixed with the metal ore. The mixture is poured into the melting furnace. The molten mixture is then released into the dropping tool for casting into ingots of the alloy product. The ingots then need to go through the oven for heat treatment. Each type of ingot product will have its recipe detailing the temperature profile for heat treatment for the desired metallurgical properties. The manufacturing process is shown schematically in Figure 1.

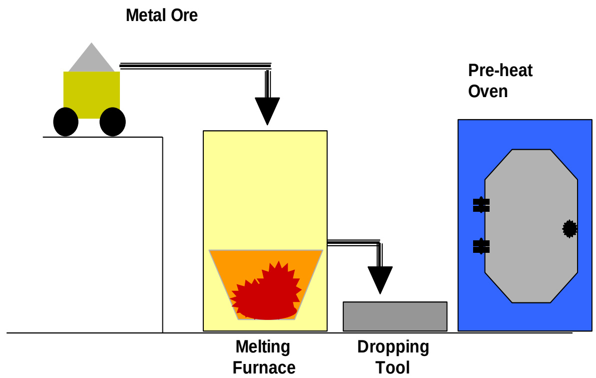

Figure 1. The metal ingot casting process.

The design of a typical production plan with the time bucket size of one week is shown in Figure 2. The maximum feasible load would then be 168 hours, if the machine is available to operate 24 hours a day, 7 days a week. Each block represents a job assigned for production within that week. The height of the block represents the load on production capacity, that is, the time duration it will have to occupy the machine. One can easily see any case of overloading, as well as the availability of capacity for production. Furthermore, each job assigned to any particular week may be late for delivery, too early for production, or optimal. The blocks are color-coded so that late jobs are red, early jobs are blue, and the ones done just in time are green. Interesting interaction can then occur on the load graph when the planner can drag and drop each block, moving it from one week to another, re-arrange their order within each week, or split up a block and move one part away. When the ramifications of these changes are computed automatically with visual feedback, the planner can then decide whether or not the change is feasible, or desirable.

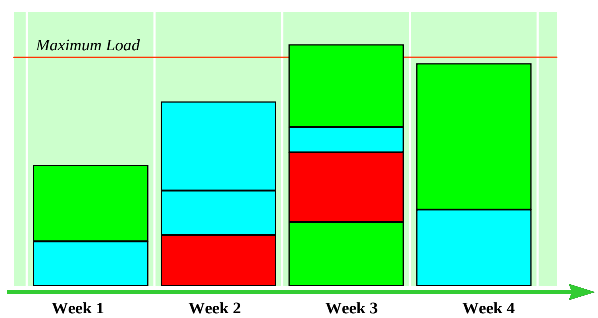

Figure 2. Production schedule showing capacity and load.

Each block may also serve as a window (screen real estate) to facilitate interaction with the planner to drill down and find more detailed information about the order such as product code, customer order number, customer name and select to display any of the information as label on the block. Further details of the system are given in a paper by [10].

3. Hot Rolling System

The overall industrial process for manufacturing steel products is shown schematically in Figure 3 while wire rod rolling process studies in this work is shown schematically in Figure 4.

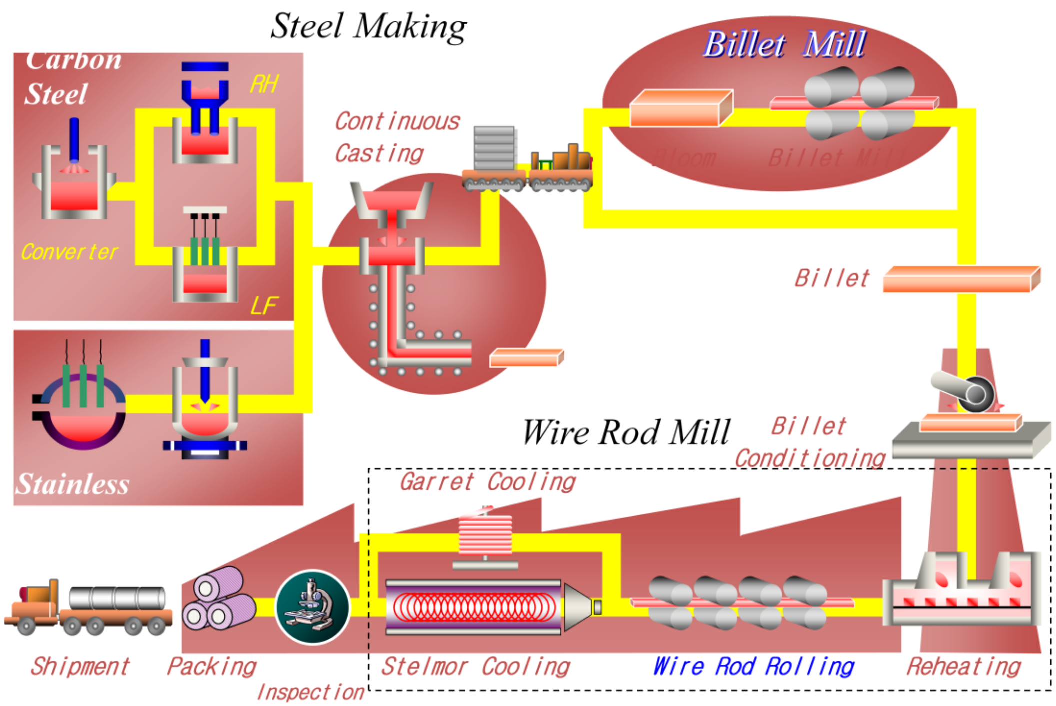

Figure 3. Overall process sequence to manufacture steel products. The details of the process sequence in the box above marked "***Wire Rod Rolling***" are shown in Figure 4 below.

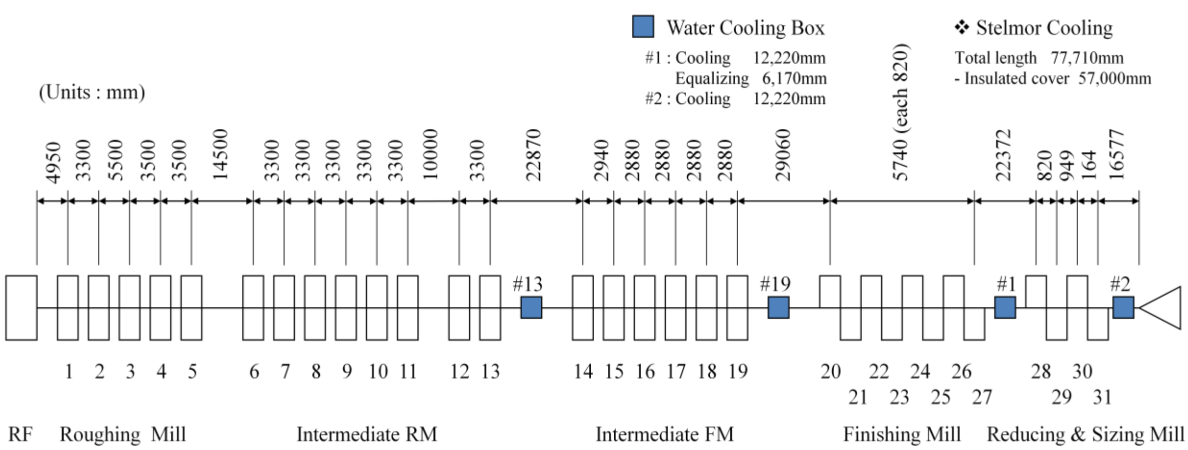

Figure 4. The details of the multi-stage wire rod rolling process selected for visualization in this work.

The process was mathematically modeled and implemented within an expert system [11,12]. The results of the calculations made by expert system were then collated and used as input for visual display. The program was implemented in C++ and a user interface was developed as shown in Figure 5.

Figure 5: Example of a user interface developed for process simulation.

A sample output of the program for medium C-Mn steel is shown in Figure 6 for a full-scale industrial rod rolling process [11,12]. The figure shows the evolution of austenite grain size as a function of process step.

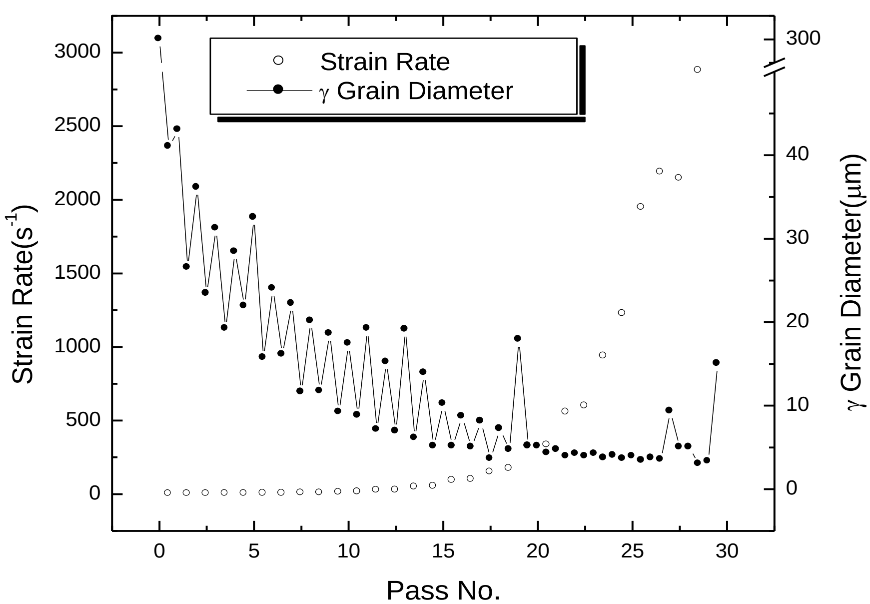

Figure 6. Predicted austenite grain evolution during rod rolling of a medium C-Mn steel.

4. Incorporation into Teaching

The projects were implemented as student work as part of independent studies and subsequently used as educational tools in ENGR 3600 Production Engineering class. Some details of this course are provided in the sections below.

4.1 Production Engineering Course Objectives

Manufacturing is the engine that powers most industrial economies of the modern world. This course presents a balanced coverage of relevant scientific and technical fundamentals and real world practices in modern manufacturing. Purpose is to develop a sound understanding of technical nature of processes involved in producing most things we use in our day-today life.

The course incorporated a significant component of the hands-on lab exercises as listed below.

4.2 List of Laboratory Exercises

The following laboratory exercises and activities were conducted throughout the term:

- Metal riveting hammer – traditional workshop – sawing, milling, turning, facing, drilling, tapping, grinding, assembly, finishing
- Auto CAD/ SolidWorks – free-form design
- Rapid prototyping – fused deposition modeling
- Injection molding - demonstration and some operation of the machine –plastic rulers
- Powder metallurgy – aluminum and stainless steel powders – cold isostatic pressing
- Several manufacturing technology videos produced by SME, History channel
- Metrology – calipers, micrometers, go – no-go gages, tolerances
- 3D CMM – Co-ordinate Measuring Machine

In addition, sand molding and casting, MIG welding, sheet metal forming, vacuum forming for plastics and metal die casting labs have also been delivered when the schedule permitted it.

The rolling process simulation and visualization tool was made available to the students to experiment with and learn the effects of process variable on the properties of the products. The applicable ABT outcomes for the course are given in the following section.

4.3 Applicable ABET Criterion 3 Outcomes and Student performance

ABET outcomes 1, 3, 5, 7 and 8 and track-specific outcomes M2 and M4 are applicable for this course according to the existing course description.

Outcome 1: RMU Graduates have an ability to apply knowledge of mathematics, science, and engineering.

Outcome 3: RMU Graduates have and ability to design a system, component, or process to meet desired needs.

Outcome 5: RMU Graduates have an ability to identify, formulate, and solve engineering problems.

Outcome 7: RMU Graduates have an ability to communicate effectively
Outcome 8: RMU Graduates have the broad education necessary to understand the impact of engineering solutions in a global and societal context.

The student performance in each assessment task was regrouped in terms of ABET outcomes to work out the percentage of students that scored ≥ 80% marks for each of the specified ABET outcomes. The bar graph depicting this analysis is shown in Figure 7.

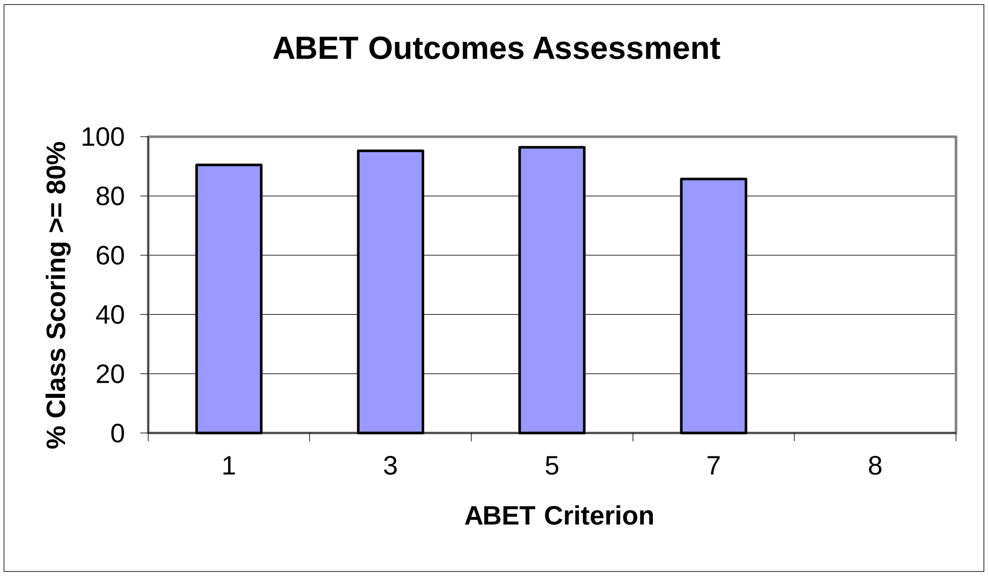

Figure 7. Class performance with respect to the applicable ABET outcomes. (The current RMU-designated benchmark for class performance is 80%).

Reflection:

- It can be seen from Figure 7 that the class performance in this course is above the RMU-designated benchmark (at least 80% students in the class score >= 80%) in applicable ABET outcomes 1, 3, 5, and 7.
- ABET Outcome 8 was not assessed at this time.

4.4 ABET Track-Specific Outcomes

The following track-specific outcomes are identified for this course:

- M2: RMU Graduates have proficiency in process assembly, and product engineering and understand the design of products and the equipment, tooling and environment necessary for their manufacture.
- M4: RMU Graduates have an ability to design manufacturing systems through the analysis, synthesis and control of manufacturing operations using statistical or calculus based methods, simulation and information technology.

85.7% students scored >= 80% points in Outcome M2 while 92.9% students scored >= 80% in Outcome M4, which is well above the RMU benchmark.

Reflection:

- Outcomes assessment for both of the applicable track-specific outcomes, M2 and M4, demonstrates that RMU benchmark is being met.

5. Summary

Process visualization using appropriate graphical user interfaces for industrially significant manufacturing processes such as ingot casting and hot rolling have been developed as educational tools. For ingot casting visualization the capacity and load in the production plan were plotted to evaluate adequacy of the designed plan as well as ramifications of the changes being considered. For hot rolling simulation and visualization mathematical models were collected and an expert system was built to capture process characteristics. The results of the computation were then used for visualization and experimentation. The computer based tools were used in the class room for teaching of these manufacturing processes. Based on the analysis of the student assessment data of the applicable ABET outcomes it appears that computer-based experimentation and visualization enhances student's understanding and learning experience.

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