

# Peanut Butter Cracker Sandwich Manufacturing Module

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## Abstract

For many engineers, their first position after obtaining a B.S. degree is in manufacturing. Job titles like process engineer, product engineer, and quality engineer are common and are directly involved in manufacturing. Most engineering curricula do not cover manufacturing concepts. A student may not even have an opportunity through electives to study manufacturing since smaller engineering colleges rarely have a department of Manufacturing Engineering.

A module on peanut butter cracker manufacturing was developed for the Introduction to Engineering course taken by most engineering students in their freshman year. The objective for the students is to design, build and then run a process to manufacture peanut butter cracker sandwiches. The culminating activity is a pilot production run where the students are assigned human operators for their process. The goal for the students is to make a profit during the pilot production run. Material costs, labor costs, quality specifications and selling price all determine whether or not the process was successful. The module includes activities where the students perform calculations and use Excel graphs to determine the process time required to make a profit, the impact of the number of operators on production, the interplay between fixed and variable costs, and the effect of yield on their profit. Students are required to write operating procedures and order supplies based on predictions of the quantity of sandwiches they will produce. Students also learn about quality control and process control, the cost of automation, development costs, and challenges in training operators. After more than two weeks of preparation, the students have 10 minutes to train their operators, and then the operators run the process for 10 minutes. After production day, the students write a report that includes an analysis of their production performance and suggested process modifications. Overall, the module provides a fun and informative introduction to some fundamental manufacturing concepts.

## Introduction

Process Engineers, Manufacturing Engineers, Quality Engineers – a search on any of the common job hunting Internet sites will turn up numerous positions across the United States for these classifications of engineers. Manufacturing activities contribute significantly to U.S. industrial vitality and to research and development of products and services that drive economic growth.<sup>1</sup> The requirements for an entry level position in these fields include degrees in Electrical Engineering, Mechanical Engineering, Materials Science, Chemistry, Physics, Chemical Engineering, and related degrees. Manufacturing, process, and quality engineering job

descriptions often require experience with at least one of the following: design of experiments, statistical process control, total preventative maintenance, evaluation and selection of materials, process optimization, failure mode effect analysis, total quality management, and ISO 9000 requirements.<sup>2</sup> These topics are taught in larger universities that have an Industrial or Manufacturing Engineering department. However, smaller universities typically do not have these departments, and few manufacturing concepts are taught in the typical undergraduate engineering curriculum. Even so, a large fraction of entry-level engineers are hired in manufacturing positions as their first job after graduating with a B.S. degree.<sup>2</sup>

Boise State University does not have an Industrial Engineering or Manufacturing Engineering department, yet many BSU graduates go on to work as manufacturing engineers or process engineers with Micron, Hewlett Packard, or one of many smaller companies in the growing high tech-focused industry in southwestern Idaho. Graduates who find employment in the aeronautics, automotive, heavy machinery, or other traditional industries also find the same manufacturing concepts are applied in those industries. These graduates must rely on their undergraduate engineering education to prepare them to succeed at these jobs. The majority of working engineers do not pursue further graduate degrees. Only a small percentage go on to graduate school and most do not further their education in Engineering<sup>3,4</sup>.

Industry professionals have identified a strong need for manufacturing education in undergraduate engineering curriculum. Incorporating manufacturing awareness, concepts, application, and terminology, particularly in mechanical engineering departments, creates a strategy to prepare students to contribute as entry-level engineers in industry.<sup>1</sup> In order to provide some foundation in manufacturing, the College of Engineering at Boise State University introduced a module on manufacturing into ENGR 120 Introduction to Engineering, a class taken by most first-year engineering students. This module was taught for the first time in the fall of 2000 and has been refined to create a learning experience that is a highlight of the class. In this three-week module, the students design, build, and then run a real process to manufacture peanut butter cracker sandwiches. They are exposed to all facets of the manufacturing process, from tooling development and procedure specification to inventory management and quality control. They also become familiar with management concepts, such as profit, labor, overhead, and development costs, which are usually outside the responsibility area of entry-level manufacturing engineers. In a survey of manufacturing engineers and managers in the Pacific Northwest, “the overall consensus was that manufacturing engineers should [not only] be well trained in the specifics of manufacturing processes, but [should also] understand how their decisions affect job scheduling, inventory control and the bottom line — company profits.”<sup>5</sup>

### Learning Objectives

Like the nutritional density of peanut butter, this teaching module is packed with crucial concepts of manufacturing. Hands-on learning is the key to successfully introducing a wide range of manufacturing concepts. Research shows that students learn best when concepts, principles, and theories are related to specific student experiences.<sup>6</sup> After the students experience the peanut butter cracker sandwich manufacturing module, they are expected to be able to:

- Calculate the cycle time, throughput, and other parameters required to build a sandwich and make a profit, given the costs of manufacturing
- Accurately predict the amount of sandwiches their process can produce in a given amount of time
- Understand the variables, costs, and process flow impacts of
  - quality control
  - inventory control
  - product and packaging specifications
  - procedure documentation and operator training
- Analyze the trade-offs between automated and manual processes
- Express familiarity with concepts of development cost, non-recurring expenses, and management issues

### The Peanut Butter Cracker Manufacturing Module

*Caution: Before starting this module, the instructor asks if any student is allergic to peanuts, as this allergy can be life threatening. If a student is allergic to peanuts, then icing can be substituted.*

The students work in groups of two or three and the module generally lasts three weeks corresponding to 12 hours of class/lab time, culminating in production day, when the students run their operations for ten minutes. The module handouts are included at the end of this paper.

**Activity I — Modeling.** Many students want to jump right in and start designing their process. However, their first class requirement is to develop a mathematical function that expresses manufacturing costs and to graph the cost of a sandwich as a function of production time. Given the selling price, the students also perform calculations related to profit and yield. These calculations, which may be done on paper or in Excel, give the students a realistic starting point to begin their process development.

**Activity II — Writing procedures.** The subtleties of communicating specific instructions are explored in this activity where students write a simple procedure to make a single peanut butter cracker sandwich with just a knife, a jar of peanut butter and crackers. When their lab partners must then follow their precise instructions to build a sandwich, it becomes apparent that writing procedures is not so simple after all. Vague instructions such as “put peanut butter on cracker” result in some unexpected configurations.

**Activity III — Process planning.** In this activity, the students begin building their process. They define product specifications, draw a flow chart of the process, develop quality control measurements, write procedures for operators, sketch tooling, and perform other development activities. They may specify as many operators as they deem necessary and may use any equipment or process, including a motorized conveyer belt, peanut butter dispensing devices, custom fixtures, or frozen peanut butter as long as they provide it themselves. Many students continue designing, building, and testing their processes outside of class time.

**Activity IV — Ordering supplies.** One of the most crucial activities is accurately predicting the amount of supplies the 10-minute pilot run will require. At the end of the pilot run, the students will have to factor in excess inventory of raw materials when computing their profits. The instructor packages and delivers the supplies on production day.

**Activity V — Production day.** Production day is a festive occasion as students unveil their manufacturing lines. They hire operators (graduate students, faculty, and staff volunteers) and are given ten minutes to train them. The students then stand back and try to keep silent as their process line runs for 10 minutes. By this time, most of the students have determined the number of crackers they need to produce to break even on their manufacturing line. After 10 minutes, the line is stopped and the students have a chance to debrief with their team and operators and count their final product. Whether their final product actually meets specifications is left to the discretion of the instructor, who sometimes assigns this responsibility to another team of students.

**Activity VI — Technical report.** A comprehensive final report is required which includes the calculations and drawings completed during the earlier activities. In addition the students are expected to describe the refinements they would make to their process in order to turn a profit in full production.

As is typical in actual industrial settings, most of the manufacturing lines do not make a profit on the pilot run. Some common reasons are:

- Inefficient use of operators (some operators standing around waiting while others have too much to do)
- Unreliable equipment such as conveyers that misdirect product or fixtures that break product
- Operators who do not understand the process because of poor training or overly complicated operations
- Inefficient placement of quality control measurements
- Ordering too little or too many supplies
- Over-engineering – processes that are more complicated than required.

### Survey Results

A survey was given following the module in the fall semester of 2003 and fall semester of 2004. Results of 34 student respondents in 2003 and 49 in 2004 are given in Table I. In both years the students indicated that they had some knowledge of manufacturing before the unit started. They also indicated that they felt they learned a significant amount about manufacturing from the module with scores of 3.7 and 3.8 out of 5. The students also clearly indicated that they felt the unit was a good introduction to manufacturing (3.9/5.0 both years) and it fairly represented what manufacturing was actually like (3.4/5.0 both years). The students did not respond as strongly to considering manufacturing as a job opportunity either before (rating 2.0 and 2.0 out of 4.0) or after (rating 2.2 and 2.3) in the two years.

In addition, three open ended questions were asked of the students:

- List three things you learned from this unit?

- Did anything in this unit surprise you?
- How could this unit be improved?

Table I Manufacturing Module Survey Results

Question	Fall 2003	Fall 2004
How much did you know about manufacturing before this unit? (5.0 is high)	2.4	2.7
How much did you learn about manufacturing from this unit? (5.0 is high)	3.8	3.7
Was this unit a good introduction to manufacturing? (5.0 is high)	3.9	3.9
Do you think this unit represented what manufacturing is really like? (5.0 is high)	3.4	3.4
How would you rate the difficulty of the manufacturing unit? (3.0 is neutral)	3.0	3.0
Did you have enough time to complete the unit? (3.0 is neutral)	3.0	3.3
Before the unit, had you considered manufacturing engineering as a job opportunity? (4.0 is high)	2.0	2.0
After the unit, are you considering manufacturing engineering as a job opportunity? (4.0 is high)	2.2	2.3

Several common themes occurred in the student-reported list of what was learned in the unit. They include:

- The importance of employees and training of employees
- Simplicity can be a good thing in manufacturing
- The relative cost of labor and materials and how it affects profits and process design
- Turning a profit is difficult
- The importance of planning
- The importance of testing the process and how easy it is to overestimate the process
- Ergonomics is important and affects the operators performance
- The importance and difficulty of process and quality control

One student commented, “There is a lot of engineering involved in making a simple peanut butter cracker sandwich because our team spent a lot of time coming up with an original process that would enable us to make a profit. I learned a lot from this project about quality and process control, and I am even more motivated than ever before to get my degree in engineering.” Another student wrote, “Our ideas were really good, but that’s not enough. Profit rests on so many variables that if one breaks down, you will more than likely fail to make a profit.” Another student responded, “I never knew how much manufacturing involved engineering. I always knew that engineers designed products, but I never knew that engineers also design the processes to manufacture products.”

Other noteworthy comments include:

- “Simplicity might make things slower but it’s more reliable.”
- “In a process that’s repeated constantly, little things make a big difference.”
- “Training takes time and money and actual products.”
- “I learned things don’t come out as you expect.”
- “Training is very important to keep the line going.”

- “Time is very valuable.”
- “A smooth process is crucial to the final product.”
- “Accurate and detailed process documentation is hard to explain and write.”
- “There are a huge number of things to consider in manufacturing – the process you design never works as well as you thought.”

The student comments and learning experiences reflect the tasks that industry engineers and managers say are the most important challenges facing engineering graduates: working collaboratively, systems engineering, design for manufacturing, dealing with change, lean manufacturing, and understanding manufacturing processes.<sup>1</sup>

### Conclusions

At the end of the module, from the final reports, the survey results and the individual conversations with the students, it is clear that the students have an understanding of the fundamental concepts of manufacturing. By this time, the terminology of yield, throughput, and other manufacturing concepts have become part of their vocabulary and their educational foundation.

As the peanut butter cracker manufacturing module comes to an end, even the most ardent peanut butter cracker enthusiasts are ready to take break from eating peanut butter crackers. One final word from a student should you decide to adopt this type of module in your class, “The smell of peanut butter is difficult to get out of clothes.”

### Handouts

ENGR 120: Fall 2004  
Unit II: Manufacturing

Objective: Design, build and run a process to build peanut butter cracker sandwiches

Boise State Engineering has been hired to develop a production process for peanut butter cracker sandwiches. The first step in developing the production process is to design a process and then run a pilot production run. The pilot production run will consist of 10 minutes of production time. A report will then be created to describe the results of the pilot production run and any suggestions for modifications before ramping up the process for full production. Your team is responsible for creating a production process for making peanut butter cracker sandwiches.

This module is split into a set of activities. Your instructor will inform you of the due dates for each.

Activity #	Description	Due Date
I	Modeling	
II	Writing Procedures	
III	Process Planning	
IV	Ordering Supplies	
V	Production Day	
VI	Technical Report	

### Activity I Modeling

List all the variables that will determine the cost of building a peanut butter cracker sandwich.

Given the following costs, **write the function** that describes the **cost** of building one peanut butter cracker sandwich. Write down any assumptions you made in order to write this function:

Costs:                      Crackers are \$0.02 per cracker  
                                 Peanut Butter is \$0.003 per gram  
                                 Plastic bag costs \$0.009 per bag  
                                 Labor is \$15/hour

Graph the cost of a sandwich as a function of the time required to make the sandwich. (You can use Excel and attach the graph)

If the selling price if the PB cracker sandwich is \$0.15 per sandwich, how many crackers will you need to produce in 10 minutes in order to make a profit?

How is this number affected if your yield is not 100%? If your yield is 90% how many crackers need to be produced in 10 minutes in order to make a profit?

### Activity II: Writing Procedures (Individual Activity)

Given that you have a plastic knife, a jar of peanut butter and a sleeve of crackers, write a procedure to build a single peanut butter cracker sandwich.

Now exchange your procedure with another person in the class. Have them follow your instructions to build a PB cracker sandwich.

How did it turn out?

Did you learn anything about writing procedures?

### Activity III Process Planning

As a team, determine how you are going to produce peanut butter cracker sandwiches. Remember you have the following parameters.

Incoming Materials:      Crackers (provided in wax paper sleeves)  
                                 Peanut Butter (provided in plastic jars)  
                                 Plastic bags

In order for you to be able to sell your crackers they must meet the following specs.

Specifications:              Weight: 10-12 grams  
                                 Thickness: 1.0 to 1.5 cm  
                                 No peanut butter can extend beyond the edge or through the holes in the cracker.  
                                 Top and bottom cracker must line up within 2 mm  
                                 No breakage of crackers  
                                 Sandwiches must be in bags with 10 sandwiches per bag

Costs:                        Crackers are \$0.02 per cracker  
                                 Peanut Butter is \$0.003 per gram  
                                 Plastic bag costs \$0.009 per bag  
                                 Labor is \$15/hour (you may use as many operators as you like)

Draw a flow chart of your process.

Sketch any tools or machinery that are part of your process.

What is your quality control plan?

What training documentation will you provide for your operators?

Activity IV Ordering Supplies for Production Day

Based on the number of sandwiches you predict that your process will build in 10 minutes, place your order for materials for Production Day.

NOTE: Your profits will be based on the materials ordered NOT on the materials used.

Production Materials Order :

# of Crackers \_\_\_\_\_ X \$.02/cracker = \_\_\_\_\_  
grams of peanut butter \_\_\_\_\_ X \$.003/gram = \_\_\_\_\_  
# of plastic bags \_\_\_\_\_ X \$.009/bag = \_\_\_\_\_  
TOTAL cost of Materials: \_\_\_\_\_

Number of Operators Required \_\_\_\_\_

Any additional requirements or requests? (Please confirm with your instructor).

Activity V Production Day

**Calculate COSTS:**

Incoming Materials (Quantity ordered):

# of Crackers \_\_\_\_\_ X \$.02/cracker = \_\_\_\_\_  
grams of peanut butter \_\_\_\_\_ X \$.003/gram = \_\_\_\_\_  
# of plastic bags \_\_\_\_\_ X \$.009/bag = \_\_\_\_\_  
TOTAL cost of Materials: \_\_\_\_\_

Labor Costs (\$15/hour or \$0.25/minute)

# of operators = \_\_\_\_\_  
Production time: 10 minutes for each operator, \$2.50/operator) \_\_\_\_\_  
TOTAL Labor Costs \_\_\_\_\_

Total Costs

Labor (production time only) + Crackers + Peanut Butter + Bags = \_\_\_\_\_

**Calculate Income**

Income

# of GOOD Sandwiches produced X \$0.15/sandwiches = \_\_\_\_\_

**Calculate Profits**

Income \_\_\_\_\_ - Costs \_\_\_\_\_ = \_\_\_\_\_

**Additional Production Metrics**

Please provide the equation for each metric.

Throughput (good sandwiches produced/minute)

Yield (good sandwiches/total sandwiches produced)

Excess Inventory (or too little) – did you have any supplies left over if so how much?

**Non-Recurring Expenses**

These are your development costs. They are not included in your calculation of whether or not your production is profitable. However, these costs need to be paid – over time – from your profits. It is important to understand how many sandwiches you will need to produce in order to pay off these development costs.

Training:

Operator time X \$15/hour X number of operators

Trainer Time X \$45/hour X number of trainers

Equipment Costs:

Estimate cost of any capital equipment used in process.



### Development Costs

- Estimate how much engineering time went into development (Engineers cost \$60/hour)
- Estimate how much material you used in development (peanut butter, crackers, etc)

### Activity VI TECHNICAL REPORT

The purpose of this report is to report to the management team of Boise State Manufacturing Company on the manufacturing process you have developed for making peanut butter cracker sandwiches. This is a report on your pilot production run and should provide recommendations on how to move forward into full production of peanut butter cracker sandwiches.

Please include

Process documentation for operators, Process flow chart, Quality control plan

Please report on the following

- Metrics: Cost to produce cracker including:
  - Incoming materials
  - Yield Loss
  - Cost of machinery
  - Throughput
  - Yield
- Development Costs
  - Engineering Time
  - Training
- Capital Costs
  - Production Equipment
- Profits expected in first year of production (after development and capital costs)
- Labor
- Excess inventory
- What is the payback period of the machinery?
- Cycle Time
- Development Materials

Based on your initial pilot production run, how would you change/improve your current process. This should be a large portion of your report. If you did not make a profit on your pilot production run, discuss why not and what you need to do to remedy the situation for full production.

### The Final Report (suggested format)

- Title Page and Executive Summary
  - Title of report, names, affiliation, date
  - Executive Summary: one or two paragraphs with the essential details of the entire report
- Introduction
  - State that a pilot production run was completed for PB cracker manufacturing
  - Objectives of the pilot production run (why do a pilot production run)
  - Overview of markets for PB cracker sandwiches (who will buy them and why)
- Data
  - Process documentation for operators
  - Process flow chart
  - Quality control plan
  - Results of Pilot Production - cracker including:
    - Development Costs
    - Capital Costs: Production Equipment
- Discussion
  - Did you make a profit during your pilot production run? If not, why not and how will you correct this?
  - Improvements to process, even if you made a profit how could your process run better
  - What profits do you expect to make in the first year of production.
  - Based on the profits you expect to make, how long will it take you to pay off capital costs (equipment) and development costs (engineering time)
- Conclusion: Highlight the major points of the report.

## References

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- [3] National Science Foundation, Science Resources Studies Division, 1997 SESTAT, Scientists and Engineers Statistical Data System.
- [4] National Science Board, *Science and Engineering Indicators — 2000*, Arlington, VA, National Science Foundation, 2000. (NSB-00-1).
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