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Incorporating the logistics of biofuel production into an undergraduate research program: An REU Experience

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Abstract: This paper presents the findings of incorporating logistics of biofuel production into an undergraduate research program, specifically the Research Experience for Undergraduates (REU) program offered by NSF. The paper consists of two parts. The first part describes the development of instructional material that seeks to address various parameters inherent in a biofuel operation. Several topics such as biofuel supply chain and decision hierarchy, product manufacture, storing and warehousing, distribution, transportation, and sustainable end of life (EOL) disposal as dictated by biofuel source are included. Furthermore, economic considerations such as cash flow, interest rates, cost/benefit, breakeven analysis, plant and equipment depreciation, process overview, manufacturing plant location, manufacturing equipment requirements, various modes of transportation to end-market, inventory control and management (especially for perishables), staffing requirements, and profitability analysis have also been addressed. The second part of the paper deals with different trends that were observed in terms of student cognition and learning.

Keywords: Economic analysis, Cash flow, profitability, Materials Requirement Planning, Project Management

1. Introduction

Beginning in Summer 2014, the Allen E. Paulson (AEP) Research Laboratory for Renewable Energy and Engines at Georgia Southern University started offering summer-term interdisciplinary research experiences for engineering undergraduate students in the field of Renewable Energy and Biofuels Combustion in Internal Combustion Engines (ICE). This project was made possible due to funding received from NSF under the Research Experience for Undergraduates (REU) program. The goal of this initiative is to train REU students to use the AEP Laboratory's state-of-the-art equipment. This equipment is valued at approximately $1.5M and includes high-speed data acquisition and gas analysis systems, engines, dynamometers. It was secured with NSF, DOE, EPA, and ORNL research grants. The Salient Features of the program include multidisciplinary strategies contributed by 8 faculty from 5 departments in 3 colleges of the university. The program provides stipends to ten students for ten weeks each summer from 2014 to 2016.In consultation with a faculty mentor, students develop an individual research plan and project, delineating their expected contribution to their assigned team. All participants attend lectures, seminars, workshops, and labs to develop their knowledge of, and skills in, renewable energy, research methods, and technical writing. The focus of this program is to investigate in depth the field of renewable energy. Within this broad framework, five specific area of concentration are addressed. They include the following:

1. Investigation of the thermo-physical and chemical properties of biofuels and their neat fatty acids: REU students conduct calorimeter tests to obtain the lower heating values for free fatty acid components of straight bio-oils and their neat methyl esters and thermo Gravity Analysis (and Differential thermo analysis to investigate vaporization and combustion properties over a large temperature range.
2. Analysis of combustion characteristics of biofuels and their neat FAMEs. Through this project, information will be gained pertaining to: 1. Biodiesel and component fatty acid properties, such as density and bulk modulus and influence on injection timing and injection law, as compared to diesel fuel. 2. Influence of fuel properties on ignition delay and premixed and diffusion combustion.
3. Investigate biofuels and their neat FAME emissions. After determining the precise conditions of the heat release and combustion phases, students will investigate emissions for various biofuel blends, C16:0-C18:3. Students, further investigate whether improved vaporization and physical changes to ignition delay affect NOx emissions, whether oxygenation and decreased aromatic content of biodiesel decrease in-cylinder soot formation.
4. Investigate advanced combustion modes in a True Omnivorous Multifuel Engine: REU students investigate FAME and neat FAME combustion behavior for various fueling strategies and injection timings in this novel engine configuration and compare the results with DI operation.

5. Instrumentation of an Extended Range Hybrid Electric Vehicle (ERHEV) with a green engine fueled by butanol: REU students work on converting a Briggs and Stratton gasoline engine to butanol and rebuilding the maps.

The REU project being discussed in this paper is one that specifically deals with renewable energy as a subset of sustainability. It seeks to target biofuels as a primary test bed. The knowledge gained through the experiments can be scaled up and is readily transferable to the myriad aspects of sustainability such as water management, pollution control, waste disposal, resource conservation etc. In order to enable a scale up of any proportion, it is necessary to understand the underlying operational aspect of any project. This can enable the transfer of technology from the laboratory to the market place. When viewed from this vantage point, the logistics of biofuel production and different pertinent aspects gain importance.

2. Logistics Module

Within the overall framework of the REU project is embedded a discussion on the logistics of biofuel production. It is worth ten contact hours of time and deals with several basic concepts that are necessary in order to enable technology transfer. Each topic is explained through a series of problem solving sessions. The emphasis is on rigorous quantitative analysis. The topics are listed below:

- **Economics of Biofuel production**: This module deals with basic concepts of economic analysis and relates them to biofuel production. Topics such as crop yield, efficiency of manufacturing processes, waste are discussed. Economic topics such as cash flow diagrams, costing analysis, cash flow analysis are examined in detail. Costing is further broken down as direct costs and indirect costs. Costing pertaining to warehousing, transportation and clerical functions is also discussed. Any project, (including a biofuels project) is worth the effort only if it makes sense economically. From this perspective, several metrics such as present worth analysis, future worth analysis, benefit cost analysis, incremental analysis and payback period analysis are discussed in detail. Numeric problems are solved and the connection with biofuels projects is clearly demonstrated. Other related factors such as depreciation are also dealt with in detail. Approximately 10-15 problems on each topic are solved in this sub module.
- **Materials Requirement Planning**: This module deals with the actual logistics of the operation. It will be appreciated that a biofuels operation involves several distinct phases and players. These include crop harvesting (farmers), fuel extraction (manufacturing), fuel blending and testing (Quality control), warehousing and storage (facilities) and transportation to end customer (operated wither by manufacturer or sub contracted to independent transporter). It should be obvious that the end customer drives ultimate demand. However, in order to successfully meet that demand, several events have to occur concurrently. Each event is somehow related to each of the aforementioned stages of biofuel production and distribution. The MRP module deals with scheduling concepts such as inventory, inventory on hand, scheduled receipts, gross requirements and net requirements etc, all tied in to a final customer order that is to be delivered at some fixed date in the future. A schematic of MRP is depicted in figure 1. An MRP schedule is depicted in table 1. Five problems of successively increasing level of difficulty are solved in this sub module.
- **PERT/CPM**: Each project can be construed to be comprised of a series of sub projects, each with its own set of constraints. The constraints can take the form of physical and material resources, human capital and time. Within this sub-module, basic concepts related to the Project evaluation review technique (PERT) are presented. These include establishing a precedence relationship, constructing an activity network and computing project time. PERT concepts are almost inextricably linked with the primary CPM concepts, namely establishment of critical path. By definition, the critical path is the longest path (in terms of time) that directly connects different activities. Students solve a variety of problems dealing with critical path analysis. The knowledge gained during the process is further extended in trying to solve problems related to crashing the network by deploying additional resources, thus accomplishing the project within a shorter duration of time. Stochastic concepts such as probability of completing the project within a certain time frame and time and cost estimates are also discussed in detail. Five to seven problems that involve a successively higher degree of complexity are solved in this sub module.

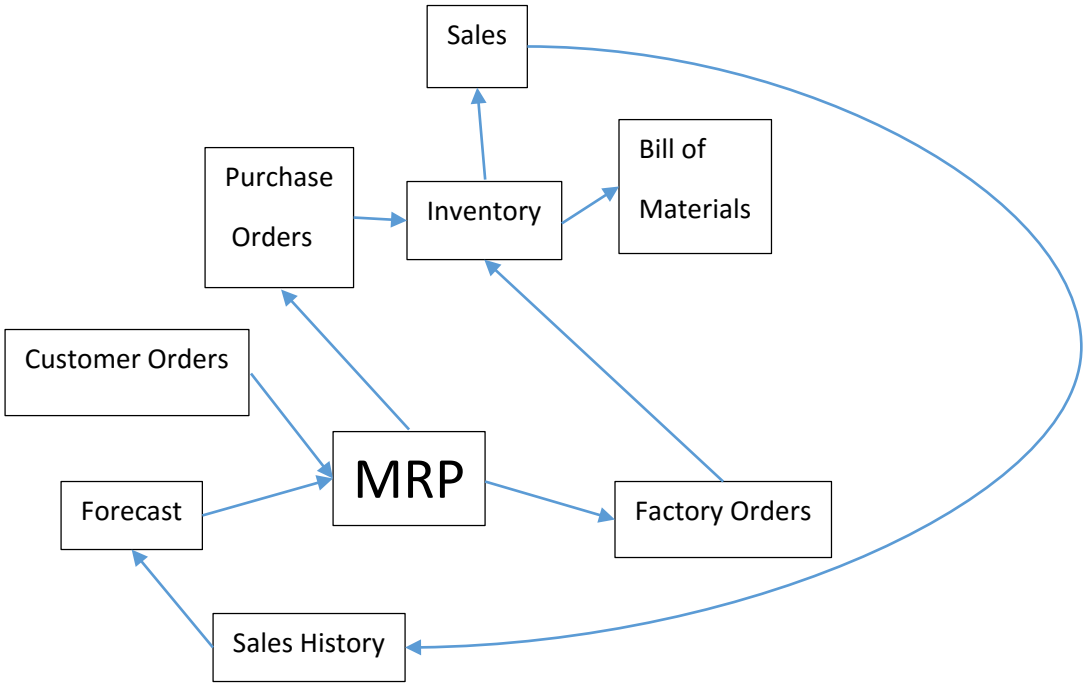

Figure 1. Structure of Materials Requirement Planning.

Table 1. Example of MRP schedule with different constraints

EOQ=150									
Week:	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Gross requirements		20	30	50	50	60	90	40	60
Scheduled receipts			50						
Projected on hand at end	40	20	40	140	90	30	90	50	140
Net requirements				10			60		10
Planned order receipts				150			150		150
Planner order releases		150			150		150		
min order = 50									
Week:	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Gross requirements		20	30	50	50	60	90	40	60
Scheduled receipts			50						
Projected on hand at end	40	20	40	40	40	30	0	10	0
Net requirements				10	10	20	60	40	50
Planned order receipts				50	50	50	60	50	50
Planner order releases		50	50	50	60	50	50		

3. Findings

The REU program and accompanying logistics module has been offered twice so far (during summer 2014 and summer 2015). It was offered to a cohort of ten students each. The following are some observations with respect to this module.

- It was observed that students were quite interested in the economic analysis of projects and the role played by such analysis in project selection. Team work was encouraged and access to MS Excel was granted. Students would solve problems using conventional a paper-pencil format and then solve the same problem using MS Excel.
- It was observed that student skills with respect to using MS Excel were initially quite weak in both cases. However, with increased exposure, they were able to more confidently use the software.
- Students has trouble visualizing and dealing with MRP schedules. This was especially the case during summer 2014. They were unable to quickly grasp the concept of a materials requirement schedule especially with respect to biofuels formulation. However, with repeated exposure to MRP problems, they gained a higher degree of proficiency over time.
- Most students were able to construct a network diagram using PERT quite easily. They did encounter a degree of difficulty understanding the concept of critical path, especially multiple critical paths. The majority of students had no prior exposure to using normal distribution tables and thus struggled with estimates and probabilities. Most students also struggled initially with successfully crashing a network.

4. Conclusion

This paper presented some unique experiences gained in a REU program dealing with the logistics of biofuel operations. The logistics module presented in this paper tries to make the connection between the experimental (lab based) aspects of biofuel production and testing and the commercial aspects. Related concepts such as profitability analysis, project management and project and materials scheduling are included in this module. Observation of student performance was also reported this paper. Given that the course has only been offered twice thus far to groups of ten students each, it is still too early to conduct any statistical analysis of such a small data set.