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Johnny C. Ho
*Columbus State University*

Francisco J. López
*Middle Georgia State College*

David Ang
*Auburn University at Montgomery*

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## TEACHING AGGREGATE PLANNING IN OPERATIONS MANAGEMENT

Johnny C. Ho, Turner College of Business, Columbus State University, Columbus, GA 31907
Francisco J. López, School of Business, Middle Georgia State College, Macon, GA 31206
David Ang, School of Business, Auburn University at Montgomery, Montgomery, AL 36124

### ABSTRACT

*This paper describes some unique characteristics of Aggregate Production Planning, which make the teaching of this topic in Operations Management courses somewhat different than other topics. A challenge when teaching Aggregate Planning is to make students understand the need to apply trial-and-error approaches to test, evaluate, and improve Aggregate Plans. In other words, do not just learn how to do the computations needed to develop an Aggregate Plan under certain conditions, but to actually analyze it and try to modify it with the objective of producing an improved plan. We recommend that in operations management courses, Aggregate Planning is taught within the context of a project, which includes a student individual element as well as a team component. The project involves the use of a spreadsheet, such as Microsoft Excel, to obtain Aggregate Plans with various input datasets and with different demand pattern and cost coefficients. It also requires each team to write a report discussing how the team derives its final plan and the insights acquired from the assignment. The paper starts with a compilation and description of unique features of Aggregate Planning, then it discusses the idea of using a students' project when teaching this topic, and it finishes with an example. The paper also provides a couple of avenues for future research.*

### INTRODUCTION

Two of the contributions of this paper are (1) collecting, describing, and synthesizing some challenges that may appear when teaching Aggregate Planning (AP) in Operations Management, and (2) recommending a method that allows students to gain a more thorough understanding of this topic than what can be obtained by just covering the material the way most textbooks do, for example, Nahmias (2009); Stevenson (2012); or Heizer & Render (2014). Aggregate Planning, also known as Aggregate Production Planning or Aggregate Scheduling, is "concerned with determining the quantity and timing of production for the intermediate future, often from 3 to 18 months ahead" (Heizer & Render 2014, p. 521). As the term aggregate implies, an Aggregate Plan combines appropriate resources into general, or overall, terms. That is, the Aggregate Plan analyzes production in the aggregate (grouped by families of products), rather than treating each individual product separately.

Aggregate Planning is one of the most important planning activities of many organizations, especially manufacturing firms. Because of this, AP appears in virtually every operations management textbook. It is arguably a must-cover topic in an operations management course, particularly in higher level undergraduate or graduate courses. AP is important for several reasons.

First, Aggregate Planning helps stay ahead of the curve as it takes time to carry out tasks related to manufacturing, such as hiring and training new employees or ordering and, after lead time, receiving materials. Second, it is hard to predict the demand levels of individual products with a high degree of accuracy, so organizations develop long term or intermediate plans in aggregate terms. As time passes and the planned manufacturing activities become closer and closer, the Aggregate Plan is broken down into specific, more detail plans, meaning the AP serves as an important bridge between long term and short term plans. Finally, Aggregate Planning is necessary for budgeting purposes and is important to keep the supply chain synchronized (Stevenson 2012).

An Aggregate Plan is a timetable with itemized information for the time periods included in the time horizon under consideration. The AP contains two types of numbers for each period or month considered: items (resources requirements) and dollars. The "items" category includes number of units to be produced, which can be met by regular time, overtime, and/or subcontracting; number of labor hours (or workers) needed; number of units in inventory at the end of each period; number of workers to be hired; number of workers to be laid-off; and other. The "dollars" refer to the cost associated to each of the items above, also per month. Thus, an AP looks like a spreadsheet where each month is assigned a row and each item or dollar category is assigned a column (some books and practitioners prefer working with these data transposed). The intersections of rows and columns contain the units or dollars of the corresponding combinations of a period with an item or dollar category. It is common practice to obtain aggregate measures by column (items or dollars), by row (month), and the total cost of the plan, which is the aggregate of all costs involved.

Aggregate Plans are subordinated to the company goals or conditions (e.g., target levels for customer service, inventory, employment, etc.) and take into account demand forecast, facility capacity, inventory levels, workforce size, and other related inputs. The job of the planner is to determine, in an itemized monthly form, the best way to meet forecasted demand by adjusting the rates of production output for a facility; the levels of workforce and inventories; and the estimated costs incurred by the firm based on these manufacturing-related activities over the next 3 to 18 months. Thus, when generating an Aggregate Plan, the operations manager must address questions like the following (Heizer & Render 2014, p. 523):

1. Should inventories be used to absorb changes in demand during the planning horizon?
2. Should changes be accommodated by varying the size of the workforce?
3. Should part-timers be used, or should overtime and idle time absorb fluctuations?
4. Should subcontractors be used on fluctuating orders so a stable workforce can be maintained?

One of the most important objectives of an AP is to meet forecasted demand. Once this is achieved, the focus turns into minimizing the total procurement-related costs over the planning horizon. "However, other strategic issues may be sometimes more important than low cost, for example to smooth employment levels, to drive down inventory levels, or to meet a high level of service, regardless of cost" (Heizer & Render 2014, p. 522).

There are a number of AP models available, which are classified in three categories based on the number of objectives of the model. Single-objective models focus on minimizing the total cost of the plan (Leung et al. 2007). In bi-objective models, the minimization of total cost is the primary objective and a second objective is incorporated, such as maximization of service level (equivalently, minimization of backordering levels and lost sales because of stock outs), or minimization of one of the following: changes in labor level, variability of total cost, financial risk (Goh et al. 2007; Mirzapour Al-e-hashem et al. 2011). Finally, multi-objective models consider a combination of objectives simultaneously (Mirzapour Al-e-hashem et al. 2012; Wang & Fang 2001; Wang & Liang 2004). For a comprehensive survey of models and methodologies of AP, refer to Nam & Logendran (1992).

There are four approaches to develop Aggregate Plans that textbooks cover in some detail or at least mention (e.g., Heizer & Render, 2014). The four approaches are: (1) Trial and Error Approaches; (2) The Transportation Method of Linear Programming; (3) Linear Programming; and (4) Linear Decision Rule.

Trial-and-error approaches generally receive the most coverage in introductory operations management textbooks, whereas linear programming has the most coverage in advanced operations management texts. Trial-and-error approaches consist of developing several Aggregate Plans based on the experience and intuition of the planner and/or as the result of analyzing an AP and modifying it trying to produce a better alternative AP. This enables the planner to visually evaluate and compare the overall costs of the different plans as well as to contrast projected demand requirements with existing capacity. Graphs are frequently used to guide the development of alternatives. Some planners prefer cumulative graphs while others prefer to see a period-by-period breakdown of a plan. The obvious advantage of a graph is that it provides a visual representation of a plan. The chief disadvantage of trial-and-error approaches is that they do not necessarily provide the optimal AP in terms of total cost.

There are three basic strategies to develop trial-and-error APs (e.g., Nahmias 2009), with the first two representing the two extremes of an AP strategy spectrum: (a) constant workforce, also known as pure level; (b) zero inventory, also known as pure chase; and (c) mixed, which is some type of combination of the first two.

(a) A constant workforce or pure level strategy maintains the number of workers invariant throughout the planning horizon so production rates using regular time are constant. Fluctuations in demand are met mainly by means of overtime production (there are slight differences in textbooks about the role of overtime in constant workforce strategies), subcontracting, inventory, and backorders (and/or lost sales). Under this strategy hiring and laying-off workers is not allowed. Hence, the largest associated costs are usually inventory holding and shortage costs.

(b) The objective of the zero inventory or pure chase strategy is to match demand period by period using regular time production. Demand changes are met by hiring or laying-off workers as needed. This pure strategy does not allow for overtime, subcontracting,

inventories, or stock outs. The highest costs for this strategy are usually incurred because of changes in the workforce.

(c) A mixed strategy contains features from the first two; for example, an AP that allows to hire and lay-off workers but also allows to use inventories and stock outs.

Some firms are continuously or occasionally subject to limited capacity, which is so restrictive that it becomes a crucial factor when developing Aggregate Plans. While subcontract capacity may vary from period to period, regular time and overtime capacities are usually, but not always, fixed. In these cases, it is common to borrow ideas from the transportation method of linear programming to develop plans relatively different from the constant workforce, zero inventory, or mixed strategies. Developing "transportation method of linear programming" APs is usually more complex than regular ones; for example, time periods appear both in the rows and in the columns of the AP. Also, some of the techniques presented in textbooks, for example Nahmias (2009); Stevenson (2012); or Heizer & Render (2014) do not guarantee identifying the optimal AP or that a solution which satisfies the forecast demand over the entire planning horizon exists. Most textbooks do not explain how to optimally solve these problems. Besides, in order to simplify these types of APs some options like hiring, layoff, and backorders are usually excluded.

Linear Programming (LP) is an optimization technique that can be used to solve Aggregate Planning problems. Most introductory operations textbooks refer to linear programming as an optimization approach for AP problems but do not explain how to obtain the formulation of the problem. A complete approach requires the formulation of basic models along with their solutions, usually obtained using software. A rigorous approach would include a number of different LP models to account for different types of AP problems; nonetheless, this approach would only be reserved for the graduate level.

Other Aggregate Planning techniques include the *management coefficients* model and *linear decision rule*; nevertheless, most textbooks only mention these methods briefly. The linear decision rule approach to solve AP problems was proposed by Holt et al. (1960). It applies quadratic approximations for all the relevant costs and obtains linear equations for the optimal policies.

**POTENTIAL FOR TEACHING AGGREGATE PLANNING MORE EFFECTIVELY**

The computations involved in the development of APs are very basic since they reduce to adding, subtracting, multiplying, and dividing. In spite of this, effectively teaching Aggregate Planning may be a little more challenging than other topics because of a number of reasons, including the following:

1. As can be deducted from the Introduction section of this paper, Aggregate Planning has an unusually large number of theoretical and computational facets that imply the students must learn a number of definitions, understand the strategic role and importance of AP

within the context of a firm, be aware of the objectives and conditions that the organization sets for the Aggregate Plan, learn that there are different approaches to develop APs, learn how to develop several different types of APs (e.g., constant workforce, chase, mixed, transportation method of linear programming), understand how to use specially designed graphs within this context, etc. At a minimum, students are expected to learn terms, concepts, definitions, and how to develop APs using the three trial-and-error approaches constant workforce, chase, and mixed. Sometimes they are also required to learn the transportation method of linear programming.

2. The format in which the data are provided is not standard; e.g., production time may be given as (a) number of units per worker per hour, (b) number of labor hours required to produce one unit, (c) number of units per worker per month, etc.

3. The quantities (both number of items and corresponding costs) per period/month that have to be calculated to develop an AP include all or some of the following: materials (the inputs needed for production and their costs), regular time production, overtime production, quantities subcontracted, number of workers needed, number of employees to hire, number of employees to lay off, on hand inventory, and number of units stocked-out.

4. Each strategy requires the computation of different types of quantities and costs; for example, inventory costs are calculated in the constant workforce strategy but not in the chase strategy, whereas hiring costs are computed in the chase strategy but not in the constant workforce. Even when using the same strategy, the quantities and costs to be computed can vary; for example (a) materials may not be considered at all in a problem; (b) an AP may allow obtaining the product using regular time, overtime, or by subcontracting, but another AP for the same problem may not allow subcontracting; (c) in the case of the transportation method of linear programming, plans are simplified by not allowing one or more of the following: hiring, layoff, backordering, or other options. The calculations in a mixed strategy tend to be more elaborated because there are usually more cost components to capture than in pure strategies and not all time periods require the same kind of repetitive calculations; e.g., there may be inventories at the end of some but not all months.

Besides, APs can be subject to additional conditions; for example, there may be limits on overtime production, or on the maximum inventory that can be built based on the firms' capacity, and these limits may be different for each time period. Textbooks usually ask students to develop just a few specific mixed APs rather than motivating them to start with one single problem and derive, evaluate, and then iteratively improve their own mixed APs. The main reason may be that it takes a considerable amount of time to perform manual

calculations particularly when the number of periods involved is large. As a result, students usually do not have the opportunity to learn how to develop a good mixed strategy plan.

5. Independently of the strategy used, what quantities and costs have to be included, and whether there are additional conditions on the AP, developing an AP may require a "fairly large" number of computations. Even for a simple pure strategy such as chase or constant workforce, the repetitive nature of calculations involving multiple periods could make it difficult for students to get a completely correct solution.

6. Frequently, students in some courses lack a good knowledge and command of mathematical techniques like linear programming or the complex function of the linear decision rule, so they tend to struggle with the abstract notation and mathematical formulations required to produce an AP. This issue is exacerbated by the fact that AP linear programs require an unusually large number of variables and constraints. Even if the basic model is mastered, most students find it challenging to go beyond. The linear programming and linear decision rule approaches are frequently left out of a course.

The combination of all these issues makes Aggregate Planning a relatively sophisticated and may be intimidating topic for students. As a result, students are likely to end up focusing on learning the mechanics of the computations rather than on seeing the big picture; for example, not trying to understand why the chase strategy works well under certain scenarios while the constant workforce strategy works well under other scenarios. Consequently, students may not gain insights behind the scenarios.

This paper proposes a project that instructors can use as a mean that supports processes of learning and teaching Aggregate Production Planning. The next section describes our Aggregate Planning project. It is followed by a project example. Finally, we give a summary and share our Aggregate Planning project experience in the conclusion section.

## THE PROJECT AND THE ROLE OF THE STUDENTS

Once all pertinent terms, definitions, and theoretical discussions have been presented in a course, students should be exposed to a simple example that illustrates the basics of the pure level and pure chase strategies. At this point, students should realize that meeting demand can be done several different ways and that the total manufacturing related costs can change significant-ly depending on the strategy selected. Now it is time for the students to change from having a passive role to become active.

The Aggregate Planning project proposed in this paper consists of two parts – the first part requires students to work individually, whereas the second part calls for teamwork. In Part 1, every student is asked to analyze an Aggregate Planning problem and to develop both a *feasible* level capacity and a *feasible* chase plan for the problem. In order to qualify as a *feasible* plan, the firm must maintain a non-negative inventory level by the end of the planning horizon, i.e., satisfy all

demand requirements of the planning horizon. Furthermore, students must obtain their plans by implementing them in Microsoft Excel. The purpose of this part is to ensure that every student fully understands how to do the required math for a level and a chase strategy as well as the relationships among various terms, such as cumulative demand and cumulative production. Part 1 is also aimed to prepare students to be effective contributing team members in Part 2. Up to now, our implementation has been to provide all relevant project information just before Part 1 of the project, but it is certainly possible to offer additional feedback between Part 1 and Part 2, or at the extreme, when students look for guidelines at any point in time during the project.

An example of an Aggregate Planning problem that could be assigned to the students for the project is given in Table 1. The Aggregate Planning problem has an 18-month planning horizon and is quite general in that the firm may vary workforce (via hiring and layoff) and inventory level (including backordering) to satisfy demand. The firm may also use overtime production to meet demand. Although subcontracting is not considered, this option still can be easily added.

Table 1. Aggregate Planning Problem Data

| Month | Gross Demand | Working Days |
|-------|-------------|-------------|
| 1 | 2,500 | 19 |
| 2 | 2,600 | 20 |
| 3 | 2,800 | 19 |
| 4 | 2,700 | 25 |
| 5 | 2,000 | 22 |
| 6 | 2,000 | 20 |
| 7 | 1,900 | 18 |
| 8 | 1,700 | 25 |
| 9 | 2,000 | 23 |
| 10 | 2,000 | 24 |
| 11 | 2,300 | 23 |
| 12 | 2,500 | 19 |
| 13 | 2,300 | 20 |
| 14 | 2,300 | 22 |
| 15 | 2,500 | 20 |
| 16 | 2,400 | 21 |
| 17 | 2,100 | 22 |
| 18 | 2,100 | 20 |
| Total: | 40,700 | 382 |
| Beginning inventory = 300 units | | |
| Ending inventory = 200 units | | |
| Beginning workforce = 200 workers | | |
| Cost of hiring = $2,000/worker | | |

| |
|---|
| Cost of firing = \$3,000/worker |
| Cost of holding = \$80/unit/month |
| Cost of backordering = \$120/unit/month |
| Incremental overtime cost = \$200/unit |
| In the past: Over 23 working days, with the workforce level constant at 200 workers, the firms produced 2,120 units. |

The second part of the project is iterative in nature and results in the development of several APs (one for each iteration) that basically improve a previously obtained AP, especially towards the end of the process. In Part 2, students are assigned to teams of three or four. One objective of using teams is to implement an approach that is consistent with the teaching philosophy of *team based learning* (e.g., Michaelsen & Sweet 2008). Each team is provided with an Aggregate Planning problem similar to that in Part 1, but subject to some additional problem scenarios or conditions. These scenarios may differ from Part 1 by demand requirements, cost coefficients such as hiring and layoff costs, or some other problem characteristics. Table 2 illustrates two of these scenarios. Scenario 1 differs from Part 1 by demand requirements only, whereas Scenario 2 only differs by cost coefficients.

Table 2. An Example of Aggregate Planning Problem

| Scenario 1 | | Scenario 2 |
|---|---|---|
| Month | Gross Demand | Cost of hiring = \$1,500/worker |
| 1 | 2,100 | Cost of firing = \$3,000/worker |
| 2 | 2,400 | Cost of holding = \$60/unit/month |
| 3 | 2,100 | Cost of backordering = \$100/unit/month |
| 4 | 2,700 | Incremental overtime cost = \$150/unit |
| 5 | 2,000 | |
| 6 | 2,000 | |
| 7 | 2,000 | |
| 8 | 2,000 | |
| 9 | 2,000 | |
| 10 | 2,000 | |
| 11 | 2,300 | |
| 12 | 2,500 | |
| 13 | 2,300 | |
| 14 | 2,300 | |
| 15 | 2,500 | |
| 16 | 2,800 | |

| 17 | 2,500 | |
|----|-------|--|
| 18 | 2,600 | |
| Total: | 41,100 | |

    The teams are then required to analyze and discuss each of the problem scenarios, including the corresponding base scenarios of Part 1. After the analysis and discussion of a problem scenario, each team proposes an initial feasible plan (Plan 1) and implements it in Excel. Each team is asked to document the reasons why it chose its AP. As stated previously, a feasible plan satisfies the total demand of the planning horizon.

    For the initial plan, the project is primarily looking for the quality of the rationale used to develop the plan, not so much for the solution quality in terms of total cost. From here the project becomes iterative as follows. Each AP obtained serves as the basis to develop the next feasible plan. Given an AP, each team has to analyze the resulting costs (such as regular time, overtime, hiring, layoff, holding, backordering) and make decisions in terms of how to modify the plan to generate an alternative feasible plan with, hopefully a lower total cost.

    The observations made by the team as well as the rationale to create the new AP must be documented at each iteration; for example, it may be that a team decides to lay off some workers at some point in time in the time horizon because the inventory costs around those periods are excessively high, suggesting that production should be decreased. The development of each new plan allows each team to analyze costs, make decisions to modify the plan, and obtain a new feasible AP. This iterative process continues until the team is satisfied with its final plan. For the final plan, say Plan 5 (P5), the team may fine-tune it further in search of the lowest overall total cost solution and label these resulting *secondary* plans as P5.1, P5.2, etc. Notice that the model built in Excel allows each team to focus on analyzing the goodness of the plan and how to further improve it instead of on conducting the required computations "manually".

    Finally, the team is required to write a report documenting the rationale it applied to select each of its plans including the final plan. It is particularly important that the team explains the logic and insights employed to move from one plan to the next, to explain the improvements that result from the changes implemented, and that the quality of the final AP is high. In the report, the team should include tables which summarize the major and secondary APs developed; see Table 3 for an example. Finally, Excel spreadsheets showing each of the major plans, as well as the fine-tuned secondary plans should be inserted in the report as an appendix.

Table 3 Summary Table

| Plan | Period | Workforce Level | Overall Total | Total Hiring | Total Firing | Total Overtime | Total Holding | Total Backorder |
|------|--------|-----------------|---------------|--------------|--------------|----------------|---------------|-----------------|
| 1 | 1 – 9 | 200, 217, … | $500 | $100 | $100 | $100 | $100 | $100 |
|   | 10 – 18 | … 190 | | | | | | |

| 2 | 1 – 9 | … | … | … | … | … | … | … |
| | 10 – 18 | | | | | | | |
| … | … | … | … | … | … | … | … | … |
| 5 | 1 – 9 | … | … | … | … | … | … | … |
| | 10 – 18 | | | | | | | |
| 5.1 | 1 – 9 | … | … | … | … | … | … | … |
| | 10 – 18 | | | | | | | |
| 5.2 | … | … | … | … | … | … | … | … |

## BENEFITS FOR THE STUDENTS

By following the approach described above the students start by learning and understanding the theoretical components of Aggregate Planning. Then they realize, with their own first APs, that the total cost can be significantly different depending on the strategy used. Building a spreadsheet model has at least three important advantages: (i) the student does not focus solely on learning how to "mechanically" do all the required computations for all possible AP strategies, (ii) the model allows conducting sensitivity analysis by simply changing some numbers and analyzing the resulting impact; (iii) since this sensitivity analysis can be done instantaneously, some class-time can be devoted to conduct discussions pertaining to issues, other than costs, that must be taken into account in Aggregate Planning; e.g., quality issues or employees morale if there is too much hiring and lay off activity. The team project also contributes some benefits since the interaction among the students inspires analysis, brainstorming, motivates exchange of insights or ideas, and helps developing teamwork skills, all on an active, hands-on learning environment. Our experience suggests to us that by working in teams, students are also exposed to the benefits of group work (e.g., Burke 2011; Payne et al., 2004).

## AN EXAMPLE

We will present several feasible plans based on the example data given in Table 1. The first plan employs a level strategy; while the second one uses a chase strategy (obtained via the hiring and/or lay off of workers). These plans together represent two extremes. Table 4 summarizes the solutions of the level capacity (Plan 1) and chase plans (Plan 2). Plan 1 has 285 workers throughout the planning horizon, implying a hiring of 85 workers in period 1. The total cost for the plan consists of two cost components – hiring and inventory holding. The total hiring cost is $170,000, whereas the total holding cost is approximately $7 million. In Plan 2, the workforce level varies between 148 and 320. The overall total cost for the plan is around $1.8 million, consisting of approximately $0.8 million hiring cost and $1 million firing cost, as well as $22,315 holding cost (due to rounding of the workforce).

In addition to these two *extreme* plans, there are many avenues that students may explore to create an initial plan. Since the backordering alternative is allowed (except for the last planning period), it is feasible to develop a constant workforce plan using the *average* number of workers required to satisfy total net demand over the entire planning horizon (called Plan 3), and thereby resulting in backordering in some periods.

Sometimes the problem data, demand in particular, may suggest that it is advantageous to divide the planning horizon into several segments and treat each one as an independent, but successive AP problem, which are simply joined and aggregated after they are developed. For example, when demand during the first half of the planning horizon is significantly different from that of the second half, then using a constant workforce size for the first half and another constant workforce size for the second half could be effective (called Plan 4). Furthermore, when the cost of hiring and/or firing is low relative to the cost of holding and/or backordering, and there are frequent but clear changes in demand, it could be particularly beneficial to partition the planning horizon into more, say four, segments, and apply the level strategy in each segment (called Plan 5).

Plan 6 can be developed after carefully analyzing demand and cost data with an aid of various graphical tools, including line graph and bar chart. Students can create a line graph of cumulative demand versus cumulative production output of an existing plan. When the cumulative demand lies above the cumulative output, excess inventory is built up, and vice versa. This graph provides students insight as to when to increase workforce/overtime or reduce workforce. Another simple graphical tool is a bar chart showing inventory level at the end of each period. Table 5 gives a summary of the four plans described above as follows:

Plan 3: Constant workforce over the entire planning horizon.
Plan 4: Break the planning horizon into two segments, use constant workforce in each.
Plan 5: Break the planning horizon into four segments, use constant workforce in each.
Plan 6: Analyze demand and cost data and use graphical tools.

Table 4. Plan 1 (Level) and Plan 2 (Chase)

| Period | Plan 1: Constant Workforce | Plan 2: Chase Demand |
|--------|----------------------------|----------------------|
| 1 | 285 | 252 |
| 2 | 285 | 282 |
| 3 | 285 | 320 |
| 4 | 285 | 234 |
| 5 | 285 | 197 |
| 6 | 285 | 217 |
| 7 | 285 | 229 |
| 8 | 285 | 148 |
| 9 | 285 | 189 |

| 10 | 285 | 180 |
|---|---|---|
| 11 | 285 | 217 |
| 12 | 285 | 286 |
| 13 | 285 | 249 |
| 14 | 285 | 227 |
| 15 | 285 | 272 |
| 16 | 285 | 247 |
| 17 | 285 | 208 |
| 18 | 285 | 249 |
| Overtime: | $0 | $0 |
| Hiring: | $170,000 | $770,000 |
| Firing: | $0 | $1,008,000 |
| Holding: | $7,054,330 | $22,315 |
| Backorder: | $0 | $9 |
| Total Cost: | $7,224,330 | $1,800,325 |

Table 5. Plans 3-8

| Period | Plan 3 | Plan 4 | Plan 5 | Plan 6 | Plan 7 | | Plan 8 | |
|---|---|---|---|---|---|---|---|---|
| | | | | | # Workers | O/T Units | # Workers | O/T Units |
| 1 | 231 | 227 | 255 | 250 | 225 | 230 | 240 | 0 |
| 2 | 231 | 227 | 255 | 250 | 225 | 526 | 240 | 400 |
| 3 | 231 | 227 | 255 | 250 | 225 | 232 | 240 | 400 |
| 4 | 231 | 227 | 255 | 250 | 225 | 0 | 240 | 300 |
| 5 | 231 | 227 | 255 | 250 | 225 | 0 | 200 | 0 |
| 6 | 231 | 227 | 192 | 240 | 225 | 0 | 200 | 148 |
| 7 | 231 | 227 | 192 | 225 | 225 | 0 | 200 | 0 |
| 8 | 231 | 227 | 192 | 200 | 225 | 0 | 180 | 0 |
| 9 | 231 | 227 | 192 | 200 | 225 | 0 | 180 | 0 |
| 10 | 231 | 236 | 230 | 200 | 225 | 0 | 180 | 0 |
| 11 | 231 | 236 | 230 | 200 | 225 | 0 | 215 | 0 |
| 12 | 231 | 236 | 230 | 225 | 225 | 0 | 240 | 200 |
| 13 | 231 | 236 | 230 | 225 | 225 | 0 | 240 | 200 |
| 14 | 231 | 236 | 240 | 225 | 225 | 0 | 240 | 0 |
| 15 | 231 | 236 | 240 | 250 | 225 | 0 | 240 | 0 |
| 16 | 231 | 236 | 240 | 250 | 225 | 0 | 240 | 0 |
| 17 | 231 | 236 | 240 | 250 | 225 | 0 | 240 | 0 |
| 18 | 231 | 236 | 240 | 250 | 225 | 0 | 240 | 62 |
| Overtime: | $0 | $0 | $0 | $0 | $128,440 | | $222,300 | |
| Hiring: | $62,000 | $72,000 | $206,000 | $200,000 | $50,000 | | $200,000 | |
| Firing: | $0 | $0 | $189,000 | $150,000 | $0 | | $180,000 | |
| Holding: | $392,849 | $290,683 | $193,559 | $302,383 | $586,637 | | $40,758 | |
| Backorder: | $818,671 | $983,423 | $298,685 | $325,983 | $295,283 | | $195,610 | |
| Total Cost: | $1,273,520 | $1,346,106 | $887,244 | $978,365 | $1,060,360 | | $838,669 | |

Table 5 shows that all four plans outperform Plans 1 and 2 significantly. Plan 5 (4 segments) yields the lowest total cost of $887,244, it is followed by Plan 6 (examining demand and cost data with graphical tools) with a total cost of $978,365, Plan 3 (1 segment) with a total cost of $1,273,520, and Plan 4 (2 segments) with a total cost of $1,346,106.

It is important that each team gives rationales to justify all its proposed plans, whichever ones are selected. When a team is satisfied with its final plan, it may further improve it by fine-tuning. Suppose that Plan 3 is selected as the final plan. By making minor changes to Plan 3 (i.e., constant 231 workers in each period), a secondary plan, say Plan 3.1, is created. Plan 3.1 utilizes 230 workers from periods 1-17 and 242 in period 18 and its total cost decreases from $1,273,520 (Plan 3) to $1,270,449. If it is undesirable to make a large workforce change in any period, a constraint can be introduced to enforce this requirement.

Now suppose that Plan 6 is chosen as the final plan. Again by modifying Plan 6 slightly a secondary plan, say Plan 6.1, is created. Plan 6.1 is identical to Plan 6 except for periods 12-14 with 226 (instead of 225) workers and periods 15-18 with 249 (instead of 250) workers. As shown in Table 6, Plan 6.1 yields a total cost of $967,277 compared with $978,365 of Plan 6.

Consider now applying the overtime production option to the problem and see if it results in a more cost effective Aggregate Plan. Table 5 also shows two additional plans − Plans 7 and 8. Plan 7 uses a constant workforce level of 225, which is cut by six workers compared with Plan 3. Overtime production is used in periods 1, 2, and 3 to compensate for the output loss. Plan 7 yields an overall total cost of $1,060,360 compared with $1,273,520 of Plan 3. Finally, Plan 8 generally employs a smaller workforce in most periods compared with Plan 5 and again makes up the difference via overtime production. It yields an overall total cost of $838,669 compared with $887,244 of Plan 5. Appendix A illustrates Plan 8 in great detail.

## CONCLUSIONS

This paper presents and discusses some factors/issues that tend to make the topic of Aggregate Planning a little more challenging to teach for instructors and to learn for students than other topics in operations management. One of these challenges is the need to apply trial-and-error approaches to test various Aggregate Plans, which involves performing repetitive calculations that tend to hinder the possible insights acquired from not just developing, but actually analyzing Aggregate Planning problems.

An additional contribution of this paper is proposing a project that instructors can use as a means to support the processes of learning and teaching Aggregate Production Planning. We recommend that students are required to work on an Aggregate Planning team project, which includes a part where the student works individually. The project involves the use of a spreadsheet, such as Microsoft Excel, to solve Aggregate Planning problems with various input datasets, taking into consideration factors such as demand pattern and various cost coefficients. The project also requires each team to write a report discussing how the team derives its final plan and the insights the students acquire from the assignment.

Some informal (not statistically rigorous) feedback received from our students is positive. Most students said that the Aggregate Planning project allows them to learn the topic more effectively than if they just did some of the end-of-chapter problems in the textbook. Among the reasons given are: (1) the project is motivational; (2) it helps understand the details of aggregate planning; (3) it allows to focus on analysis of different problem scenarios rather than the repetitive computations; and (4) the Excel spreadsheet and project report are good for the student's college portfolio. Additionally, the project is useful because students start by learning how to develop a given Aggregate Plan in a spreadsheet (and thus by hand) individually. Then, they work as a team with benefits such as interacting, collaborating, brainstorming, and thinking critically so as to derive rationales that justify each of their proposed plans in their reports.

Since we have not collected data in a rigorous manner, one opportunity for future research is to conduct formal statistical analysis to compare scientifically the "traditional" way of teaching Aggregate Planning to the method proposed in this paper. It is also possible that obtaining other type of information from students helps improving the approach presented in this paper. For example, a study can be conducted on students that are exposed only to the "traditional" way of teaching/learning AP with the objective of identifying the issues that students find the most difficult to understand or learn. Incorporating the "voice of the student" into our method may result in a better approach to teaching Aggregate Planning.

Appendix A

| Period | Number of Workers | Number Hired | Number Fired | Number of Units / Worker | # of Units Produced | # Overtime Units | Cumulative Production | Cumulative Demand | Ending Inventory | Surplus Inventory | Deficit Inventory |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 200 | | | | | | 0 | 0 | | | |
| 1 | 240 | 40 | 0 | 8.757 | 2,101.6 | 0 | 2,101.6 | 2,200 | -98.4 | 0 | 98 |
| 2 | 240 | 0 | 0 | 9.217 | 2,212.2 | 400 | 4,713.7 | 4,800 | -86.3 | 0 | 86 |
| 3 | 240 | 0 | 0 | 8.757 | 2,101.6 | 400 | 7,215.3 | 7,600 | -384.7 | 0 | 385 |
| 4 | 240 | 0 | 0 | 11.522 | 2,765.2 | 300 | 10,280.5 | 10,300 | -19.5 | 0 | 19 |
| 5 | 200 | 0 | 40 | 10.139 | 2,027.8 | 0 | 12,308.3 | 12,300 | 8.3 | 8 | 0 |
| 6 | 200 | 0 | 0 | 9.217 | 1,843.5 | 148 | 14,299.8 | 14,300 | -0.2 | 0 | 0 |
| 7 | 200 | 0 | 0 | 8.296 | 1,659.1 | 0 | 15,959.0 | 16,200 | -241.0 | 0 | 241 |
| 8 | 180 | 0 | 20 | 11.522 | 2,073.9 | 0 | 18,032.9 | 17,900 | 132.9 | 133 | 0 |
| 9 | 180 | 0 | 0 | 10.600 | 1,908.0 | 0 | 19,940.9 | 19,900 | 40.9 | 41 | 0 |
| 10 | 180 | 0 | 0 | 11.061 | 1,991.0 | 0 | 21,931.8 | 21,900 | 31.8 | 32 | 0 |
| 11 | 215 | 35 | 0 | 10.600 | 2,279.0 | 0 | 24,210.8 | 24,200 | 10.8 | 11 | 0 |
| 12 | 240 | 25 | 0 | 8.757 | 2,101.6 | 200 | 26,512.4 | 26,700 | -187.6 | 0 | 188 |
| 13 | 240 | 0 | 0 | 9.217 | 2,212.2 | 200 | 28,924.6 | 29,000 | -75.4 | 0 | 75 |
| 14 | 240 | 0 | 0 | 10.139 | 2,433.4 | 0 | 31,358.0 | 31,300 | 58.0 | 58 | 0 |
| 15 | 240 | 0 | 0 | 9.217 | 2,212.2 | 0 | 33,570.1 | 33,800 | -229.9 | 0 | 230 |
| 16 | 240 | 0 | 0 | 9.678 | 2,322.8 | 0 | 35,892.9 | 36,200 | -307.1 | 0 | 307 |
| 17 | 240 | 0 | 0 | 10.139 | 2,433.4 | 0 | 38,326.3 | 38,300 | 26.3 | 26 | 0 |
| 18 | 240 | 0 | 0 | 9.217 | 2,212.2 | 62 | 40,600.5 | 40,600 | 0.5 | 0 | 0 |
| Total | | 100 | 60 | | | 1,710 | | | | 309.5 | 1,630.1 |

| | |
|---|---|
| Hiring | $200,000 |
| Firing | $180,000 |
| Overtime | $222,300 |
| Holding | $40,758 |
| Backorder | $195,610 |
| Total Cost | $838,669 |

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## ABOUT THE AUTHORS

**Johnny C. Ho** is a Professor of Operations Management at Columbus State University. He received an M.B.A. in management science from State University of New York at Buffalo and a Ph.D. in operations management from the Georgia Institute of Technology. Recipient of the Columbus State University Faculty Research and Scholarship Award in 1997, 2004 and 2008, Dr. Ho has published four dozen articles in journals such as *Naval Research Logistics*, *Annals of Operations Research*, *Journal of the Operational Research Society*, *European Journal of Operational Research*, *International Journal of Production Research*, *Mathematical and Computer Modelling*, *Omega: The International Journal of Management Science*, *Computers & Operations Research*, *Production Planning & Control*, *Computers & Industrial*

*Engineering*, *Journal of Intelligent Manufacturing* and *International Journal of Production Economics*, and has made 75 presentations in various conferences. In 2008, he received the Best Paper in Conference Award from the 44th Annual SE INFORMS Conference. He is a *Certified Quality Auditor* and *Certified Quality Engineer* through the American Society for Quality for 18 years.

**Francisco J. López** is a Professor of Management at Middle Georgia State College. He received a college degree in Actuarial Sciences from Universidad Anahuac in Mexico City in 1984 and a Ph.D. in Business from the University of Mississippi in 1999. Awards received include Outstanding Scholarly Activity in 2010 from Macon State College (currently Middle Georgia State College); Professor of the year, College of Business Administration, from University of Texas at El Paso in 2005; outstanding Doctoral Student in Production Operations Management from the University of Mississippi in 1999; and a couple of Best Paper Awards at conferences. Some of the journals where he has published include *Computational Geometry: Theory and Applications*; *INFORMS Journal on Computing*; *European Journal of Operational Research*; *the Journal of the Operational Research Society*; *Omega: the International Journal of Management Science*; *Computers and Operation Research*; *Computers and Industrial Engineering*; etc.

**David S. Ang** is a Professor at Auburn University at Montgomery. His teaching and research interests span the substantive areas of manufacturing and quality management. He actively consults with local manufacturing company, small business, and non-profit sector. He has published more than 35 articles in a variety of academic journals and academic society proceedings. His current research focuses on applying lean and quality management in local educational systems and manufacturing industries.