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Holt, Modigliani, Muth, and Simon's work and its role in the renaissance and evolution of operations management

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Abstract

Early work in aggregate production planning has evolved into a major business process known as sales and operations planning. In the 1950s, a team led by Holt, Modigliani, Muth, and Simon, which also included Bonini and Winters, worked on aggregate production planning and forecasting and published a series of papers and a book. The literature contains reports of at least 73 applications of their work in four companies and three application studies. Holt et al.'s work and its visibility led to a renaissance of the field of operations and supply chain management as we know it today and brought two paradigm changes in the domain and the role of operations and supply chain management. First, seemingly unrelated and non-managerial individual functions started to emerge as parts of an integrated system of managing production. Second, aggregate production planning brought to forefront the central role of operations management by linking it with supply chains and other functions in the organization.

Keywords: Aggregate planning; Capacity management; Evolution of operations management; Interdisciplinary; Manufacturing planning and control; Sales and operations planning

1. Introduction: the genesis of Holt, Modigliani, Muth, and Simon's work

In the early 1950s, Charles C. Holt, Franco Modigliani, John F. Muth, and Herbert A. Simon (HMMS) began work on a project, ''Planning and Control of Industrial Operations'', at the Graduate School of Industrial Administration (GSIA) at the Carnegie Institute of Technology. William W. Cooper, who was also at GSIA, initiated the project, and the Office of Naval Research supported it. Our goal in this paper is to document the early work of HMMS in aggregate production planning and to describe how this work has evolved into a major business process known as sales and operations planning.

Holt had four degrees in electrical engineering and economics from MIT and the University of Chicago, and he wanted to study how instability in the economy was related to firms' management of their inventories. Modigliani (awarded the Nobel Prize in 1985) received a J.D. in 1939 from the University of Rome and a D.S.S. in 1944 from the New School of Social Research. He had worked on production smoothing. Simon (awarded the Nobel Prize in 1978) received his Ph.D. from the University of Chicago in 1943. A cognitive scientist, economist, organizational theorist, and political scientist, he had worked on the dynamics of inventory feedback on production rates. He was interested in understanding how managers made their decisions, and he wanted to model their behavior. Muth had an undergraduate degree in industrial engineering and was a graduate student at the GSIA where he earned a Ph.D. in 1962. He published a paper on rational expectations in 1961, derived from

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the work on the project, "Planning and Control of Industrial Operations". Robert Lucas built on Muth's work and won a Nobel Prize in 1995.

According to Simon (1978a), the goal of the GSIA, which was newly established in 1949, was "to place business education on a foundation of fundamental studies in economics and behavioral science". Simon noted that the work on the HMMS project was a part of this effort, and that fortunately the computer and the new management science techniques had just started appearing.

1.1. Production management just before the HMMS work

Commenting on the state of operations and supply chain management in the early 1950s, Muth (2004a) noted, "Textbooks at the time focused on the EOQ formula, Gantt chart displays, punched card systems for dispatching, moving average forecasts, and that's about it". In the textbook, *Analysis of Production Management*, Bowman and Fetter (1957) (then assistant professors at MIT) essentially covered hypothesis testing, various charts (Gantt charts, activity charts, and so forth), mathematical programming, statistical control, sampling inspection, industrial experimentation, total value analysis, Monte Carlo analysis, and equipment investment analysis. Holt (2002) said that a few years before they started work on the project, a consulting firm had sold "A simple lot size formula to Westinghouse Electrical Corporation for something like $100,000". It presumably included the consultants' time. The HMMS work was a turning point in the direction of operations management.

2. The HMMS model and its solution

The HMMS team started the project by interviewing managers at about 15 companies. According to Holt (2002), the managers initially denied that they had any problems, but after persistent questioning, the team found that the managers were simply going from one crisis to another: inadequate forecasts of "wildly fluctuating demand for thousands of products", huge fluctuations between overtime and idle time, and gross incompatibilities between aggregate production plans and plans for individual products.

The team finally focused on an "application oriented" context (Cooper, 2004) for scheduling paint production at the Springdale plant of the Pittsburgh Glass Corporation (now PPG Industries) because it "had the generic system problem in a fairly simple form". Augier and March (2004) observed that the project was essentially a study of decision making under uncertainty.

2.1. The HMMS model

The core of HMMS' work was a linear-quadratic model of aggregate production planning. HMMS submitted an article based on their findings to *Operations Research*, which rejected it on the basis that the work was "not operations research" (Cooper, 2004). HMMS then published their findings in two papers in the second volume of *Management Science* (Holt et al., 1955, 1956). Several other papers concerning the "Planning and Control of Industrial Operations" project accompanied these two, for example, Simon (1955, 1956), Bonini (1958), Muth (1960), and Winters (1960). Holt et al. (1960) then published a book that covered these papers and the two in *Management Science*. Bonini and Winters, Ph.D. students at GSIA at the time, also contributed to the book. Several other papers on parts of the project and some derived from it followed (Muth, 1961; Holt and Modigliani, 1961; Holt, 1962; Winters, 1962).

The Holt et al. model (1960) consists of selecting production and workforce levels in each of T periods so as to satisfy ordered shipments while minimizing the sum of the costs over the T periods. Let P_t, W_t, I_t, and S_t represent production volume, workforce level, end-of-period inventory, and ordered shipment for period t, and let I_0 and W_0 represent the specified values of the initial inventory and the initial workforce. The cost in period t consists of the following components:

$$\text{Regular payroll costs}: \quad C_1 W_t + C_{13}$$

$$\text{Hiring and layoff costs}: \quad C_2(W_t - W_{t-1} - C_{11})^2$$

Overtime costs:

$$C_3(P_t - C_4 W_t)^2 + C_5 P_t - C_6 W_t + C_{12} P_t W_t$$

$$\text{Inventory-related costs}: \quad C_7(I_t - C_8 - C_9 S_t)^2$$

The model was thus formulated as

$$\begin{aligned} Z = \sum_{t=1}^{T} [&(C_{13} + C_1 - C_6) W_t \\ &+ C_2(W_t - W_{t-1} - C_{11})^2 + C_3(P_t - C_4 W_t)^2 \\ &+ C_5 P_t + C_{12} P_t W_t + C_7(I_t - C_8 - C_9 S_t)^2] \end{aligned} \tag{1}$$