FORD WHITMAN HARRIS'S ECONOMICAL LOT SIZE MODEL

by

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This year we celebrate the centennial of Ford Whitman Harris's model for determining economical lot sizes, which was published in the A. W. Shaw Company's magazine *Factory, The Magazine of Management* in February 1913. The square-root formula derived by Harris has become one of the most cited and applied results in production and operations management. Here we examine the circumstances under which this result was derived, and explore the probable causes for the later obscurity of Harris's paper, which was forgotten for many years.

In 1913 Ford W. Harris published a paper with the title "How Many Parts to Make at Once" (Harris, 1913). This paper addresses the problem of finding the most economical quantity to be made of each lot of a product so as to meet a demand that continues over time at a constant rate. His derivation of the square-root formula for this quantity is a foundation result in operations research and the theory of inventory management, which is commonly known as the "economic order quantity" (EOQ) formula. It has appeared in countless articles and texts over the past 100 years. A reprint of Harris's original 1913 paper accompanies this article.

The fundamental issue in Harris's model is the balancing of two cost components: the cost of carrying inventory, which increases with the lot size; and the average set-up cost per unit, which declines with larger lots. This tradeoff is depicted in the "Manufacturing Quantities Curves" of Figure I in Harris's paper. These curves also have appeared countless times in other publications during the past 100 years.

Harris's foundation paper was lost from sight for many years and was finally rediscovered 75 years later (Erlenkotter, 1989 & 1990a). After an additional 25 years, there are still questions about the circumstances underlying the origin of the EOQ model and the reasons behind its disconnection from its origin. Although there seems to be no way to settle all these questions definitively, there is enough evidence available for some intelligent discussion here.

Harris and the Origination of the EOQ Model

Certainly there is nothing in Harris's early life that would lead one to expect that he might produce such an original and fundamental result. He was born in 1877 and grew up in the Portland, Maine area, where he received a high school education. After high school he worked for four years as an engineering apprentice and draftsman for two Portland employers, the Belknap Motor Company and the Maine Electric Company. In 1900 he moved to Pittsburgh, Pennsylvania where he became a draftsman and engineer for Heyl and Patterson. During the period from 1904 to 1912 Harris was employed as an engineer for the Westinghouse Electric and Manufacturing Company in East Pittsburgh (Erlenkotter, 1990a).

In 1912 Harris left Westinghouse and moved to Los Angeles, California (Leonard, 1922). Family sources suggest several reasons for this move. One of his wife's sisters was ill with consumption (tuberculosis), and the Mellon family had decided that the Southern California environment would be more favorable to her health. After his years in Maine and Pittsburgh, Harris had grown tired of cold weather and snow and looked forward to a warmer climate (Smith, 1988). He also may have wanted to expand his horizons beyond the confines of Westinghouse. Tutoring and self-study had educated him in electrical engineering, and he had patented a number of inventions in the electrical field. However, these patents had all been assigned to Westinghouse as his employer. Patents continued to be granted in his name and assigned to Westinghouse as late as 1916 (Erlenkotter, 1990a).

So, at the age of 35 Harris was faced with the need to retool his career. His daughter believed that he had an agreement with Westinghouse that barred competitive employment, and this blocked him from further inventions of an electrical nature (Smith, 1988). He had little in the way of formal educational credentials. But he did have an engineering background and experience in a major industrial corporation. It appears, then, that he began writing and publishing work on industrial management topics in 1913 to help establish his credentials in this broader field.

The first such paper was the one on the EOQ formula (Harris, 1913), which appeared in *Factory, The Magazine of Management* in its February 1913 issue. *Factory*, which was published by the A. W. Shaw Company of Chicago, had an intended audience of "the manager in manufacturing," with 10,000 readers in 1913. What better media outlet could there have been for Harris's writings in this area? A dozen more of his articles were published in *Factory* over the next five years.

The A. W. Shaw Company's flagship publication was *System, The Magazine of Business*, which was renamed *Business Week* after it was acquired by McGraw-Hill in 1928. Harris contributed an article on the "make or buy" problem to *System* in 1914. In 1915 Shaw published *The Library of Factory Management* in six volumes, which presented a remarkable view of the field of factory management at the time of the First

World War (Erlenkotter, 1990b). It was oriented towards an audience of practitioners, and its initial notice promised the "hard-fisted ideas that pay." The *Library* was drawn mainly from the two Shaw periodicals *Factory* and *System*, and three chapters were based on articles by Harris. One of these covered his EOQ model (Harris, 1915).

Harris's EOQ Contribution Obscured

How, then, did Harris's EOQ contribution end up lost from view and unrecognized for so many years? Initially it would have appeared that its publication in the popular magazine *Factory*, followed by republication in the widely distributed and practitioner-oriented *Library of Factory Management*, would have ensured its continued visibility. As mentioned, *Factory* had a target audience of 10,000 manufacturing managers. The *Library* was in its third printing by August 1916, and the volumes were issued again separately in 1921 in the *Shaw Factory Management Series*.

But, as I have documented elsewhere, his original 1913 paper seems to have been forgotten, and the 1915 *Library of Factory Management* version was misreferenced for decades in such a way that it was almost impossible to locate (Erlenkotter, 1989 & 1990a). Once the erroneous citation was embedded in the literature, those who did reference his chapter merely repeated it and didn't make the effort to seek out and access the original.

There were several causes contributing to this obscurity. First, the publishers of *Factory* actively encouraged destruction of the magazine! Readers were advised to tear out articles and file them by topic for future use. Perhaps this was useful in the short run, but it was fatal to long-term preservation. Second, the practitioner audience was mainly interested in immediate results, and had little or no interest in the origin or history of ideas. The field of management, which was just beginning to develop, lacked academic and intellectual roots.

Moreover, as management did develop as a discipline, various groups drew boundaries and tended to exclude contributions made by outsiders. Taylor's "Scientific Management" movement had its own agenda, and disciples within this cult could be savage towards outsiders. The roots of the eventual field of industrial engineering were in the Management Division of the American Society of Mechanical Engineers (ASME), for which L. P. Alford was the long-time gate-keeper. Elsewhere I have documented how Alford ignored early work on EOQ models that didn't originate within his own circle, and how others appropriated this model for themselves without recognition of prior contributions (Erlenkotter, 1990a).

A. W. Shaw, who published Harris's EOQ work, was closely affiliated with the Harvard Business School during its early years and was the first there to use actual business cases in teaching. He financed the establishment of the School's Bureau of Business Research in 1911, and the A. W. Shaw Company was the first publisher of the

Harvard Business Review. However, establishment of the case method at the school took it on a path away from formally codified knowledge such as the EOQ formula.

A final consideration here is Harris's diversion of his efforts to other directions. He had no academic credentials or connections that would have supported promotion of his ideas beyond his published writings. Los Angeles in 1913 was not a very fertile environment for managerial or engineering pursuits since the city had yet to develop a manufacturing base. Also, a two-year economic recession began in this year. In September 1914 Harris wrote of making patent office drawings for a local attorney "during a stringency in [his] personal finances" (Harris, 1914). He also commented that

> A patent lawyer should be about eight-tenths engineer or inventor and two-tenths lawyer. If he has the mechanical gifts he can pick up the law, but unless he has a constructive imagination and the mechanical sense he will never get it by studying law books.

So, even though he had never attended college, Harris decided to become a patent lawyer. He sought employment in a law firm and began reading the law in addition to his regular work. The evolution of his career is clearly documented in Los Angeles city directories. In 1913 he is listed as an electrical engineer; in 1914 as a consulting engineer with the law firm of Townsend and Graham; in 1915 as a member of the law firm of Townsend, Graham & Harris; and from 1916 through the end of the decade as a member of the law firm of Graham & Harris. He was admitted to practice before the U.S. Patent Office in 1914 and became a member of the California Bar in 1916. About this time his published writings shifted from managerial to legal topics. Harris was admitted to practice before the U.S. Supreme Court in 1922, and opened his own patent law office in Los Angeles in 1923. He was founding president of the Los Angeles Patent Law Association in 1934.

In April 1943 Harris commented that

> . . . I made a precarious living as an engineer for a considerable period before I broke down the fence into what I thought was a greener pasture (Harris, 1943).

The "greener pasture," however, was far removed from his EOQ model!

In this connection, I would note that Harris's family had no knowledge that he had any involvement with the EOQ formula. In 1989 his grandson Laird W. Smith wrote me and said that

> I spent several years in the Air Force as a supply officer . . . their whole supply system instituted in the 1960s was an early use of the EOQ formula for inventory control. I stayed in the California National Guard through 1985 and we were still using the same basic system then. I vaguely recall working through the calculus of the differentials used to derive the actual EOQ formula and am really impressed by my grandfather's analysis as you have so ably described. A further

irony is that I've spent some time teaching part-time and highlighted EOQ analysis as a valued concept because of my Air Force experience (Smith, 1989).

Harris's Life in Los Angeles

Ford Whitman Harris (FWH) thoroughly enjoyed life in Los Angeles and the American West. He was an enthusiastic and lifelong golfer, although only an average player. He also loved trout fishing and took many pack trips into what was then a very inaccessible British Columbia. FWH was a photography nut who developed his pictures in his own darkroom. Purely social activities bored him, so Eugenia, his gregarious wife, went out and about in the daytime and they stayed home nights (Smith, 1988).

As the family pictures show, the Harrises dressed in what today would be considered a rather formal style even on their outdoor excursions. The first picture shows them on one of these outings, enjoying sitting by a stream near a large grove of trees. In the second picture, they are about to leave on an excursion, with their son, FWH, Jr., in the car. This picture was taken in about 1915, around the time the EOQ model appeared. Their daughter Jean was born in 1916 and is shown in the third picture. Both children graduated from Stanford University, and after graduating from law school FWH, Jr., joined his father's law firm. Ford Whitman Harris died in Los Angeles on October 27, 1962 at the age of 85; his widow Eugenia died there on April 30, 1979 at the age of 97.

FWH and his wife Eugenia, enjoying the California outdoors

FWH and his wife Eugenia, with son FWH, Jr., in car (ca. 1915)

FWH with daughter Jean, standing on case (ca. 1926)

Closing Reflections on Harris's EOQ Model

A mystery about Harris's EOQ model is what led him to come up with this model with its simple square-root solution formula. The one explanation I have seen is that it may have been inspired by Lord Kelvin's so-called law for determining the economical size of an electrical conductor. This law, which dates back to 1881, involves balancing the costs of the conductor, which increase proportionally with the cable's cross-sectional area, against those for energy losses, which drop in relation to the inverse of the area. From this relationship, Lord Kelvin derived a square-root formula to calculate the economical conductor size. Most likely Harris learned about this model in his electrical engineering studies. Although the context of the lot size problem is very different from that of electrical conductors, the key idea of trading off two cost components does carry over to the determination of order quantities.

The nature of the paper's abstract suggests that it most likely was written by an editor who didn't understand the problem. The statements that inventory carrying costs set a maximum limit on the quantity, while the set-up costs fix a minimum level, deny the fundamental tradeoff relationship between these two cost components, which is the key concept in the paper. The abstract's closing sentence assigns all the credit to one manager's "experience," thereby ignoring the analysis in the paper that actually determines the economical size for lots.

There has been confusion over just how Harris derived his square-root EOQ formula. First he constructed the cost expression for the total unit cost. Notably, this is on a per item basis, rather than the average cost per unit of time that is used in most textbooks. Although these are equivalent and give the same solution, the cost per item amount is

much easier to interpret than the cost per unit of time. Harris then noted that the problem here is the old one of finding the minimum of the cost expression and stated that ". . . the solution of this problem involves higher mathematics . . ." Obviously he was referring to the use of calculus to find the derivative of the cost expression, which was then set equal to zero. One would expect that he had learned at least the rudiments of calculus from his engineering tutors. But several authors have stated that he *assumed* the solution was where the two cost components were equal and then used this relationship to derive the formula (Erlenkotter, 1989). Actually, the equality of the cost components is noted only on the figures in his paper and in the caption for Figures II and III, where he states "The sum of the two elements gives total costs the curve of which is the upper one and shows a minimum opposite where the two lower curves cross."

As is common in many situations, Harris's classical EOQ model was followed by a number of related papers by others, some of which added their own embellishments. During the 1920s there was a proliferation of such papers, which appeared mainly in magazines addressed to practitioners and paid little attention to previous work (Erlenkotter, 1990a). The situation became so confusing that the ASME requested Fairfield E. Raymond of MIT to survey the literature with the goal of comparing and combining the previous studies. Raymond catalogued some 38 derivations of various formulas up through 1929. When he presented his *simplified* EOQ formula, one discussant commented about "Professor Raymond's radical embracing most of the letters of two alphabets" (Raymond, 1930). The simpler formula suggested by several other discussants was the same as the one originally given by Harris (1913). In his final study, Raymond missed Harris's 1913 paper and gave an erroneous citation for Harris's 1915 *Library of Factory Management* chapter (Raymond, 1931). This error misdirected researchers up through the 1980s (Erlenkotter, 1989).

Following the appearance of Raymond's book in 1931, there seems to have been little progress in the EOQ area during the next twenty years. The country had to cope first with the Great Depression and then with the Second World War. The next major wave of progress in the production and inventory field began in the 1950s with the blossoming of stochastic inventory models and the application of mathematical programming to production and inventory problems. But Harris's classical EOQ model continues to survive after 100 years, and has accommodated innovations such as methods for reducing setup and ordering costs, which in turn lead to reductions in economic lot sizes and average inventories.

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I would like to thank Sheryl (Smith) King and her husband Ken King for providing the Ford Whitman Harris pictures that appear here as well as other family information. Sheryl, Harris's granddaughter, says that he was known by his initials FWH and that was the way he signed family communications. When I was working on this project 25 years ago, I was surprised to discover that Ken had been a classmate of mine in the Stanford University MBA class of 1963. Sheryl was a Stanford undergraduate student at the time.

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