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Of battleships and horseshoes: seriation, multivariate statistics and the interpretation of coin hoards

Kris Lockyear

Abstract

This article considers the fundamental distinction between battleship and horseshoe curves and their relationship to seriation studies, particularly in the context of the study of coinage production and circulation.

Keywords: numismatics; data analysis; seriation

Introduction

The initial impetus for this article is an analysis of the coinage of the seventh-century AD Umayyad caliph Muʿāwiya published by Mehdy Shaddel (2021). Although I am not competent to comment on the majority of the details of this generally convincing paper, the section on page 291 therein confuses battleship and horseshoe curves, a fundamental distinction with important ramifications. In addition, the quote from my own previous work in footnote 118 is partial and misleading. This short note is intended to clarify these issues.[1]

In archaeology, the development of seriation techniques for determining a relative date sequence for artefacts and assemblages is generally attributed to Petrie (1899). Numismatists had, however, been using the same principles for dating coins for some time previously (Crawford 1990). Seriation techniques can be divided into incidence, frequency and phyletic (O'Brien and Lyman 1999), of which the first two are of relevance here. In essence, either the presence/absence, or the frequency, of object types in assemblages is used to rearrange the order of rows and columns of a table to concentrate the first occurrence of those types along a diagonal. Table 1 illustrates the idea.

Mathematical approaches to seriation started to be developed in the 1950s (for example, Brainerd 1951; Robinson 1951) and some of the earliest applications of computing to archaeology also address this problem (for example, Ascher and Ascher 1963; Hole and Shaw 1967; Kuzara et al. 1966). Underlying this work is the concept of the *battleship curve*. Battleship curves describe the frequency of an artefact over time (Lockyear 2007, 229; see

Table 1. Idealised frequency seriation.

	Time	Time+1	Time+2	Time+3	Time+4	Timee+5	Time+6	Time+7
Object A	1	10	8	5	3	–	–	–
Object B	–	1	12	8	7	4	1	–
Object C	–	–	1	9	5	3	2	1
Object D	–	–	–	1	10	7	5	3
Object E	–	–	–	–	1	11	8	6

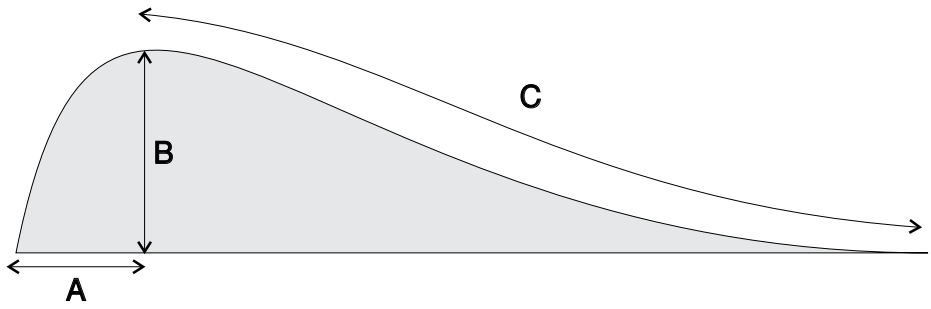

Figure 1 A battleship curve – see text for details (Source: Lockyear 2007, fig. 8.1)

Figure 1). An artefact is manufactured over a certain period (Figure 1, A). The numbers of that artefact in circulation rise as they are manufactured. Over that period, some of the artefacts are lost, broken or recycled into something else (Figure 1, C). The proportion lost has been, in numismatic contexts, called the loss, wastage or decay rate. It is, however, simply a compound depreciation that can be described by the formula: $x = y \times (1 - d)^i$, where y is the number of objects originally created, d is the loss rate expressed as a proportion and i is the number of years since the objects were made. When the period of manufacturing ceases, the maximum abundance is reached (Figure 1, B). From then on, the total number in circulation slowly declines. The curve can be used to describe the pattern for any artefact, from coins to smartphones. For coinage, the curve can have a number of interesting aspects. First, the period of manufacture of an individual type can be very short, perhaps a matter of months. Second, the length of time that coins stay in circulation can be very long. Certain Roman Republican coins, for example, remained in circulation for more than 200 years. In most numismatic situations the values of the parameters must be estimated, although an exception is the so-called Lohe hoard due to the survival of the Swedish mint figures for the seventeenth–eighteenth centuries (Lockyear et al. 2022; Thordeman 1948). By calculating the curves for a variety of artefacts, they can be combined to give an estimate of the population composition at a variety of dates (Lockyear 1999; 2007, chapter 8; Lockyear et al. 2022). Unfortunately, Shaddel confuses battleship curves with *horseshoe curves*, to which I now turn.

Reorganising a table to create a seriated sequence is potentially an enormous task. One solution is to use multivariate statistics, especially ordination methods. Early studies included the use of non-metric multidimensional scaling (NMDS) (Kendall 1971), although in recent years correspondence analysis (CA) has been the preferred method. If there is an underlying *gradient* or sequence in the data, it will show in the results of a multivariate

analysis as a 'horseshoe curve' such as that in Figure 2. In that figure, the early periods (I, II, III and so on) are at one end of the curve and the late periods (XX, XXI) are at the other. The underlying gradient, however, does not have to be due to time. In ecology it is often due to the transition from one environment to another; for example, the changes in plant populations as one moves from riverbank to hilltop. The horseshoe curve is, therefore, the result of the analysis of a dataset where each artefact category forms a battleship curve. For coinage, a simulation study showed that CA was the most effective method for seriating coinage issues and hoards (Lockyear 2022), although one of the best examples from my work derives from a Principal Coordinates Analysis of 294 Roman Republican coin hoards (Lockyear 2007, Fig. 6.7, reproduced here as Figure 3).

A final point, however, brings us to Shaddel's misleading footnote 118. Although it is possible to calculate the curves for the *global coinage pool*, either from estimated coinage production figures (Lockyear 1999) or actual published records (Lockyear et al. 2022), we need to remember that the global coinage pool is made up of a large number of *local* coinage pools. The representation of coins in the local coinage pools will depend on the pattern of production and supply. I showed some time ago (Lockyear 1993) that periods where there is a large difference in the composition of coin hoards are a result of recent issues of coinage forming a large proportion of the global coinage pool, and thus, potentially, a very large proportion of local coinage pools (see Lockyear et al. 2022, 287–91 for a longer discussion). By contrast, periods where there is little difference in the composition of coin hoards are a result of recent issues forming a small part of the coinage pool. The Lohe hoard

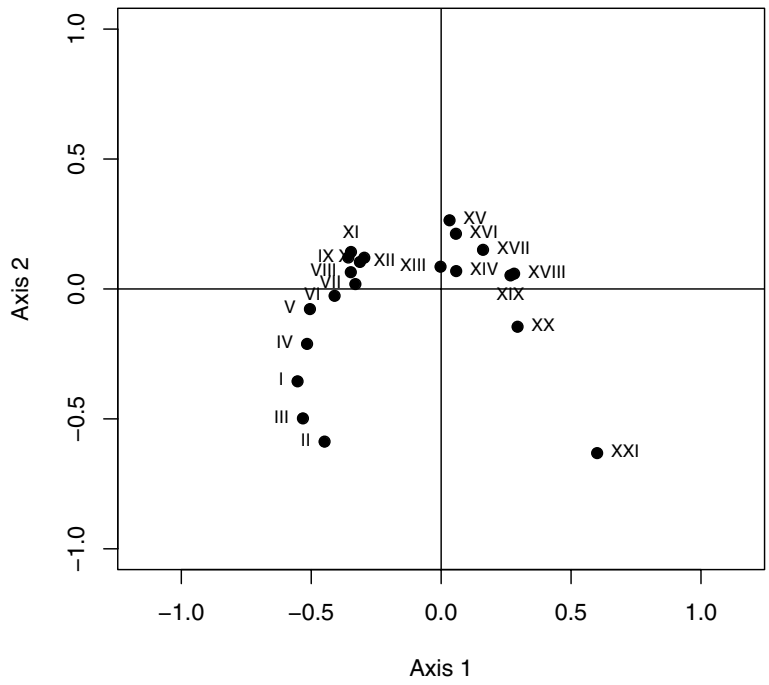

Figure 2 A horseshoe curve deriving from the CA of coin finds from excavated sites published by Reece (1991). The data points are Reece's 21 periods ranging from early first century (period I: before AD 41) to the late third century (period XXI, AD 388 to 402) (Source: Lockyear 2000, fig. 8)

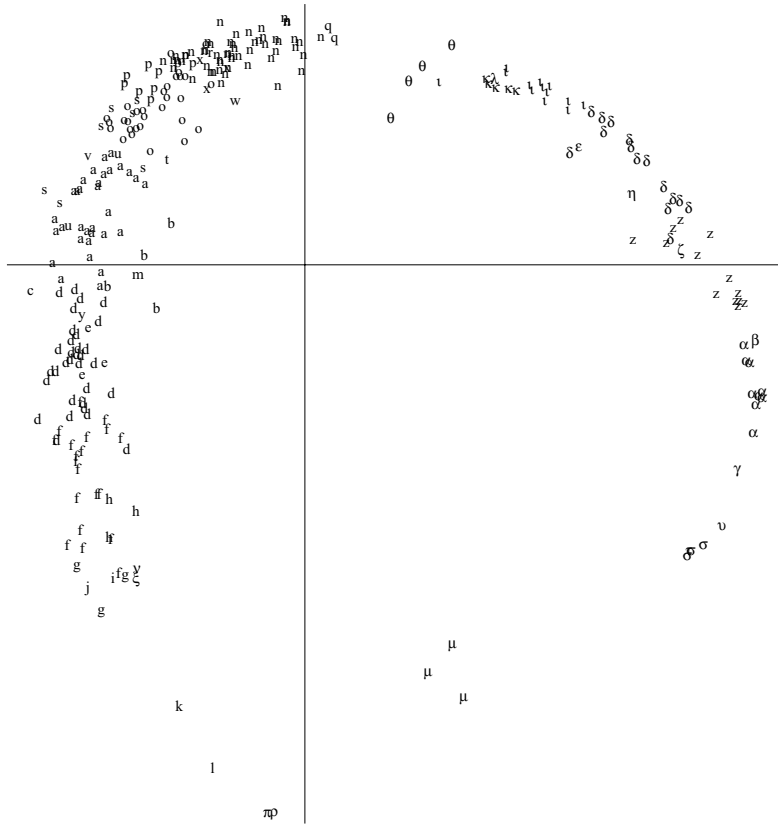

Figure 3 Results from a Principal Coordinates Analysis of 294 Roman Republican coin hoards using the Kolmorgov-Smirnov statistic as a measure of dissimilarity. The symbols represent groups of hoards derived from a cluster analysis (Source: Lockyear 2007, fig. 6.7)

forms an excellent example (Lockyear et al. 2022). The hoard's composition almost exactly matches the global coinage pool as calculated from the mint figures. This is a reflection of the fact that hardly any mark coins were struck in the 20 years or so before the hoard was concealed. The Lohe hoard most probably consists of a combination of multiple hoards with almost identical compositions due to the absence of much new coinage.

We can also see this in the Roman Republican period where the issues of 90 BC formed about 22 per cent of the global coinage pool, but coins struck in that year in hoards closing then or soon after can include anywhere between 0 per cent and 35.3 per cent (Figure 4). By contrast, coins of 74 BC were only 2 per cent of the global coinage pool when they were struck but only formed, at most, 4.3 per cent of coin hoards (Figure 5).

Understanding this aspect of coin hoard formation is essential for the correct interpretation of patterning between hoards, and how representative hoards are of the pattern of production. For example, using inter-hoard variability to demonstrate changes in the speed of coinage circulation can only work if the pattern of coinage production and supply is constant (Lockyear 2007, chapter 7, *contra* Creighton 2014). Although my emphasis has been on coin assemblages, these issues can be generalised to other assemblages of artefacts.

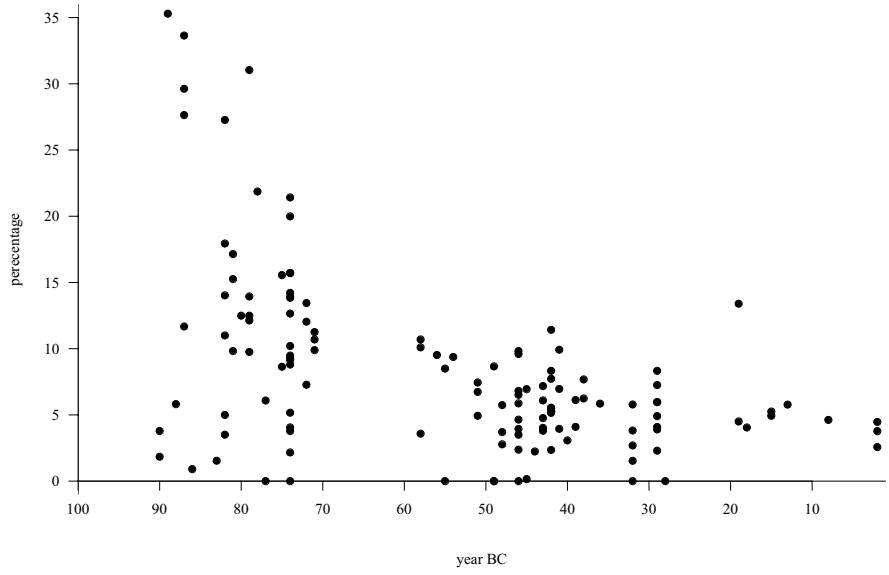

Figure 4 The proportion of coins of 90 BC in coin hoards closing from 90 BC onwards (Source: Lockyear 2007, fig. 7.11a)

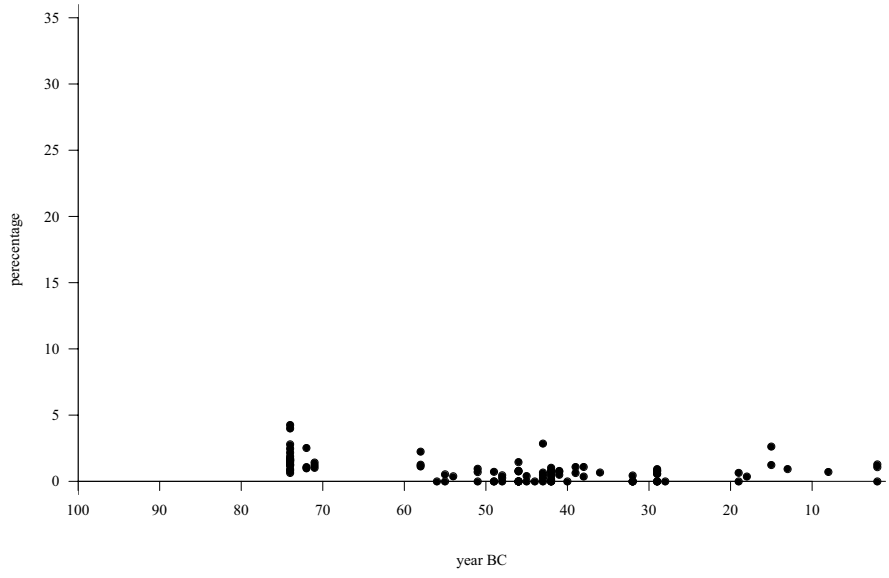

Figure 5 The proportion of coins of 74 BC in coin hoards closing from 74 BC onwards (Source: Lockyear 2007, fig. 7.11b)

Conclusion

Although the points raised above may seem minor issues of detail, they are the fundamental underpinnings of seriation and the interpretation of the variation between artefact assemblages. It is therefore essential to understand the principles involved.

Declarations and conflicts of interest

Research ethics statement

Not applicable to this article.

Consent for publication statement

Not applicable to this article.

Conflicts of interest statement

The author declares no conflicts of interest with this article.

Note

1 A version of this note was submitted to the *Bulletin of SOAS* but the author was informed that the journal did not publish corrections or comments on previous papers published within the journal, hence this slightly expanded version here.

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