

10

Seriation with parallel series—an historical example

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10.1 Introduction

The aim of this paper is to present a case-study of a use of the statistical technique of seriation in an unfamiliar field—the study of medieval church bells. It will show how simple ancillary techniques can considerably improve the usefulness of seriation, and will highlight the pitfalls and limitations of the technique.

10.2 The data and their historical background

The data used in this experiment consist of details of 798 bells which were cast in the City of London or its suburbs in the late medieval period up to 1540. Of these, 604 include details of the foundry marks which appear on the inscription bands. The remainder are either uninscribed, have plain inscriptions consisting only of lettering, or are not adequately recorded. The different sets of lettering used, although they appear specific to certain founders and foundries, were not taken into account in the analyses because their recording is not reliable. Fortunately the records of foundry marks on these bells are much more accurate, since they were early recognised as distinctive of certain founders.

Foundry marks can be divided into three main categories:

1. *stops*, which separate words in inscriptions and tend to be fairly early in date. However, the data are not very accurate since, for example, it tends to be recorded that a stop was a fleur-de-lys, rather than that it was a particular type of fleur-de-lys.
2. *initial crosses*, which are more informative since they tend to be used for a considerable span of time, and to be passed from one founder to another,

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3. *miscellaneous heraldic devices and initials*. Although identification is by no means obvious, these stamps are important because possession of them can be assigned to specific people who appear in the written record. Thus they can be securely dated.

10.2.1 Stamps securely dated by written records

For the purposes of this paper, eight stamps have been selected as particularly reliably dated, so that they may demonstrate the relative accuracy of different seriations.

Stamp 14 bears the words 'William ffondor me fecit' around two birds perched on a bush. This man, whose surname was Dawe, is attested in documents in the City of London between 1385 (Stahlschmidt 1884, p. 45–6) and 1420, when his will was proven (Walters 1912, p. 188). This is the only dated stamp for which there is evidence of re-use at a later period; it was occasionally used by the Wokingham foundry in the Elizabethan period (Cocks 1897, p. 76–7). As this period of re-use is after the period covered by this paper, the re-use does not affect the analyses.

Stamps 40, 41, 42 and IS. A group of stamps which may be attributed to founders because of the lozenge (the heraldic symbol of womanhood) which appears both above the impression of a half-groat with the initials IS and above stamp 41. An indenture from Faversham, Kent, in 1441 mentions a 'Johane Hille of London' (Stahlschmidt 1884, p. 52–3) who later in the same document appears as Johanna Sturdy. The will of Richard Hille left the residue of his estate to his widow Johanna in 1440 (Elphick 1970, p. 43). Thus stamp 41 (a shield without a lozenge) may be attributed to Richard Hille who is attested from c. 1420–1440; stamp 42 (the shield with the lozenge) to his wife, most probably during her widowhood, who is attested in 1441; stamp 40 with lozenge and initials IS may be attributed to Johanna after she acquired the name Sturdy; by extension the initials IS with the impression of the half-groat, but without the lozenge, may be attributed to John Sturdy who is attested in the Hustings rolls of 1449 and was probably dead by c. 1458 (Elphick 1970, p. 45). Johanna was dead by 1465 when she was buried with Richard Hille in St. Botolph's, Aldgate. To summarise, stamps 40, 41, 42 and the initials IS are attested between c. 1420 and 1465, probably in the order 41, 42, IS, 40.

The initials ID are attributed to I. Danyell who is attested in 1460. In that year King's College, Cambridge paid £3.13s.4d for transporting a bell of Danyell fondor's from London to Cambridge (Raven 1880a, p. 56). A bell bearing the initials ID and the quartered royal arms was recorded at King's College before being sold for scrap to the Whitechapel bell-foundry in 1754 (Raven 1880a, pl. VII).

Stamp 51 bears the initials TB and, on these grounds, is attributed to T. Bullisdon who is attested between 1508 (Cocks 1897, p. 42–4) and 1511 (Elphick 1970, p. 60).

Stamp 50 is a rebus of the name William Culverden (Raven 1880b, p. 38–9; Owen 1889, p. 15). He is mentioned with T. Bullisdon in 1510. His will was proven on 2.vi.1523 (Raven 1880b, p. 44).

The dating of these stamps is summarised in Table 10.1.

| stamp no. | founder | dates recorded | |
|-----------|-------------------|----------------|--------|
| | | earliest | latest |
| 14 | William Dawe | 1385 | 1420 |
| 41 | Richard Hille | 1420 | 1440 |
| 42 | Johanna Hille | 1441 | 1441 |
| IS | John Sturdy | 1449 | 1458 |
| 40 | Johanna Sturdy | 1458 | 1465 |
| ID | I. Danyell | 1460 | 1460 |
| 51 | T. Bullisdon | 1508 | 1511 |
| 50 | William Culverden | 1510 | 1523 |

Table 10.1: Summary of dating evidence for dated stamps.

10.3 Computer analysis

10.3.1 The bells database

A catalogue of all 798 bells has been created as a database on the Institute's PDP 11/73, using Informix. It is seen as a pilot study for a catalogue of all surviving medieval church bells in England, some 6000 in all. Information is included on the location, dedication, size, founder, inscription and stamps of bells; selected fields can easily be extracted for analysis, as in the work described below. The initial stages of the work have been reported (Bayliss 1987).

10.3.2 Seriation of the complete dataset

10.3.2.1 The program

Seriation was carried out using the program *seriate*, part of the *iagraves* package written at the Institute (Tyers and Hodson, this volume). This program carries out correspondence analysis—using Ihm's (Ihm 1981) algorithm—on an incidence matrix of the occurrence of 'types' in 'contexts' (in our example, stamps on bells). The outcome is tested to see whether it could be improved by moving contexts up or down the order. Improvement is measured by scoring the orderings, using either the Doran or Wilkinson scoring function. Finally, the types are sorted according to the earliest context in which each occurs, and the contexts are sorted according to their latest occurring types.

10.3.2.2 Results

The relative positions of the dated stamps in the overall ordering of the stamps is shown in Table 10.2, where the results of 'forward' and 'backward' seriation, using both the Doran and the Wilkinson criterion, are compared with the 'documentary' order. Because the algorithm sorts the stamps into the order of their first occurrence, the 'backward' order would not be expected to be the same as the 'forward' order, since it is sorting into order of the last occurrence.

There is close agreement between the results using the two criteria, and the 'forward' order correlates well with the known chronological order. The only serious difference is for stamp ID, which is placed at the end of the sequence, although chronologically it is near the middle. However, this conceals a more serious weakness, which is exposed when the overall sequence is compared with the foundries with which stamps are primarily associated (Table 10.3; see also 10.3.2.2 and Table 10.4 below). Stamp ID is thought to belong to Group 3 because of the recorded bells from King's College Cambridge (see section 10.2.1), although it fails to meet the statistical criterion for membership of a group. Clearly, the principal axis of the underlying correspondence analysis has picked up a major source of variation other than time—the differences between the foundries. This may also be a chronological factor, but it cannot be assumed to be so, and there is evidence (Tables 10.1 and 10.4) that the foundries are at least partly contemporaneous. The foundries must be separated before seriation is attempted.

It is interesting to compare the 'forward' and 'backward' orders. Since one measures the first occurrence and the other the last occurrence of a stamp, a comparison should give information on the life-spans of the stamps. If there are n stamps, and the 'forward'

| | W | D |
|------------|---|---|
| Group 1 | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50 | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50 |
| Group 2 | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50 | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50 |
| Group 3 | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50 | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50 |
| Group 4 | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50 | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50 |
| Group 5 | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50 | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50 |
| Unassigned | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50 | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50 |

| stamp no. | forwards | | | backwards | | |
|-----------|----------|---|---|-----------|---|---|
| | doc. | D | W | doc. | D | W |
| 14 | 1 | 2 | 1 | 8 | 5 | 5 |
| 41 | 2 | 1 | 2 | 7 | 8 | 8 |
| 42 | 3 | 3 | 3 | 6 | 6 | 4 |
| IS | 4 | 4 | 4 | 5 | 7 | 6 |
| 40 | 5 | 5 | 5 | 3 | 4 | 7 |
| ID | 6 | 8 | 8 | 4 | 1 | 1 |
| 51 | 7 | 6 | 7 | 2 | 2 | 2 |
| 50 | 8 | 7 | 6 | 1 | 3 | 3 |

Table 10.2: Orders of dated stamps, sorted forwards and backwards by documentary evidence (doc.) and seriation, using the Doran (D) and Wilkinson (W) criteria.

| D | | W | |
|-------|-------|-------|-------|
| stamp | Group | stamp | Group |
| TH | 4 | TH | 4 |
| 55 | 4 | 55 | 4 |
| 54 | 4 | 54 | 4 |
| 10a | 5 (1) | 10a | 5 (1) |
| 10 | 5 | 10 | 5 |
| 26 | 1 | 26 | 1 |
| 13 | 1 | 25 | 1 |
| 25 | 1 | 13 | 1 |
| 22 | 1 | 22 | 1 |
| 12 | 1 | 21 | 1 |
| 45a | 2 | 14* | 1 |
| 41* | 2 | 11 | (1) |
| 16 | 2 | 47 | 2 |
| 14* | 1 | 48 | 2 |
| 20 | ? | 49 | 2 |
| 21 | 1 | 46 | 2 |
| 9a | 2 | 45a | 2 |
| 46 | 2 | 41* | 2 |
| 47 | 2 | 16 | 2 |
| 48 | 2 | 9a | 2 |
| 49 | 2 | 43 | 2 |
| 11 | (1) | 18 | 2 |
| 45 | 2 | 42* | 2 |
| 43 | 2 | 19 | 2 |
| 42* | 2 | 45 | 2 |
| 19 | 2 | 15* | 2 |
| 44 | 2 | 15 | 2 |
| 24 | 1 | 24 | 1 |
| 15 | 2 | 44 | 2 |
| 18 | 2 | 20 | ? |
| 15* | 2 | 21 | 1 |
| 40* | 2 | 40* | 2 |
| 50* | 2 | 50* | 2 |
| 36 | 3 | 11a | 1 |
| 11a | 1 | 51* | (3) |
| 33 | 3 | 36 | 3 |
| 51* | (3) | 52 | 3 |
| 35 | 3 | 27 | 3 |
| 34 | 3 | 35 | 3 |
| 37 | 3 | 34 | 3 |
| 52 | 3 | 37 | 3 |
| 27 | 3 | 28 | 3 |
| 28 | 3 | 17 | 3 |
| 29 | 3 | 32 | 3 |
| 31 | 3 | 31 | 3 |
| 32 | 3 | 29 | 3 |
| 17 | 3 | ID* | (3) |
| ID* | (3) | 30 | 3 |
| 30 | 3 | 33 | 3 |

Table 10.3: Orders of all stamps, seriated using the Doran (D) and Wilkinson (W) criteria. The order corresponding to the chronological order of Table 2a has been chosen in each case. The second and fourth columns show the foundry-groups with which each stamp is associated. A bracket indicates a stamp which was not linked to the group by *jaccard*. Dated stamps are indicated by a *.

| | | |
|------------|---|--------------------|
| Group 1: | stamp nos. 11a, 12, 13, 14*, 21, 22, 24, 25, 26 | Dawe |
| Group 2: | stamp nos. 9a, 15, 16, 18, 19, 40*, 41*, 42*, 43, 44, 45, & 45a, 46, 47, 48, 49, 50*, IS* | Hille/Sturdy |
| Group 3: | stamp nos. 17, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 52 | William Chamberlyn |
| Group 4: | stamp nos. 54, 55, TH | |
| Group 5: | stamp nos. 10, 10a | |
| Ungrouped: | stamp nos. 11, 23, 51*, ID* | |

Note: stamp no. 20 has links with groups 1 and 2.

Table 10.4: Groups of stamps linked at the 10% level (single-link, Jaccard coefficient), with suggested foundries.

| | | |
|-----------|---------------------------|---------------------------|
| Group 1a: | stamp nos. 12, 13, 14, 25 | William Dawe & ?John Bird |
| Group 1b: | stamp nos. 22, 26 | John Bird? |
| Group 2a: | stamp nos. 15, 19 | A. Burford? |
| Group 2b: | stamp nos. 16, 45 | A. Burford? |
| Group 2c: | stamp nos. 41, 45, 45a | Richard Hille |
| Group 2d: | stamp nos. 40, IS | Johanna Sturdy |
| Group 2e: | stamp nos. 43, 44 | John Kebyll |
| Group 2f: | stamp nos. 46, 47, 48, 49 | principally John Kebyll |
| Group 3a: | stamp nos. 27, 28 | R.C. |
| Group 3b: | stamp nos. 29, 36 | I.W. |
| Group 3c: | stamp nos. 30, 31, 32 | I. Danyell |
| Group 3d: | stamp nos. 33, 34, 35 | William Chamberlyn |

Table 10.5: Groups of stamps linked at the 20% level (single-link, Jaccard coefficient), with suggested names of founders.

rank of a stamp is denoted by f and its 'backward' rank by b , its 'score'

$$n + 1 - (f + b)$$

will have zero expectation. Large positive scores suggests stamps with long life-spans (here, nos. 14, 20, 26; possibly 34, 35); large negative scores suggest short lifespans (possibly nos. 9a, 45). Because of the problem noted above, these results should be treated with caution, but will be compared with the detailed results in 3.4.

10.3.3 Similarity analysis of the complete dataset

10.3.3.1 *The program*

The program *jaccard*, also part of the *iagraves* package, was used here. As a prerequisite for carrying out principal coordinates analysis, it calculates a matrix of Jaccard similarity coefficients of the 'types'. This type of similarity coefficient is the most appropriate for incidence data, as it scores only the common presence of two types in a context, and not the common absence. If there is a strong simple structure to the data (for example, the differences between male and female graves) it can be revealed by single-link cluster analysis, or even visual inspection of the similarity matrix, which was all that was needed in our example.

10.3.3.2 *Results*

Visual examination of the matrix of similarity coefficients showed that a single-link cluster analysis with a cut-off level of 10% similarity would create three main groups (Groups 1 to 3), two minor groups (Groups 4 and 5) and leave only 11 of the original 56 stamps ungrouped (see Table 10.4). Groups 1, 2 and 3 represent the William Dawe, Hille/Sturdy and William Chamberlyn foundries respectively. Group 5 consists of stamps used by the predecessors of William Dawe, but as both stamps occur only once with other stamps they fail to achieve 10% similarity with Group 1. The stamps in Group 4 belong to TH, who may not be a London founder at all, but a Salisbury man (Walters 1929, p. 257; Tyssen 1908, p. 351; Bliss & Sharpe 1986, p. 16; Deedes & Walters 1909, p. 41).

Demanding a higher level of similarity (20%) broke down these groups into sub-groups (Table 10.5), which correlated well with individual founders. Even stricter criteria split the stamps of individual founders.

10.3.4 Seriation of the groups separately

Each of the three main groups (Groups 1, 2 and 3) defined in 3.3.2 (Table 10.4) was seriated separately; the results are shown in Tables 10.6, 10.7 and 10.8 respectively. The left-hand part of each table includes other stamps that were also present on the bells defined by the 'diagnostic' stamps of Table 10.4; for the right-hand part only diagnostic stamps were included in the seriation. Once again, both the Doran and the Wilkinson criterion were used, and 'forward' and 'backward' seriations are presented.

The orders produced by seriating each group separately do not in general correspond to those produced by the overall seriation (Table 10.2).

| | stamp no. | forward | | backward | | forward | | backward | |
|------------|-----------|---------|----|----------|----|---------|---|----------|---|
| | | D | W | D | W | D | W | D | W |
| diagnostic | 11a | 15 | 15 | 2 | 4 | omitted | | | |
| | 12 | 9 | 8 | 7 | 7 | 4 | 4 | 5 | 5 |
| | 13 | 2 | 2 | 13 | 14 | 8 | 8 | 1 | 1 |
| | 14* | 4 | 5 | 10 | 11 | 7 | 7 | 2 | 2 |
| | 21 | 14 | 14 | 5 | 5 | 1 | 1 | 7 | 7 |
| | 22 | 12 | 13 | 9 | 9 | 3 | 3 | 8 | 8 |
| | 24 | 13 | 12 | 4 | 2 | 5 | 6 | 6 | 6 |
| | 25 | 8 | 7 | 8 | 8 | 6 | 5 | 3 | 3 |
| | 26 | 7 | 9 | 6 | 6 | 2 | 2 | 4 | 4 |
| others | 10 | 10 | 10 | 12 | 13 | omitted | | | |
| | 10a | 11 | 11 | 11 | 12 | | | | |
| | 11 | 5 | 4 | 15 | 10 | | | | |
| | 20 | 6 | 6 | 14 | 15 | | | | |
| | 34 | 16 | 16 | 3 | 1 | | | | |
| | 35 | 17 | 17 | 1 | 3 | | | | |
| | 43 | 3 | 3 | 16 | 16 | | | | |
| | 47 | 1 | 1 | 17 | 17 | | | | |

Table 10.6: Orders of stamps in Group 1 (diagnostic) and occurring on bells with Group 1 stamps (others). Stamps with less than two occurrences on bells with two or more diagnostic stamps have been omitted.

rank of a stamp is defined by F and the 'backward' rank by B (28 items).

$$W = 1 - (F + B)$$

will have been reported. Large positive scores suggest stamps with long runs occur there, not 14, 20, 26, possibly 14, 17, large negative scores suggest short runs (possibly not 14, 20). Exclusion of the problem noted above, these results should be treated with caution, but will be compared with the detailed results in 3.4.

10.3.3 Similarity analysis of the diagnostic orders

| stamp no. | forward | | backward | | forward | | backward | |
|---------------|---------|----|----------|----|---------|----|----------|----|
| | D | W | D | W | D | W | D | W |
| diagnostic 9a | 19 | 19 | 4 | 4 | 3 | 1 | 17 | 14 |
| 15 | 17 | 17 | 7 | 7 | 1 | 3 | 16 | 17 |
| 16 | 16 | 16 | 3 | 3 | 2 | 2 | 10 | 8 |
| 18 | 4 | 2 | 11 | 11 | 14 | 14 | 3 | 4 |
| 19 | 7 | 15 | 9 | 9 | 4 | 4 | 7 | 7 |
| 40* | 1 | 3 | 20 | 20 | 17 | 17 | 1 | 1 |
| 41* | 18 | 18 | 2 | 2 | 6 | 5 | 15 | 16 |
| 42* | 9 | 7 | 10 | 10 | 13 | 13 | 9 | 10 |
| 43 | 8 | 9 | 13 | 13 | 10 | 8 | 8 | 9 |
| 44 | 10 | 10 | 17 | 17 | 9 | 9 | 14 | 15 |
| 45 | 15 | 6 | 6 | 6 | 7 | 6 | 5 | 5 |
| 45a | 20 | 20 | 1 | 1 | omitted | | | |
| 46 | 11 | 11 | 5 | 5 | 5 | 10 | 13 | 13 |
| 47 | 5 | 4 | 8 | 8 | 8 | 7 | 4 | 3 |
| 48 | 13 | 13 | 15 | 15 | 11 | 11 | 12 | 12 |
| 49 | 14 | 14 | 14 | 14 | 12 | 12 | 11 | 11 |
| 50* | 6 | 8 | 19 | 12 | 15 | 15 | 6 | 6 |
| IS* | 2 | 1 | 12 | 19 | 16 | 16 | 2 | 2 |
| others 13 | 12 | | 16 | | omitted | | | |
| 20 | 3 | | 5 | | 18 | | | |

Table 10.7: Orders of stamps in Group 2 (diagnostic) and occurring on bells with Group 2 stamps (others). Stamps with less than two occurrences on bells with two or more diagnostic stamps have been omitted.

10.3.4 Section of the group secondary

Back to the three main groups (Groups 1, 2 and 3 defined in 3.1.2 (Table 10.6)) and treated separately, the results are shown in Tables 10.8, 10.7 and 10.9 respectively. The left-hand part of each table includes other groups that were also present on the bells defined by the diagnostic stamps of table 10.6, but the right-hand part only diagnostic stamps were included in the analysis. Once again, both the Dorset and the Wiltshire extensions were used, and forward and backward settings are presented.

* The other groups are listed separately in this group separately in order to correspond to those produced by the vessel section (Table 10.2).

| | stamp no. | forward | | backward | | forward | | backward | |
|------------|-----------|---------|-----|----------|---------|---------|----|----------|---|
| | | D&W | D&W | D | W | D | W | D | W |
| diagnostic | 17 | 8 | 12 | 6 | 6 | 9 | 9 | | |
| | 27 | 2 | 15 | 2 | 2 | 11 | 11 | | |
| | 28 | 4 | 16 | 3 | 3 | 12 | 12 | | |
| | 29 | 7 | 14 | 5 | 5 | 10 | 10 | | |
| | 30 | 11 | 10 | 8 | 8 | 8 | 8 | | |
| | 31 | 12 | 9 | 9 | 9 | 5 | 7 | | |
| | 32 | 9 | 7 | 7 | 7 | 6 | 5 | | |
| | 33 | 13 | 4 | 10 | 10 | 3 | 3 | | |
| | 34 | 15 | 3 | 11 | 12 | 2 | 2 | | |
| | 35 | 16 | 2 | 12 | 13 | 1 | 1 | | |
| | 36 | 6 | 5 | 4 | 4 | 7 | 4 | | |
| | 37 | 14 | 8 | 13 | 11 | 4 | 6 | | |
| | 52 | 1 | 17 | 1 | 1 | 13 | 13 | | |
| | others | 11a | 17 | 1 | omitted | | | | |
| 23 | | 5 | 6 | | | | | | |
| 51* | | 3 | 13 | | | | | | |
| ID* | | 10 | 11 | | | | | | |

Table 10.8: Orders of stamps in Group 3 (diagnostic) and occurring on bells with Group 3 stamps (others). Stamps with less than two occurrences on bells with two or more diagnostic stamps have been omitted.

10.3.4.1 *Group 1 (the Dawe foundry)*

The orders according to the D and W criteria are in close agreement. The 'forward' and 'backward' orders do not agree so well, suggesting that there are some high and some low scores. Stamp 26 has a consistently high score; it and stamp 12 are the only ones to co-occur with all other 'diagnostic' stamps. The 'other' stamps have generally low scores, perhaps because they co-occur with only a restricted range of stamps of this foundry, and thus do not exhibit their full date range.

Since only one of the dated stamps (no 14) belongs to this foundry, additional evidence must be used to determine the chronological order. One source of evidence is the lettering with which the stamps are associated on the bells. During the period being studied, inscriptions changed from 'Lombardic' to 'black letter' lettering sets, thus dividing roughly into early and late types. On this basis, stamps 13, 14 and 24 (sometimes associated with Lombardic script) should start earlier than stamps 12, 21 and 22 (not associated with Lombardic script), although in a period of transition it is difficult to be precise. It seems therefore that the chronological order is the 'forward' one (all stamps) and the 'backward' one (diagnostic stamps). The order omitting the 'other' stamps agrees slightly better with the historical evidence.

10.3.4.2 *Group 2 (the Hille/Sturdy foundry)*

Five of the dated stamps belong to this foundry; a comparison of Table 10.7 with Table 10.1 shows the chronological order to be the 'backward' one (all stamps) and the 'forward' one (diagnostic stamps only). The order of the dated stamps is correct except for stamp 50, which always occurs before stamp 40 and often before IS, probably because of a single co-occurrence with stamp 19. The orders according to the two criteria are in close agreement, except for stamps 50 and IS which vary by seven positions. Each has a single co-occurrence with an earlier stamp (50 with 19, IS with 45); the criteria seem to treat them differently.

This order is supported by other evidence; for example, stamps 9a, 15 and 16 should be early as they are associated with Lombardic script (see 10.3.4.1).

Only one stamp has a consistently high score (no 47); it also co-occurs with more stamps than any other. Stamps 48 and 49 have consistently low scores, as do the 'other' stamps.

There are considerable differences between the orders including and excluding the 'other' stamps, which is surprising as only two extra stamps are involved. The seriation appears to show two subgroups (stamps 9a, 15, 16, 19, 41, 45, 45a, 46, 47 and stamps 18, 40, 42, 43, 44, 48, 49, 50, IS), within each of which the order is not consistent.

However, the overall structure appears to be weak. For example, of the dated stamps only 40 and IS co-occur. Some stamps have very few occurrences (only 3, 4 or 5) and the results appear unstable. The Jaccard analysis indicates four distinct groups—(9a, 16, 41, 45), (15, 19, 43, 44), (42, 46-9) and (18, 40, 50, IS)—with relatively few links between them. Fortunately, three of these sub-groups include dated stamps and can therefore be put in order. The fourth sub-group (15, 19, 43, 44) appears to overlap the others, thus breaking a strictly linear chronological pattern.

10.3.4.3 Group 3 (the William Chamberlyn foundry)

Only two of the dated stamps belong to this foundry, and neither is included in the diagnostic group. The orders according to the two criteria are in very close agreement (identical in some cases). The 'backwards' orders correspond exactly with what is known historically about these stamps. Apart from a local re-ordering of stamps 31, 32, 36 and 37, there is no difference between the order produced using all stamps and that produced using diagnostic stamps only.

This group comes closest to the ideal P form of seriation theory (Laxton 1987, p. 214). Stamp 36 has a consistently high score.

10.4 Integrating the sequences

We now have three chronological sequences, one for each foundry, which may overlap in time. To what extent can they be put together to form a single ordering? Two approaches are apparent; (i) through the stamps which are diagnostic of one group and occur as 'other' stamps in another group, (ii) through the dated stamps.

10.4.1 Approach (i)

There are three such links—(a) through stamp 20, which appears as an 'other' stamp to both Groups 1 and 2, (b) through stamp 13, which belongs to Group 1 and is an 'other' stamp to Group 2, and stamps 43 and 47 for which the converse is true, (c) through stamp 11a, which belongs to Group 1 (but is not diagnostic of that group) and is an 'other' stamp to Group 3.

Stamp 20: has links with 'early' stamps in Group 1, in particular the dated stamp 14. In Group 2 it has links with 'later' stamps, in particular the dated stamps 42, 15, 40 and 50. It therefore has an extremely long life, from 1420 at the latest to 1510 at the earliest, and is therefore of no value for dating or linking sequences.

Stamps 13, 43 and 47. In Group 1, stamp 13 has strong links with the dated stamp 14 and with stamp 25; it is therefore early in the sequence. In Group 2, it has links with fairly late stamps, in particular the dated stamp 42, and of course stamp 43 and 47, which also appear as 'other' stamps to Group 1. It therefore has a potentially long life, depending on the length of its overlap with stamp 14, and does not give additional information beyond that which can be gleaned from the dated stamps of Groups 1 and 2.

Stamps 34 and 35: are securely placed at the start of Group 3, and have a tenuous link with stamp 11a, probably the latest stamp of Group 1. This link could cautiously be taken as evidence that the start of Group 3 overlaps slightly with the end of Group 1.

10.4.2 Approach (ii)

Fig. 10.1 shows the three sequences ranged against a scale of dates from 1380 to 1520. It is based on the 'forward' and 'backward' results of the seriation, taking into account the need for stamps that co-occur to have a date in common, and anchored by the dates of the 'dated' stamps. The solid lines show dates at which the stamps were probably in use and the broken lines those at which they may have been in use. Arrows at the end of a line indicate possible extensions in time.

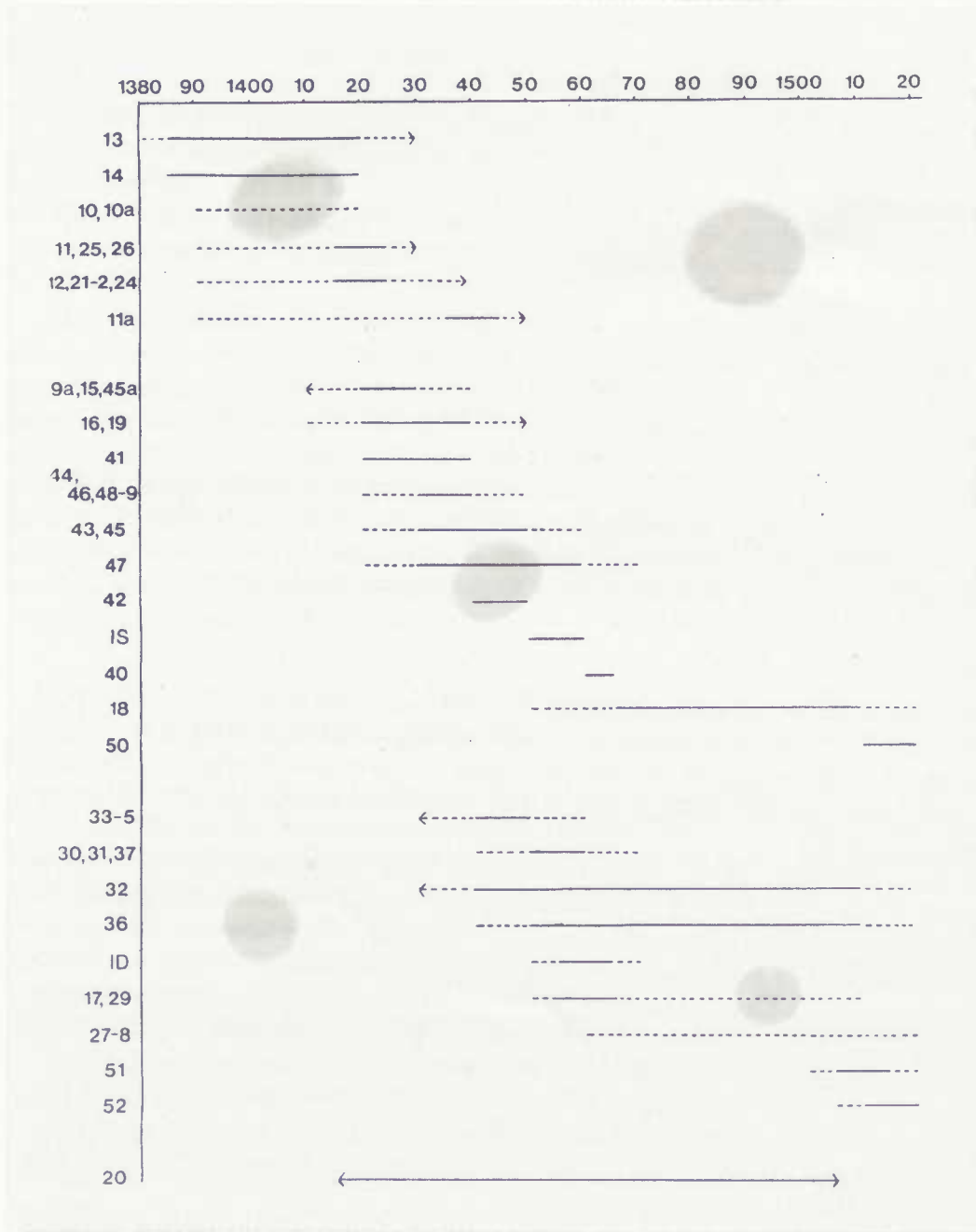


Figure 10.1: Suggested date ranges of the stamps, based on their co-occurrences on bells and on the dates of the 'dated' stamps. Dates have generally been rounded to ten-year intervals.

In general, the conclusions of the seriation are not contradicted by the historical evidence. However, in two cases there may be a conflict between the two sorts of evidence:

1. Stamps 10 and 10a, which the seriation suggests should start later than stamps 13 and 14. Since 5 out of the 12 twelve bells which bear the stamps 10 and 10a have inscriptions in Lombardic capitals, and only 1 of the 28 bells bearing stamp 14 has such an inscription, the date ranges of these stamps ought perhaps to be earlier.
2. Stamp 43, which is the family arms of the Kebyll family. The only Kebyll who appears in the City records is a certain Stephen Kebyll, Wheelwright, who did some work for St Stephen's, Walbrook, in 1480 (Elphick 1970, p. 46). This need not, of course, be the man who used stamp 43, but it does raise a doubt.

10.5 Conclusions

In this example, seriation has been a useful tool in helping to organise a large body of data, and pointing the way towards the organisation of the whole corpus of material from which the sample was drawn. But it only made sense in the context of either (i) prior historical knowledge (e.g. about the different foundries) or (ii) ancillary techniques (e.g. the similarity analysis). Its uncritical use would have led to a false interpretation.

Why should this be so? The answer seems to be that the technique is not *robust* against departures from its implicit assumptions, or against apparently minor irregularities in the data. As an example of the latter, even a single co-occurrence of an early stamp with a late one (perhaps because it had been re-adopted after a period of disuse) will tend to force the late type earlier in the sequence. An example is the re-use by T. Bullisdon (c. 1510) of a black letter minuscule set of lettering widely used by the group 1 founders, ending c. 1440. In this case, the assumption that types are in use continually, from their introduction to their last use, has clearly been breached.

Another, but less obvious, assumption is that of *independence*. There is an implicit assumption that the choice of one type from the set available at a certain time does not affect the choice of the second, third, ... types from the same context. This is not to say that all types have the same probability of selection—some may be more 'popular' than others—but that knowing one of the types chosen does not help us predict which other types have been chosen. This assumption is violated in our example:-

1. at the level of the foundry. Although stamps from different foundries are not completely mutually exclusive, those from the same foundry occur together more often than those from different foundries. There is thus a negative association between contemporaneous stamps from different foundries.
2. at the level of individual stamps. Some stamps (e.g. nos 25 and 26) are varieties of the same basic pattern, and may therefore be seen as alternatives and rarely co-occur even though contemporaneous.

A related problem is that of name changes. For example, of the main Hille/Sturdy stamps (nos. 41, 42, IS, 40; Richard Hille, Johanna Hille, John Sturdy, Johanna Sturdy)

only IS and 40 co-occur, although all are closely related in time. Sudden changes from one to another (e.g. at death or marriage) violate the assumption that changes in popularity of types take place gradually.

The lack of independence between observations is a common problem in archaeology. It also occurs, for example, in the quantification of pottery (Orton 1982, p. 6). It may be a major problem in the use of conventional statistical methods in archaeology, and needs to be faced.

10.6 Acknowledgement

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