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ABSTRACT

The study of three ledgers from the archives of a prominent Parisian violin maker's workshop (active from 1796 to 1948) reveals that some of their content was encrypted. We present here the deciphering of the code, and a discussion of its use in the context of the workshop. Charles-Adolphe Gand introduced this code around 1847 to encrypt values of antique/used violins he would buy and resell. His successors maintained the use of this code at least until 1921. Taking a few examples of instruments by Stradivari and other violin makers, we illustrate how the decoded ledgers –listing transactions for more than 2,500 instruments– are of high interest as historical sources documenting the margins, rebates, and commercial practices of these violin dealers. More generally, will contribute to better describing the evolution of the market for antique instruments of the violin family.

KEYWORDS

Monoalphabetic Substitution Cipher, Violin Trade, Charles-Adolphe Gand

1. Introduction

Despite the outstanding growth of the violin market during the 19th century, little data is available to precisely study and quantify the trade of these instruments. In particular the trade of used/antique instruments, which developed together with the growing interest of musicians, collectors and investors in 16th-18th-century instruments, is particularly opaque to us today due to this lack of data (Gand 1870-1891)[1]. Previous works allow for an initial assessment of long-term market trends (mid-19th to early 21st c.), focussing on datasets limited to a few violin-makers (Graddy, and Margolis 2011, Ross, and Zondervan 1989). However, these studies do not provide any information on the business practices (including profits, margins, discounts, etc.) of 19th-century violin dealers.

Charles-François Gand (1787-1845) was trained and worked at the workshop of Nicolas Lupot, the most important violin-maker in Paris at the turn of the 19th century, who was nicknamed "the French Stradivarius" (Milliot 2015). At the death of Lupot in 1824, Charles-François Gand succeeded him at the head of the established business, maintaining and developing it. The workshop restored and maintained in playing condition instruments brought by musicians, made new instruments –which are now often considered to be excellent– and also bought and sold used instruments. During this time, Paris was a very important artistic and musical centre, and the Lupot-Gand workshop, which was continuously active from 1796 until after World War II, was one of the main, if not the main, workshops in town and was internationally renowned (Laloue (in press))[2]. The Musée

[1] This rare expert notebook was held by Charles-Nicolas-Eugène Gand between 1870 and 1891, to note descriptions of old and possibly valuable instruments. This document shows a few examples of encrypted instrument values.

[2] Charles-Adolphe Gand took over the workshop at the death of his father in 1845. He partnered with his brother Charles-Nicolas-Eugène in 1855 (« Gand frères » period). When Charles-Adolphe died in 1866, Charles-Nicolas-Eugène Gand partnered with Ernest and Bernardel (« Gand & Bernardel frères » period). Ernest Bernardel died in 1886, and the association became « Gand & Bernardel» until the death of Charles-Nicolas-Eugène Gand in 1892. In 1901, the business held by Gustave Bernardel alone was taken over by Albert Caressa and Henri Français, until the death of the later in 1920 (« Caressa & Français» period). From 1920 to 1938, Albert Caressa ran the workshop and was succeeded by Emile Français until 1948.

de la musique holds more than 11,000 pages of archival documents from this worskhop, mostly consisting of clients' repertoires and accounting ledgers. A large part of these archives are accessible online ("Fonds Gand, Bernardel, Caressa et Français"). Among these archives are three ledgers held by Charles-François Gand and his successors to keep track of their business of more than 2,500 used instruments, covering the early 1840s to 1921 at least. The recent study of these largely underexploited (Milliot 2015) documents reveals the extensive use of a code for values assigned to each of the described instruments. This paper discusses the use of the code in the Gand workshop, explains how it was deciphered, and presents a few of the research perspectives opened up by this deciphering.

2. Description of the archives and of the data structure

Three ledgers of the same format (height 35 cm x width 22 cm) are entitled « n°1 Signalements », « n°2 Signalements », « n°3 Signalements » (inventory numbers E.981.8.35-37). The ledgers are filled chronologically, one line per instrument, by order of purchase of the used instruments. Each instrument is given an incremented number, from 1 to 2317 for violins (Fig. 1, first column), from 1 to 93 for violas and from 1 to 177 for cellos[3].

When a used instrument is purchased by the workshop, it is described in the second column by the name of its maker, its year of making, a description of the principal material and construction features and the state of conservation. This field also contains:

- at the bottom left corner, a string of letters (which we will refer to as A), and a personal name in parentheses,
- at the bottom right corner, a number (B), and a string of letters in parentheses (C).

The last columns were filled once the instrument was sold. The third column usually indicates "sold to M…." and the date of the sale, and the fourth indicates a number (D).
Throughout the ledgers, slight formal changes in the page and table setup are observed, without altering the nature of the data.

The strings of letters 'A' and 'C' are coded information. Violin #1342 is the only instrument described in the ledgers which is known to be today in the collection of the Musée de la musique as the 'Tua' violin, made by Antonio Stradivari in 1708 (Echard 2016). Comparisons between the known history of the instrument and the data in the ledgers allows us to confirm or explain the meaning of A, B, C and D. This instrument was donated to the Musée by the violinist Teresa Tua in 1935. The sale of the instrument by the workshop to Teresa Tua in 1885 is indicated in the third column (Fig. 1, line #1342). Tua's client account indicates clearly that she paid 8,000 francs for this violin, in two instalments of 4,000 francs each in February and March 1886 (Fonds Gand - Bernardel - Caressa et Français 1881–1887). It is thus confirmed that 'D' is the sale price of the instrument. In the same source (Fonds Gand - Bernardel - Caressa et Français 1881–1887), it is also found that a Mr de Rivals-Mazères brought this instrument to the workshop from Toulouse. This is the name indicated in the bottom left corner of the second column, in parentheses next to the 'A' string of letters. We thus assume that 'A' is the coded purchase price, i.e. the price paid by the workshop to the previous owner of the instrument. A reasonable hypothesis is then that the non-coded number 'B' is the tag price in *francs*, i.e. the price announced to a potential client. Next to this one, in parentheses, the coded 'C' is very possibly the reserve price, i.e. the price below which the violin dealer would not want to sell the instrument.
In few instances, another coded entry (E) marked *réparation* (i.e. repair/restoration) is indicated next to 'A', combined with it in what looks like two coded strings being added together.

A	purchase price
B	tag price
C	reserve price
D	sale price
E	repair cost

[3] The specific numbering for violas and cellos seems to have been stopped at an undetermined time. These instruments are listed in the later periods together with the violins. Towards the end of World War I, a transition to a renewed numbering system is observed, and larger numbers are also given also a new, smaller number, as if the inventory had been completely redone, possibly when a succession at the head of the workshop occurred.

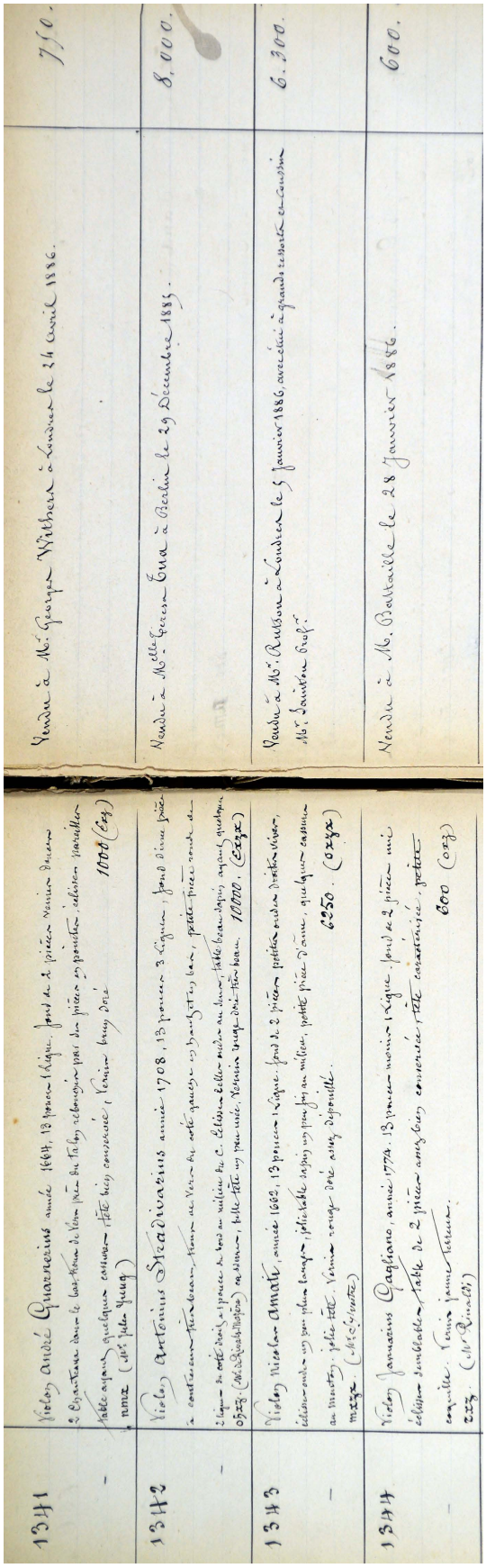

FIGURE 1: *Typical example of original data (from "n°2 Signalements", coll. Musée de la musique, inv. num. E.981.8.36).*

3. *History of use of the code in the workshop*

From various indirect observations, we assessed that purchases and sales of used instruments were reported from before 1842 to ca. 1921. Additional remarks on attributions or later owners were added until 1951 at least. From instruments #1 to #351, initial indication of the 'A' and 'C' values in non-coded, Arabic numbering was later overwritten by the encryption (Fig. 2).

FIGURE 2: *Detail view of the tag price and of the reserve price (in parentheses) for entry #5 (a violin by the Cremonese maker Giuseppe Guarneri 'filius Andreae'). The reserve price, first indicated in unencrypted text, was written over with the encrypted version. Some elements of the number are still visible, in particular of the '7' beneath the 'i'.*

From instrument #352 on, 'A' and 'C' values were directly written in code (Fig. 1). We deduced that the code was introduced around mid-1847, two years after Charles-Adolphe Gand (1812-1866) succeded his father Charles-François at the head of the workshop. At this time Charles-Nicolas-Eugène (1825-1892), the second son of Charles-François, was already working at the workshop, and was 22 years old (Milliot 2015). We do not have any information in the Gand family archives indicating any interest in codes and cryptology. It is probable that one of the two brothers invented the code especially to be used in these ledgers. As the head of the workshop, it is certain that Charles-Adolphe knew the code, since he was responsible for the accounting and the financial health of the business. As for Charles-Nicolas-Eugène, it should be noted that he was an employee until he formally partnered with his older brother in 1855, creating the "Gand frères" company (Milliot 2015). The number of people in the workshop with whom the code was shared, if any, is unknown. On-going research work will hopefully provide better insights of the workshop organisation and the distribution of tasks among the staff. It can only be assumed that evaluation of instruments, decisions on purchasing, and negotiations were probably conducted by the workshop head. From #1525 (around year 1893, the "Gustave Bernardel" period), even the tag price 'B' is written in code for most instruments.

The reasons for encrypting values in these ledgers may have been multiple. One possible reason is that this allowed opening and reading the ledger in front of a potential client, without him being able to read purchase and reserve prices, thus maintaining a strong bargaining position for the dealer. Another would be that it would allow concealing a part of the accounts of this business from tax controllers.

Although we do not know the precise event that motivated the encryption, the general context might also have played a role. This occurred at a time when the electrical telegraph was being quickly deployed around the world –the first French line was constructed in 1845– and concerns about the security of the transmissions were rising, not only for diplomatic or military communications, but also for business and private issues (Kahn 1996, Standage 1998). Code books, mechanical devices, substitution or transposition methods were numerous, and many amateurs were inventing their own algorithms.

4. *Deciphering method*

Given the general context of use, it was unlikely that we were facing some advanced encryption method. Indeed, from Fig. 3, it seemed to be possible to do simple calculations easily; furthermore we assumed that the decryption had to be done quickly by the dealer during a negotiation with their client, without having to use an additional code-book or apparatus.

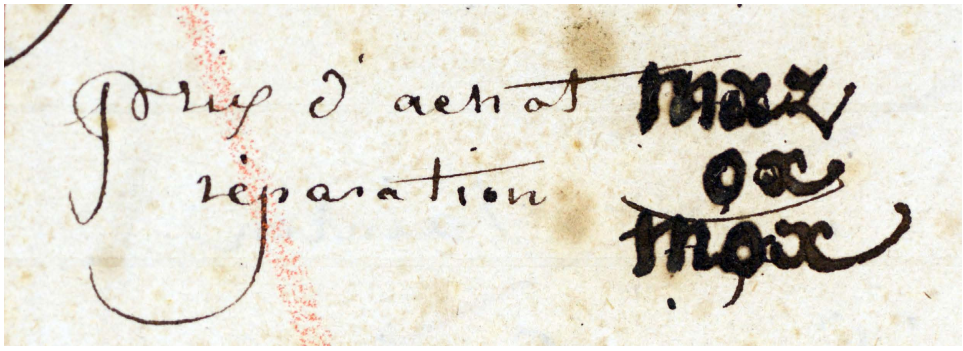

FIGURE 3: *Detail view of the purchase price (Prix d'achat) the cost of repair (reparation) and the result of their addition for entry #6 (a violin by the Cremonese maker Roggeri). Such additions confirm that 'x' corresponds to '0' and that 'x' and 'z' are homophones.*

The hypothesis of a simple monoalphabetic substitution did not work: this is incompatible with the addition shown in Fig. 3. More generally, the *xz*, *zx*, *xzx*, *zxz* patterns occurring mostly at the end of the encrypted numbers were a bit puzzling. But, assuming again that some simple transformation preserving the positions of the digits was used, these are the lowest significant parts of the prices and do not carry a lot of information. So we concentrated on what we assumed were the most significant digits of the numbers.
We used, as a working hypothesis, the relation between the reserve price 'C' and the tag price 'B': if the meanings were correct, it would make no sense to have a reserve price higher than the tag price. So we would have

$$C \leq B$$

where C is encrypted and B is not. We also kept in mind the general idea that most of the time the reserve price should be larger than the purchase price 'A', which is encrypted:

$$C > A \text{ [most of the time]}$$

Furthermore, in most of the cases, we can assume that the negotiation went well and that the sale price 'D', which is unencrypted will be larger than the reserve price:

$$C \geq D \text{ [most of the time]}$$

The amount of data for categories 'A', 'B', 'C', 'D' is large enough to test the monoalphabetic substitution hypothesis. We did not use the repair prices 'E' in this first phase, because not enough data was available.
We used about one hundred (A,B,C,D) quadruples taken from two different periods (instruments around #400 and around #1300). This quickly allowed us to determine that the digits '1' and '2', were encoded by the letters 'h' and 'a' respectively. More generally, the relation 'C ≤ B' translated easily into a similar relation between the encrypted digits (taking care of carried digits). We soon arrived at a first guess of 'harmoneiu' for the digits '123456789' and this was quickly corrected to the keyword '*harmonieux*' for the digits '1234567890'.

1	2	3	4	5	6	7	8	9	0
h	a	r	m	o	n	i	e	u	x

The choice of the adjective *harmonieux* (in English: harmonious) as a code key by a dealer of musical instruments is very understandable in a musical context. In particular, one should note that the front part of the violin, the soundboard, is named in French *table d'harmonie*. The use of a ten-letter word as a key to encode decimal digits was also not unusual at that time.
Therefore, at this point, it was clear that the key was found. The last part to understand was the '*z*', but it was then easy to guess that this was just another possible encryption for '0', in order to avoid the too-obvious '*xx*' or '*xxx*' that would be systematically written at the end of the encrypted rounded numbers.
In the end, our solution proved to be consistent with everything we could check: the inequalities C > A and C ≥ D were indeed verified most of the time, and the repair cost calculations were valid once deciphered. Also, in the cases where the encrypted version had been written on top of the non-coded value, the decrypted version was compatible with the parts of the digits that were still visible (Figs 2 and 3).

5. *Discussion about the cipher*

The cipher chosen by Gand is definitely a weak one, even by 19th-century standards. There is no doubt that specialized governmental entities could break it (and the *French Bureau du Chiffre* was quite powerful at that time). But, given the conditions of usage, it was probably not so bad: since the encryption / decryption operations had to be done as a quick mental calculation, many advanced algorithms were not possible. Also the natural «attackers» were numerous (all the buyers), but even if a few of them managed to guess the cipher, it would still be effective against the others.

The main easy protection that could have been added would have been to include more homophones, in order to protect not only the '0' digit, but also the most important ones, namely '1' and '2'. Of course, this would have required a bit more practice to do the mental calculation, so a compromise would need to be reached. Another very easy protection would have been to use 'null' symbols; in particular this would have been a convenient way to hide the number of digits of the price, which sometimes gives away a lot of information (for instance, if the price is guessed to be around 1000 francs, the attacker can see whether it is less or more). These two techniques (homophones and null symbols) were well known at that time.

As a side note, we remark that the digit '9' was almost never used, which makes sense because it is the digit that carries the least information: rounding it up or down changes the value by at most 11.1%. This can be seen as a consequence of Benford's law, where an additional bias is added by a human who tends to like round numbers (Knuth 1997). However, with today's commercial trend of having all prices finish with '.99', the statistics would be biased differently. Also, one can observe that the digit '7', encrypted with the letter 'i' is almost never used, while the digit '8', encrypted as 'e' was often used. Here, we can just assume that the dealer, consciously or unconsciously, had the habit of rounding values to avoid 7's or 9's. This remark is valid only for numbers that were not the result of a negotiation: in the purchase prices 'A' or the sale prices 'D', the digits 7 and 9 are not rare.

6. *Perspectives*

The deciphering of the code now makes possible new studies on the economics and commercial practices of the workshop. In particular, with the decoding of A and C, new insights can now be gained on the minimum and maximum margins the workshop would expect, and the margins they would effectively realize.

Maximum expected margin = tag price – purchase price = B – A

Minimum expected margin = reserve price – purchase price = C – A

Realized margin = sale price – purchase price = D – A

As an illustration, we selected in the ledgers a consecutive series of 39 instruments, which were sold around 1887. Their A and C values were decoded, allowing for the various calculations described above. Data are plotted in Fig. 4.

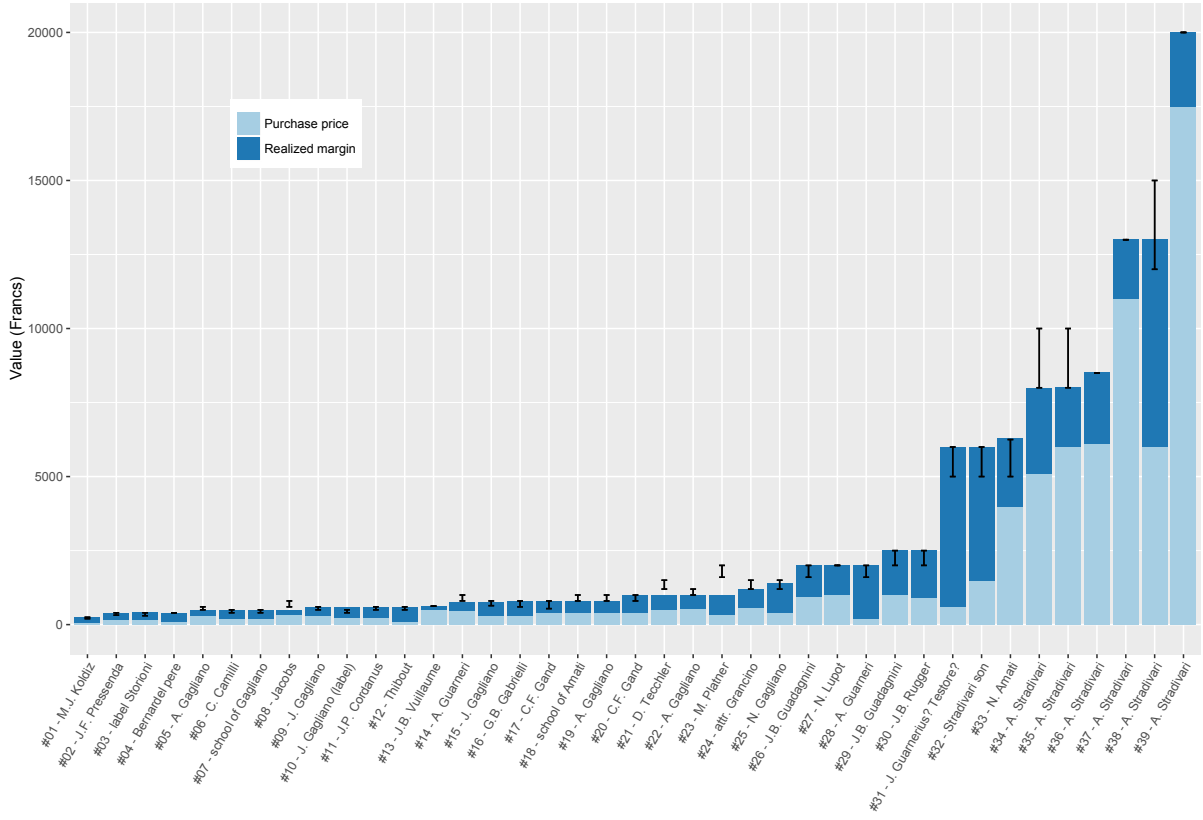

FIGURE 4: *Purchase price and realized margin for 39 instruments sold by the workshop ca. 1887. Instruments sorted and numbered by increasing sale price. The vertical black segments indicate the expected negotiation limits for each instrument, between reserve price C (lower limit) and tag price B (upper limit)..*

The price range among this series of used instruments is broad, from a few hundred to 20,000 francs. This probably reflects the intention of Gand to offer a wide range of instruments, adapted to the diversity of the

workshop's clients. It appears that margins are highly variable, even for instruments in the same price range. No statistical trend appears from this small set of data which would indicate a systematic way to determine the tag and reserve prices. This suggests that the assessment of these values by the violin dealer was an unformulated human-based choice. The six Stradivari violins presented here are the most expensive ones of the set: the sale prices among Stradivari instruments may differ by a factor up to 2.5, possibly accounted for by variable states of conservation. More surprisingly, margins differ a lot: for two Stradivari instruments purchased at the same price (6,000 francs), one was sold for 8,400 whereas the other was sold for 13,000 francs, after a rebate accepted by the workshop!

Another possible use of these now-decoded data would be to study the evolution of the commercial practices of the workshop over the seven decades documented by these ledgers. It is possible to easily compare the values in *francs* at various dates because the price levels in France show neither rapid variations, nor upward or downward trends between 1870 and 1914 (Bernholz 2003). Reviewing some instruments, which were traded several times by the workshop, may illustrate this perspective. Accessing the decoded purchase and reserve prices allows for a better assessment of the evolution of a given instrument's market value.
For instance, we can study the violin made by Antonio Stradivari in 1710, which appears twice in the ledgers, at #1187 and #1390. The workshop purchased it in 1877 from a Mr Florent for the sum of *mxzx* (4000) francs. The tag price then was "5000____" francs (with no reserve price, which probably indicates that this price was not negotiable). It was rapidly sold at that price, on August 20th of the same year, to a Mr Meier, from London. Less than seven years later, the same instrument was sold again to the workshop by the French violinist and composer Charles Dancla (1817-1907) for the sum of *hxxzx* (10000) francs. It was sold on January 29th, 1884 to a Mr Legrand, at the tag price (11000 francs). This violin is very probably the one, later played by Nathan Milstein, known today as the 'Dancla, Milstein'.
Another example is the violin made by Antonio Stradivari in 1707, registered as #1611 by Gustave Bernardel in the first half of the year 1897. This instrument is probably the one known today as the 'Dushkin, Bellarossa'. The ledger contains information about several transactions, with most values being encrypted; these are summed up in Table 1.

TABLE 1: *Trade history of violin #1611 (instrument by Antonio Stradivari, dated 1707) reconstructed from data in the studied ledgers. Only one value was written in clear numbering, the purchase price on June 12th, 1897.*

Date				Encrypted price	Decoded price
	G. Bernardel	purchases it from	Mr de Villeneuve	*axzx*	2000
			Tag price	*hoxzx*	15000
			Reserve price	*haxz*	1200
1897, June 12th	G. Bernardel	sells it to	Mr Germain [violin-maker in Paris]	7000	
1898	Mr Schörg	purchases it from	Silvestre [violin-maker]	*axzxz*	20000
	Caressa & Français	purchases it from	Mr Schörg	*aixzx*	27000
			Tag price	*moxzx*	45000
			Reserve price	*mxzxz*	40000
1911, May 16th	Caressa & Français	sells it to	Mr Courvoisier (Vidoudez)*	*ooxxz*	55000

* Alfred Vidoudez, violin-maker in Geneva, acted probably as an intermediary

7. Conclusion

The encryption algorithm used in this violin maker's workshop was rather easy to decipher, even without having access to a crib due to the arithmetic relations inherent to data from a ledger. Given the context where it was used, it was probably good enough, but adding more homophones and nulls could have made it much stronger. The use of the code was reserved to the trade of used instruments. It was strongly linked to the evaluation of the quality and commercial potential of the instrument. This decoding opens the way for the complete analysis of the data from these ledgers, leading to the objective description and understanding of the workshop's business practices for used instruments over more than seven decades. A more refined development will involve studying the value differences between instruments from various makers and production centres, and their evolution over time.

ABOUT THE AUTHORS

Jean-Philippe Echard is curator in charge of the collection of bowed string instruments at the Musée de la musique in Paris, France. He received his PhD in 2010, on the materials and techniques used to varnish 16th-18th-c. lutes and violins. His current research interests are within material, cultural, technical and economical history of bowed string instruments, with a particular focus on the individual history of the instruments now in the collection of the Musée de la musique.

Pierrick Gaudry is a computer science researcher at the CNRS in Nancy, France. He received his PhD from École polytechnique in 2000. Since then, his research interests are within algorithmic number theory in relation to public key cryptography, with a particular taste for elliptic curves, integer factorization and the discrete logarithm problem.

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