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Evidential Value of Particle Combination Profiles on Common Items of Evidence

I. Purpose of the Project

Prevailing methods of trace evidence analysis have been limited by three major aspects:

- Difficulties in the measurement of probative value
- Increased specialization, focusing on smaller numbers of particle types, in correspondingly smaller numbers of cases
- Relatively long analytical times and high levels of effort for required tasks

Together, these limitations combine to reduce the overall value of trace evidence, resulting in the major challenges voiced by leaders in the discipline for the last 15 years: low perceptions of probative value, small numbers of case requests, and high costs relative to case contributions.[1-6] The impact within forensic laboratories has been substantial, resulting in reductions in funding, restriction of services, and even complete closure of trace analysis sections within laboratories.[1, 5]

Within this context, methods focusing on the analysis of combinations of very small particles (VSP) show exceptional promise to address the limitations facing trace evidence analysis. In prior NIJ-funded research we have (1) characterized VSP combinations using analytical instrumentation and expertise commonly available in forensic laboratories, (2) developed statistically rigorous measurements of the strength of correspondence between VSP profiles, and (3)

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measured the probative value of the resulting associations within well-defined experimental parameters.[7-8] Each of the bulleted limitations above is addressed: probative value can be measured, cases are not restricted by small numbers of particle types, and both the required analytical times and level of effort are practically achievable.

As the next step for testing and evaluation of this new approach, this project used the analytical tools and statistical methods developed in prior NIJ research to measure the evidential value of VSP profiles found on four common types of physical evidence: handguns, cell phones, drug packaging, and ski masks.

II. Project Design

Project objectives were to: (1) expand, refine and test VSP harvesting protocols to accommodate non-porous, paper, and fabric surfaces; (2) harvest VSP from 100 evidence items representing four important and commonly occurring types of physical evidence; (3) apply the established analytical and interpretive methods to measure evidential value, and (4) present the project results to the forensic practitioner and research communities in an interactive format allowing full presentation and thorough discussion.

VSP were collected from actual evidence items at the San Diego Sheriff's Department Crime Laboratory (evidence from cases where detectives had determined these items to no longer be of value and had approved them for disposal). The four evidence types (handguns, drug packaging, cellular phones

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and ski masks) were selected because: (1) they regularly occur as evidence left and collected at major crime scenes, (2) associations of these items to one another, to individuals and to locations is of broad investigative significance, (3) they include a wide range of surface types, including most that are likely to be found on evidence, and (4) as a set, they are a good proxy to assess the levels and probative value VSP on common items of evidence.

Particle analysis and interpretive methods developed and applied under NIJ Award 2012-DN-BX-K041 [8, 10] were used for measurement of evidential value of particle combination profiles on each of the four evidence types. The results were presented to forensic practitioner and research communities in an interactive format to (1) gather meaningful and timely feedback that will help guide further development of this new approach, (2) disseminate the results to practitioners who can consider the adoption and testing of prototype methods in their laboratories, and (3) to disseminate the results to researchers who can consider a broad range of opportunities for follow-on research.

III. Methods

A. VSP Harvesting

VSP were harvested from evidence items at San Diego County Sherriff's Office Crime Laboratory. Samples were collected from 31 cell phones, 30 firearms, 36 plastic bag drug packaging specimens and 32 ski masks.

Commercially-prepared SEM stubs were used to harvest VSP from plastic bags used in drug packaging. These were analyzed directly. For handguns, cell

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phones and ski masks, non-shedding clean room swabs (slightly dampened with pre-filtered distilled water) were used for VSP harvesting. The swab heads were then removed and VSP were recovered into a suspension using a washing procedure as in [9] followed by dropwise vacuum filtration through 0.4 micrometer polycarbonate filters. These filters were then mounted onto SEM stubs for analysis.

B. SEM/EDS Analyses

SEM/EDS analyses were conducted at the Defense Forensic Science Center on an Aspex Corporation 3025 SEM-EDS system using the Automated Feature Analysis (AFA) program within the Aspex Corporation Perception software (low vacuum conditions, 20.0 kV accelerating voltage, backscatter electron detector).[8] The analysis provided a dataset of up to 5,000 particles for each sample, with x-ray counts binned into energy ranges corresponding to the 18 elements in Table 1.

C. Measurement of Evidential Value of Particle Combination Profiles

Particle data were filtered to remove (1) particles that fail to show any dominant composition as represented by the calculated percentages of the elements and (2) elements that are present in minute amounts. Based on the analysis of the entire Reference Source Dataset (for each evidence type) a set of 10 Target Particle Types (TPTs) were defined using a semi-supervised hierarchical clustering algorithm relying on Normal Mixture Modeling. The TPT profile for any specimen was then determined by categorization of each of that specimen’s particles into the most closely fitting TPT, based the probability of the

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particle's class membership in each of the TPTs. Comparison of a specimen to each of the Reference Sources proceeds based on the specimen's 10 most commonly occurring TPTs, with the remaining TPTs grouped into an 11th class. The degree of correspondence (with each Reference Source) is measured based on the multinomial probability distribution and probative value is measured based on the likelihood ratio for each source based on the assumption of the representativeness of the Reference Source dataset.

The Matching Ability of the System is determined by randomly dividing the particle data within each of the Reference Sources into training and test sets and evaluating how well the system matches the "training set" sources to the corresponding "test set" traces. This set of measurements establishes a baseline performance of the system under ideal conditions. Rates of correct and incorrect classification are determined based on classification to the source of highest probability and DET diagrams are used to examine classification performance based on specific thresholds. Where test specimens are misclassified, the rank of the probability for true source is determined.

IV. Data Analysis

A. Drug Packaging

Data for drug packaging are shown in Table 2 and Figure 1. Table 2 shows the results of classification using the test set for each of the specimens: 35 of 36 test sets from the drug packaging specimens are correctly classified. Figure 1 (left) is a network diagram representation of these results. Each

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specimen is represented by a numbered colored circle on the diagram. The axes are arbitrary. Isolated circles indicate that they are differentiated from all of the other specimens. A gray arrowhead just to the right of an isolated circle and pointing toward the circle indicates that that specimen has sufficient character that the system correctly associates the specimen with itself. Any arrows starting from one circle and leading to another would represent that the data from the first circle are insufficient to differentiate it from the second. The diagram shows that the specimen “C P30” is incorrectly associated to “C P25”, corresponding to the red cell on Table 2.

Figure 1 (right) shows a bar chart of the rank of the true source, with the 35 correctly classified specimens at Rank 1 and the single misclassified specimen at Rank 36. This indicates a specimen that does not have sufficient character to result in a strong association.

B. Handguns

Results for handguns are shown in a network diagram in Figure 2 (left) and the classification results are shown in Table 3. Of the 30 specimens, 27 were correctly classified and 3 were misclassified. Figure 2 (right) shows that one of the three misclassified specimens showed the true source at Rank 3. The other two misclassified specimens had correct sources ranked 26th and 30th, indicating that these specimens did not have sufficient character to result in a strong association.

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C. Cell Phones

Results for cell phones are shown in a network diagram in Figure 3 (left) and the classification results are shown in Table 4. Of the 31 specimens, 27 were correctly classified and 4 were misclassified. Figure 3 (right) shows that one of the three misclassified specimens showed the true source at Rank 2. The other three misclassified specimens had correct sources ranked 29th, 30th and 31st, indicating that these specimens did not have sufficient character to result in a strong association.

D. Ski Masks

Results for ski masks are shown in a network diagram in Figure 4 (left) and the classification results are shown in Table 5. Of the 32 specimens 17 were correctly classified and 15 were misclassified. Figure 4 (right) shows that four misclassified specimens had the correct source ranked 2nd, one had the correct source ranked fourth and the other 10 showed ranks greater of 23rd or higher, indicating that these specimens did not have sufficient character to result in a strong association.

E. Summary of Results and Discussion

VSP were recovered from actual items of evidence of four types: drug packaging, cell phones, handguns and ski masks. The VSP were analyzed in an operational crime laboratory setting, using a practical, efficient analytical protocol.

Results were mixed. Overall classification rates for the four evidence items are given in Table 6. Under the experimental conditions drug packaging showed excellent results for classification of test specimens (97%). Handguns and cell

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phones showed good classification results (90% and 87%, respectively). Ski Masks showed poor results, with correct classifications at 53%.

Most misclassifications (70%, 16 of 23) showed the correct source ranked very remotely, indicating that these specimens did not have sufficient character to result in a strong association. The remaining seven misclassifications showed the true source ranked among the top four (five ranked 2nd, one 3rd and one 4th).

It is clear from these results that most of the specimens showed sufficient variety and complexity in their VSP profiles to allow meaningful classification among closed sets of approximately 30 specimens. It is also clear that some specimens lacked any meaningful basis for comparison. This is not unexpected. VSP profiles on any given item of evidence need not be complex and diagnostic. What is important is that on many (or most) they are unquestionably so. This finding encourages the follow-on research that will allow refinement and testing of the analytical and interpretational approach.

The present work was conducted employing a set of simplifications and assumptions appropriate for testing of the overall reasonableness of the approach. These included choice of a well-defined, efficient and practical method of analysis as well as choice of reasonable parameters for the computational methods. With these choices we were able to test (and demonstrate) a potential, but the methods are by no means optimized and by no means able to demonstrate the full potential. Follow-on study of variability among VSP profiles and the effects of changes in (1) the analytical protocols and (2) key parameters of the computational methods, will enable systematic improvement, optimization

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and transition to practice.

V. Scholarly Products Produced or in Process

A. Presentations

1. Stoney, D.A. and Stoney, P.L., Practical Applications of Very Small Particles and Particle Combinations in Forensic Science, San Diego County Sheriff's Department Crime Laboratory, San Diego, CA, April 5, 2016.

2. Stoney, DA and Stoney, PL “Probative Value of Very Small Particles Adhering to Common Items of Physical Evidence,” Georgia Microscopical Society, and United States Army Criminal Investigation Laboratory, Defense Forensic Science Center, Duluth, GA, October 24, 2016.

3. Stoney, DA and Stoney, PL “Probative Value of Very Small Particles Adhering to Common Items of Physical Evidence,” San Diego County Sheriff's Department Crime Laboratory, San Diego, CA, November 2, 2016.

4. Stoney, DA and Stoney, PL “Probative Value of Very Small Particles Adhering to Common Items of Physical Evidence,” California Association of Criminalists 128th Seminar, Rancho Mirage, CA, November 3, 2016.

5. Stoney, DA and Stoney, PL “Probative Value of Very Small Particles Adhering to Common Items of Physical Evidence,” American Academy of Forensic Sciences 69th Annual Meeting, New Orleans, LA, February, 17, 2017. (Upcoming)

B. Publications

1. Stoney, DA and Stoney, PL. Evidential Value of Particle Combination Profiles on Common Items of Physical Evidence,” (in progress).

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VI. Implications for Criminal Justice Policy and Practice in the United States

This research has measured the evidential value of combinations of very small particles (VSP) as they occur on common items of physical evidence. VSP show exceptional promise to expand the numbers of cases where trace evidence can be used and provide quantitative statistical measures of evidential value. The laboratory analyses are highly efficient and can be conducted using existing crime laboratory personnel and equipment.

The results of this project provide (1) knowledge of the evidential value of particle combination profiles on common evidence type, and (2) improved understanding of the factors affecting how well particle combination analysis of VSP works in different situations. These results encourage specific follow-on research directed toward the systematic improvement and optimization of these methods. This will lead to prototype casework applications and will further the development of solutions for important investigative problems that cannot be addressed by current forensic laboratory methods.

In a broader context, the approach used is highly significant for its potential to expand the number of cases to which trace evidence can meaningfully contribute and for its ability to include a quantitative statistical approach to data interpretation. Newly developed quantitative statistical tools were used to measure the individuality of particle combinations that are ubiquitous in our environment, long recognized for their possible potential, but left unused for want of a practical and meaningful way forward.

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VII. Appendix: Tables, Figures and References

A. Tables

Table 1. The 18 Elements Detected by the Automated EDS Procedure

Sodium (Kα, Kβ)	Magnesium (Kα, Kβ)	Aluminum (Kα, Kβ)
Silicon (Kα, Kβ)	Phosphorous (Kα, Kβ)	Sulfur (Kα, Kβ)
Chlorine (Kα, Kβ)	Potassium (Kα, Kβ)	Calcium (Kα, Kβ)
Titanium (Kα, Kβ)	Vanadium (Kα, Kβ)	Chromium (Kα, Kβ)
Manganese (Kα, Kβ)	Iron (Kα, Kβ)	Cobalt (Kα, Kβ)
Nickel (Kα, Kβ)	Copper (Kα, Kβ)	Zinc (Kα, Kβ)

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Table 2. Results of Classification of Test Sets for Each of 36 Drug Packaging Specimens ("1" indicates the classification based on the highest multinomial probability of origin). Green cells indicate correct classification. Red cells indicate incorrect classification.

Sources	P01_C	P02_C	P03_C	P04_C	P05_C	P06_C	P07_C	P09_C	P10_C	P11_C	P15_C	P16_C	P18_C	P19_C	P20_C	P21_C	P22_C	P23_C	P24_C	P25_C	P26_C	P27_C	P28_C	P29_C	P30_C	P31_C	P32_C	P33_C	P34_C	P36_C	P37_C	P38_C	P39_C	P40_C	P41_C	P42_C
P01_C	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P02_C	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P03_C	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P04_C	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P05_C	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P06_C	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P07_C	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P09_C	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P10_C	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P11_C	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P15_C	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P16_C	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P18_C	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P19_C	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P20_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P21_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P22_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P23_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P24_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P25_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P26_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P27_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P28_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
P29_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
P30_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P31_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
P32_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
P33_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
P34_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
P36_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
P37_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
P38_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
P39_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
P40_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
P41_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
P42_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

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Table 3. Results of Classification of Test Sets for Each of 30 Firearm Specimens ("1" indicates the classification based on the highest multinomial probability of origin). Green cells indicate correct classification. Red cells indicate incorrect classification.

Sources	F01_C	F02_C	F03_C	F04_C	F05_C	F06_C	F07_C	F08_C	F09_C	F10_C	F11_C	F12_C	F13_C	F14_C	F15_C	F16_C	F18_C	F19_C	F20_C	F21_C	F22_C	F23_C	F24_C	F25_C	F26_C	F27_C	F28_C	F29_C	F30_C	F31_C
F01_C	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F02_C	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F03_C	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F04_C	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F05_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
F06_C	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F07_C	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F08_C	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F09_C	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F10_C	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F11_C	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F12_C	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F13_C	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F14_C	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F15_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F16_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F18_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
F19_C	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F20_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
F21_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
F22_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
F23_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
F24_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
F25_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
F26_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
F27_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
F28_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
F29_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
F30_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
F31_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

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Table 4. Results of Classification of Test Sets for Each of 31 Cell Phone Specimens ("1" indicates the classification based on the highest multinomial probability of origin). Green cells indicate correct classification. Red cells indicate incorrect classification.

Sources	C01_C	C02_C	C03_C	C04_C	C05_C	C06_C	C07_C	C08_C	C09_C	C10_C	C11_C	C12_C	C13_C	C14_C	C15_C	C16_C	C17_C	C18_C	C21_C	C23_C	C24_C	C25_C	C27_C	C28_C	C29_C	C31_C	C32_C	C33_C	C34_C	C35_C	C36_C
C01_C	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C02_C	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C03_C	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C04_C	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C05_C	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C06_C	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C07_C	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C08_C	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C09_C	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C10_C	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C11_C	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C12_C	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C13_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
C14_C	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C16_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C17_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
C21_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
C23_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
C24_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
C25_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
C27_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
C28_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
C29_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
C31_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
C32_C	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C33_C	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C34_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
C35_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
C36_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

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Table 5. Results of Classification of Test Sets for Each of 32 Ski Mask Specimens ("1" indicates the classification based on the highest multinomial probability of origin). Green cells indicate correct classification. Red cells indicate incorrect classification.

Sources	M01_C	M02_C	M03_C	M04_C	M05_C	M06_C	M07_C	M08_C	M09_C	M10_C	M11_C	M12_C	M13_C	M14_C	M15_C	M16_C	M18_C	M19_C	M20_C	M21_C	M22_C	M23_C	M24_C	M25_C	M26_C	M27_C	M28_C	M29_C	M30_C	M31_C	M32_C	M33_C
M01_C	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M02_C	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M03_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
M04_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
M05_C	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M06_C	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M07_C	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M08_C	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M09_C	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M10_C	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M11_C	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M12_C	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M13_C	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M14_C	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M15_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
M16_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
M18_C	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M19_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M20_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
M21_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
M22_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
M23_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
M24_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
M25_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M26_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
M27_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
M28_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
M29_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
M30_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
M31_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
M32_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
M33_C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

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Table 6. Overall Classification Rates for the Four Evidence Types

	Correctly Classified (Rank 1)	Incorrectly Classified (Rank <5)	Incorrectly Classified (Rank > 20)
Drug Packaging	97% (35)	0.0% (0)	3.0% (1)
Handguns	90% (27)	3.3% (1)	6.7% (2)
Cell Phones	87% (27)	3.2% (1)	6.5% (3)
Ski Masks	53% (17)	15.6% (5)	31.3% (10)

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B. Figures

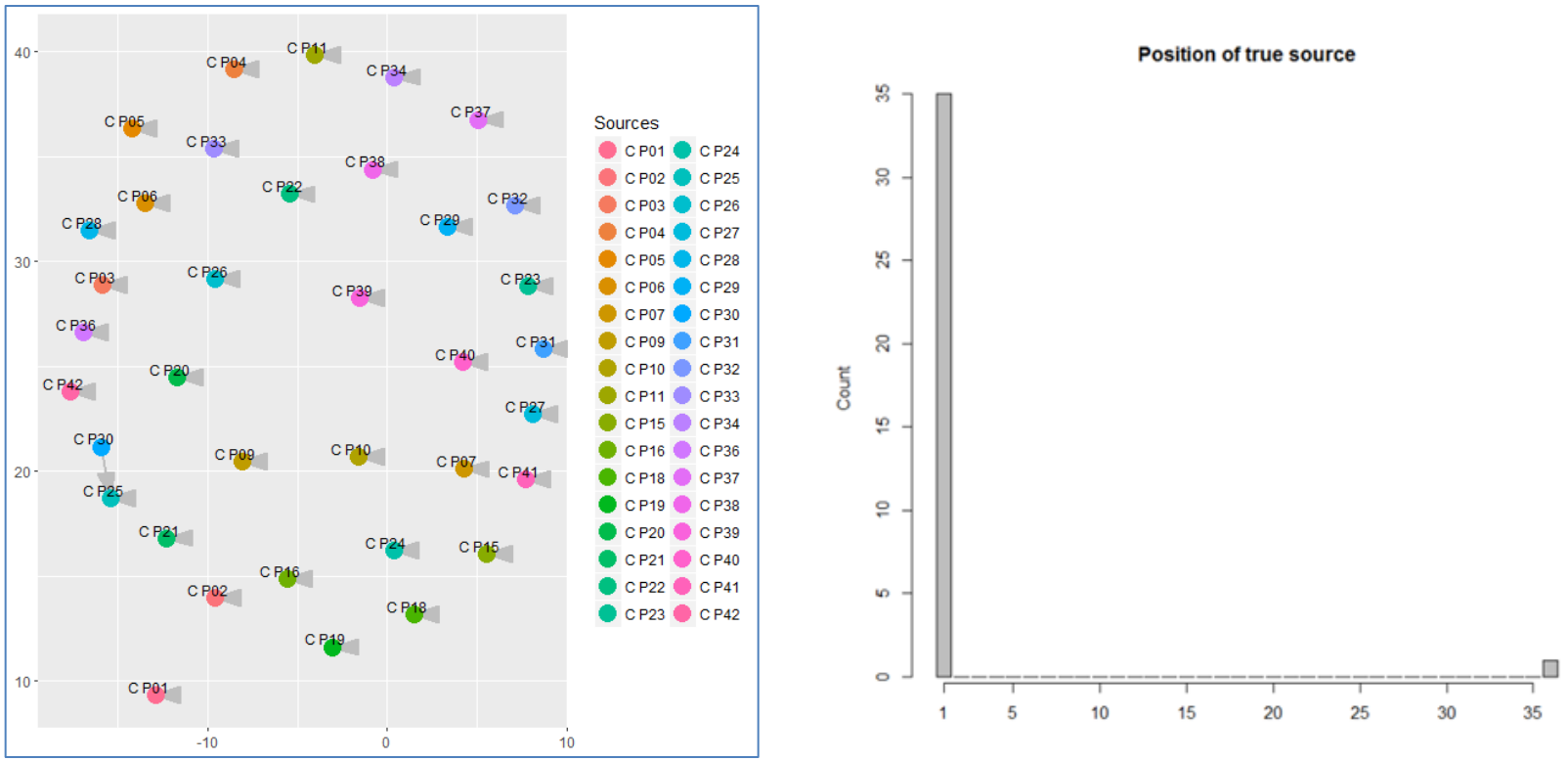

Figure 1. Network diagram (left) illustrating the classification results for training and test sets for drug packaging. Chart of the rank of the true source (right) showing that the single misclassified specimen had the correct source ranked 36th.

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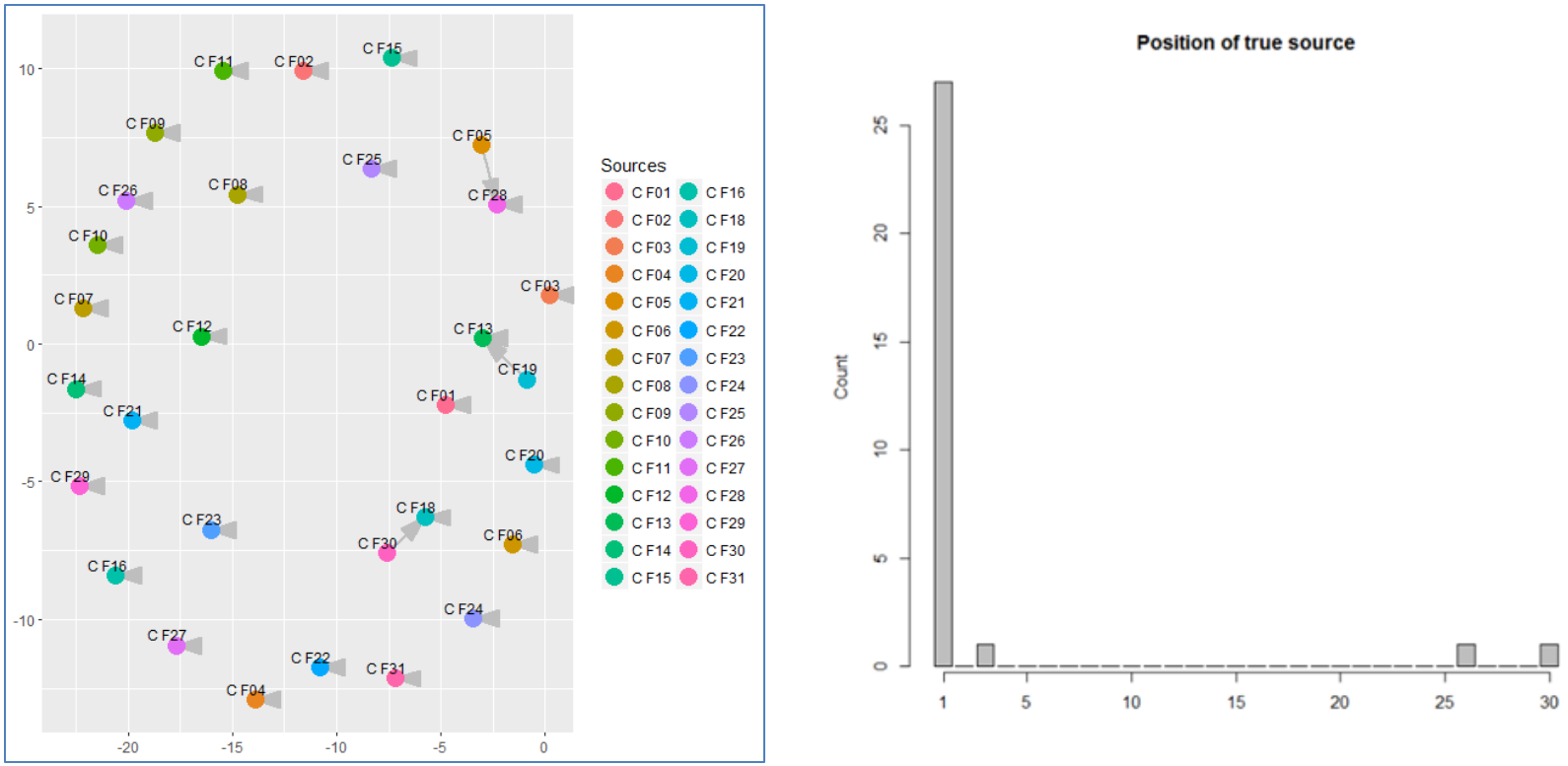

Figure 2. Network diagram (left) illustrating the classification results for training and test sets for handguns. Chart of the rank of the true source (right) showing that one misclassified specimen had the correct source ranked 3rd, and the other two had correct sources ranked 26th and 30th.

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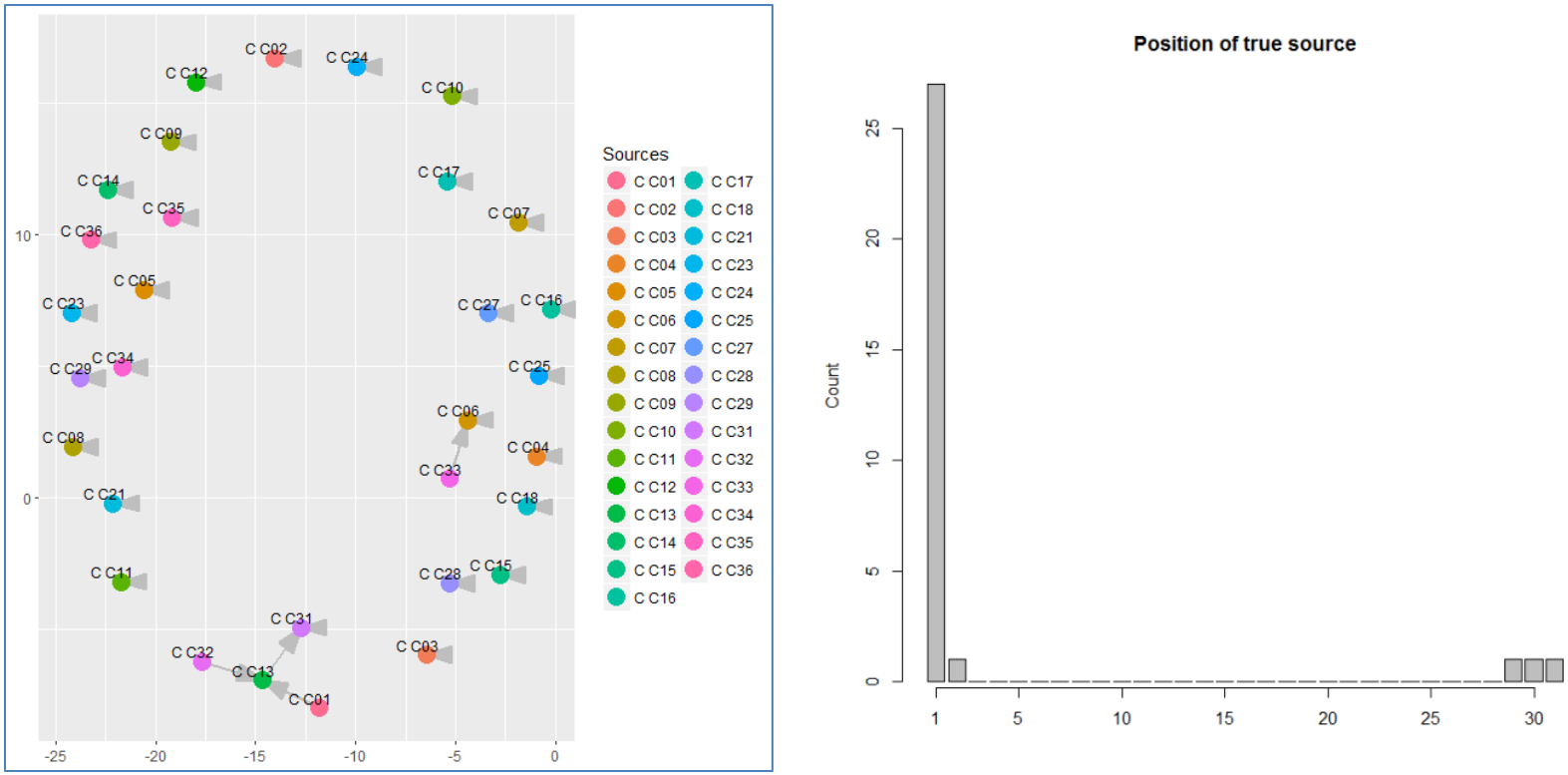

Figure 3. Network diagram (left) illustrating the classification results for training and test sets for cell phones. Chart of the rank of the true source (right) showing that one misclassified specimen had the correct source ranked 2nd, and the other three had correct sources ranked 29th, 30th and 31st.

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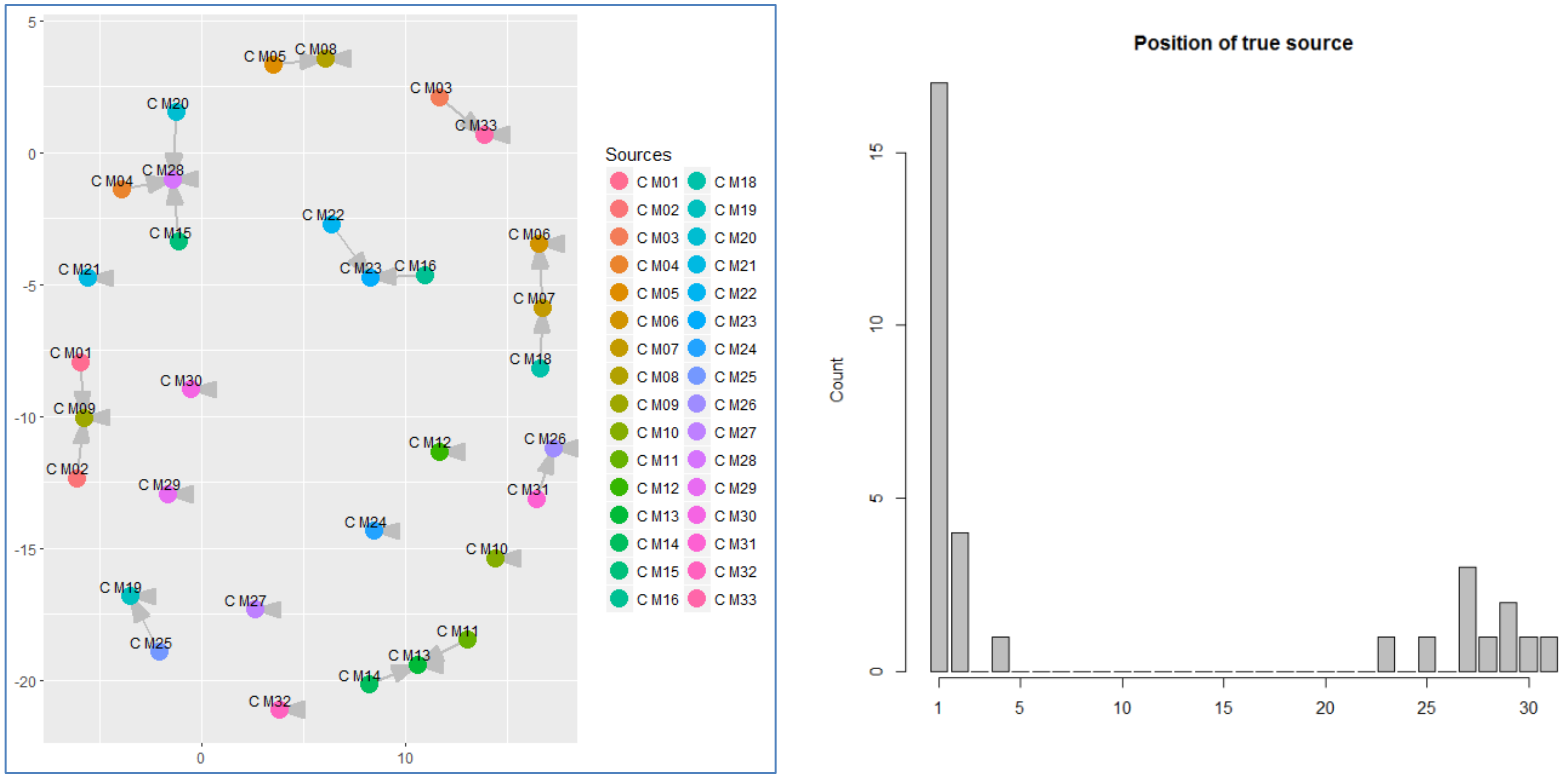

Figure 4. Network diagram (left) illustrating the classification results for training and test sets for ski masks. Chart of the rank of the true source (right) shows that four misclassified specimens had the correct source ranked 2nd, one had the correct source ranked fourth and the other 10 showed ranks greater of 23rd or higher.

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C. References

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