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Contraband tobacco: Systematic profiling of cigarette packs for forensic intelligence

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ABSTRACT

Tobacco smuggling remains a widespread illegal activity in Canada, associated with important social and economic impacts, and often linked to organized crime. This study explores the application of forensic profiling as an intelligence tool to support the analysis of contraband cigarette production and distribution. Physical and chemical manufacturing characteristics of seized contraband cigarette packs, provided by police forces, were observed and coded using macroscopic, microscopic, and spectroscopic techniques. Multivariate statistical analyses were then conducted to compare manufacturing characteristics between packs and identify potential links. The analyses highlighted links between cigarette packs and seizures based on shared manufacturing characteristics. The results and the identified groups were also compared with seizure data provided by our collaborator. The results demonstrate the relevance of forensic profiling to formulate hypotheses regarding shared production processes or supply networks. These hypotheses provide information that contributes to understanding tobacco smuggling and aim to examine how forensic intelligence can support law enforcement and measures to prevent and disrupt this criminal activity. A preliminary optimal procedure for applying forensic profiling in operational contexts targeting contraband tobacco was finally proposed. Despite limitations in the dataset creation that were beyond our control, this study represents a starting point for applying this scientific approach to tobacco smuggling.

1. Introduction

Contraband tobacco refers to tobacco products that do not comply with federal or provincial laws governing their importation, manufacturing, stamping, marking, distribution, or the payment of applicable duties and taxes [1]. This illegal activity remains a complex and persistent criminal phenomenon in Canada, with significant economic and social consequences. Primarily driven by lower prices and tax avoidance, the illicit tobacco market results in substantial tax losses, undermines public health objectives, and fosters organized crime [2,3].

Although tobacco smuggling has been the subject of some research, most studies focus on its history, context, and socio-economic impacts [4–7]. Few studies have adopted an operational perspective aimed at developing tools to directly support law enforcement investigations targeting this criminal phenomenon. Some of them have focused on describing and understanding the shift to online tobacco sales through cryptomarkets in the context of tobacco trafficking [8,9]. Others have applied a forensic approach to the chemical analysis of cigarette filters and papers, without tobacco smuggling being the primary focus of these studies [10–12]. The present study, grounded in forensic intelligence, introduces a forensic profiling approach for contraband cigarette packs, based on a comparative analysis of the physical and chemical characteristics associated with their production. This method is designed to support the analysis and understanding of criminal activities related to the supply of raw materials, the production, and the distribution of contraband cigarette packs, particularly within the context of organized crime.

Using samples from seizures provided by police forces, an exhaustive observation and analysis of the physical and chemical manufacturing characteristics of the packs was conducted to establish their profiles. These characteristics were classified based on their potential source level: raw material supply (i.e., cardboard, aluminum, and plastic),

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packaging, or printing. Multivariate statistical analyses, including Factorial Analysis of Mixed Data (FAMD), were then performed to reduce the number of variables and to assess the similarity between the profiles based on shared or distinct manufacturing characteristics. The statistical results were also compared to seizure data. Through these comparisons, it becomes possible to formulate hypotheses regarding the supply, production, and distribution networks of the contraband cigarette packs analyzed in this study.

Finally, a preliminary optimized forensic profiling procedure is proposed to guide its application in operational contexts. To optimize the procedure, characteristics were classified according to their relevance for forensic profiling and for developing hypotheses on the production process, based on two criteria: selectivity of the characteristic and its temporal stability. This study thus aims to demonstrate the potential of forensic profiling to support forensic intelligence and to guide law enforcement actions, as well as other measures aimed at preventing and disrupting tobacco smuggling and associated criminal networks.

1.1. Forensic intelligence applied to contraband cigarettes packs

Traces, which have been central to many scientific contributions in forensic science, can be defined as remnants or vestiges of a presence and/or an action [13]. Once searched for, detected, recognized, and observed, these traces become a key element in reconstructing an event or activity of interest [14,15]. When exploited within a structured framework, such traces provide valuable information to feed forensic intelligence, helping to better understand the structures and mechanisms associated with criminal activities and informing law enforcement actions as well as broader crime prevention and disruption measure [13–16]. Thus, the trace can be integrated into a data-driven decision-making process, aligning with the model of intelligence-led policing [17]. This enhances the reactive, case-by-case approach with a methodical and proactive forensic approach that can potentially reveal links between seizures and identify patterns and trends in the data [18,19].

In order to be a useful source of information, traces must first be processed and analyzed to establish their profile. This process, known as forensic profiling, involves observing and measuring characteristics that represent a trace of interest [19,20]. These profiles can then be used to compare traces, determining their similarities or differences with other profiles, which can be stored in a database [21]. Ultimately, these comparisons allow for hypotheses to be formulated and communicated to law enforcement agencies to guide future operations [22].

Various studies evaluating the proactive forensic approach have

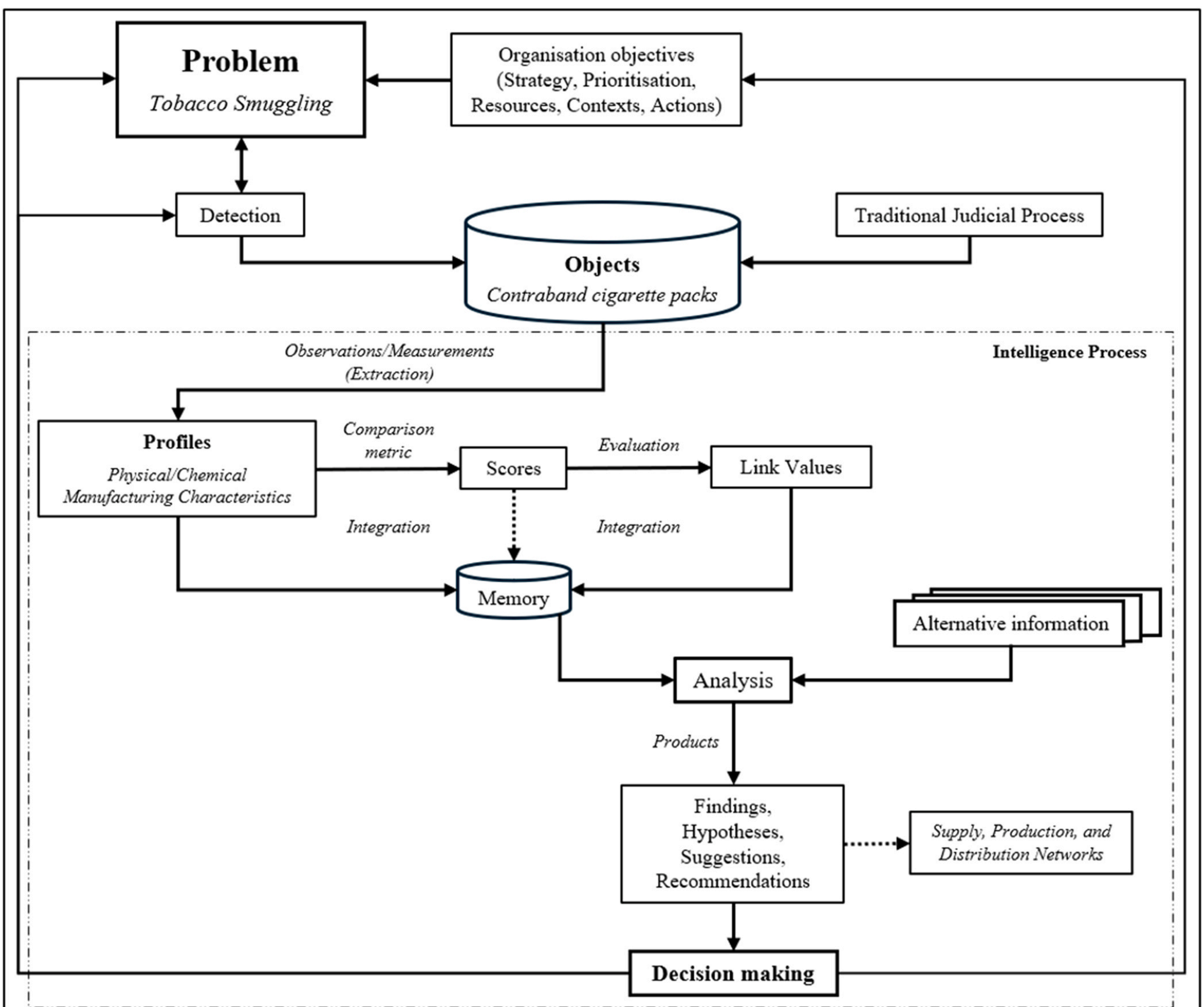


Fig. 1. The forensic intelligence process as presented by Morelato and al. (2014), adapted for tobacco smuggling.

demonstrated that it is possible to structure a general forensic intelligence process, applicable in a similar manner to various types of forensic data [19,23,24]. This process is illustrated in Fig. 1, as presented by Morelato and al. [19] but applied here to tobacco smuggling. Furthermore, forensic profiling for intelligence purposes has been conducted in a few studies so far, targeting different traces of interest. For example, this process has been applied to illicit drugs and counterfeit medicines, aiming to establish links between samples and to identify supply sources and common origins among seizures [22,25–30]. The forensic profiling approach has also been applied to counterfeit identity documents, focusing on physical and chemical characteristics [23,31,32]. Based on these previous studies, the present study seeks to assess the potential of forensic profiling of contraband cigarette packs as a forensic intelligence tool to support investigations into tobacco smuggling, by considering the characteristics and traces resulting from their manufacturing process.

In operational contexts, the value of forensic intelligence relies not only on the relevance of the information produced but also on how quickly it can be applied in practice. The methods used should therefore remain sufficiently simple and accessible to be applied within investigative timelines, while considering constraints related to resources and expertise. Balancing analytical rigour with practical applicability is essential to ensure that forensic intelligence provides meaningful support in real-world law enforcement contexts.

2. Material and methods

2.1. Specimens

In this study, observations and analyses were conducted on a total of 64 contraband cigarette packs, corresponding to 32 different cartons for which two packs were provided each. Due to legal constraints surrounding the handling and transfer of illicit tobacco products, all cigarette packs had to be emptied prior to shipment. After discussion with

Fig. 2. Cigarette packs provided by police forces.

our collaborator, the inclusion of two packs per carton was determined to be the most appropriate and compliant solution under the circumstances. These packs represent various brands and models (Canadian Goose™, Canadian Classics™ [Original, Light™, Ultra Light™], Putter's™, DisCount™, and NexX™) (Fig. 2). Based on their format, the packs were grouped into two distinct sets: one comprising all 20-cigarette packs (square format), and the other including the Canadian Goose™ brand (rectangular format). This distinction was made to simplify observations and analyses. Additionally, each pack consists of four components where manufacturing characteristics were examined: 1) the outer cardboard, 2) the inner cardboard, 3) the aluminum foil packaging, and 4) the plastic wrapping.

2.2. Observations

To establish the profiles of the packs, the physical characteristics of each component were systematically observed, measured, and coded, following a procedure designed to ensure reproducibility of handling for each sample. This process led to a list of multiple characteristics common to the packs. When new characteristics were identified during the observations and had not been noted on previously analyzed packs, those packs were re-examined to confirm the presence or absence of these characteristics. Observations were made with the naked eye, under a stereomicroscope, and using the VSC® 8000/HS foster+freeman® device under various lighting conditions such as white light, coaxial episcopy, and infrared and ultraviolet radiation. Dimensions and other measurements were taken using a standard ruler, and thickness was measured with a digital thickness gauge. Regarding chemical characteristics, the chemical composition of the plastic wrapping was analyzed using Fourier Transform Infrared Spectroscopy (FTIR).

2.3. Classification of characteristics

Although it was not possible to determine the exact manufacturing processes used by illegal factories producing the contraband cigarette packs, knowledge of the legal manufacturing process helped guide the interpretation of observed traces and hypotheses regarding their potential sources. The information gathered supports that the production of a cigarette pack generally involves more than one manufacturer. A distinction can notably be made between the printing process and subsequent production steps. Based on this knowledge and the observations made, characteristics were grouped into three classes, each corresponding to a potential source. The first class is **printing**, including characteristics related to the printing process, design, and ink. The second class is **supply**, including characteristics related to materials used and therefore raw materials. The third class is **packaging**, grouping characteristics that may be associated with the machinery used during pack formation.

2.4. Data processing

Once the physical and chemical characteristics were observed and analyzed, they were compared to assess similarities or differences between the profiles of the cigarette packs. To achieve this, the characteristics were represented as mixed variables (quantitative, qualitative, continuous, or discrete) and analyzed using multivariate statistical methods. Factor Analysis of Mixed Data (FAMD) was selected, as it allows for the simultaneous consideration of variables of different types. By integrating both qualitative and quantitative variables as active elements in a single analysis, this method combines the advantages of Principal Component Analysis (PCA), suitable for quantitative data, with Multiple Correspondence Analysis (MCA), specific to qualitative data [33–36]. This approach makes it possible to assess the proximity between packs based on their shared manufacturing characteristics.

During data processing, a selection of relevant variables was performed to identify the characteristics with the most weight for forensic profiling, based on the results obtained from statistical analyses. Three selection steps were applied sequentially. First, invariant variables, those showing no variation within or between groups of packs, were excluded due to their low discriminating power. Next, variables showing strong imbalance between classes (e.g. 99/1 %, 95/5 %, …) were removed, as they lacked discriminating relevance. Finally, variables displaying intra-variability between the two packs from the same carton were also excluded.

Statistical analyses were performed sequentially on different subsets of the global dataset: 1) all packs and all characteristics together, then 2) separating the two sets, and 3) separating the characteristics by their class (printing, supply, and packaging). More details about the workflow are given in the results Section 3.2.

Group assignment was based on the projection of packs within the primary and supplementary dimensions generated by the FAMD. Packs positioned sufficiently close to each other across all dimensions were considered part of the same group. If separation was observed in supplementary dimensions, the responsible variables were examined to assess the relevance of this separation based on production process hypotheses. Groups were thus established for each analysis (supply/packaging and printing), for both sets of packs, and including all components. The groups obtained were then compared across analyses.

The groups established through statistical analyses highlight cigarette packs that share similar manufacturing processes based on their common characteristics. These groups can then be compared with seizures data. In other words, packs from the same seizure are checked against the groups formed by the statistical analyses. This comparison is conducted for both sets of packs. The results of this comparison enable the formulation of hypotheses regarding the manufacturing processes of the packs.

3. Results and discussion

3.1. Overview of observed characteristics

In total, 240 characteristics were recorded following the observations of the cigarette packs. As previously explained, the characteristics were divided into three classes based on their potential source. A summary of the observed and measured characteristics for each class is presented in Fig. 3. Some of these are illustrated in Fig. 4 with additional explanations provided according to their respective class.

3.1.1. Printing characteristics

The main printing method used for cigarette packs is offset printing. This process involves a system of metal plates, ink rollers, and blankets, arranged in sequence. The plates are engraved with the required patterns and text based on a pre-designed digital model. The desired image is achieved at the end of the process through the transfer of ink between the plates and the cardboard [37,38].

Several factors related to the printing system can generate characteristics relevant for forensic profiling. First, the type of ink affects the chemical properties observed under ultraviolet and infrared radiation (c.f. Fig. 4 – A, B). The model used to create the plates also plays a key role in differentiating printing systems that produce the same brand and model of packs but originate from different printers (c.f. Fig. 4 – C). Maintenance of the plates and rollers directly influences print quality. The presence of impurities in the ink, on the paper, or on the printing surfaces can cause defects that may be more or less reproducible (c.f. Fig. 4 – D). In contrast, characteristics related to plate wear or roller condition remain reproducible as long as the printing system is not replaced. However, the reproducibility of characteristics specific to the rollers and plates also depends on parameters currently unknown, such as the cardboard sheet format, the number of packs printed per sheet, as well as the dimensions of the rollers, plates, and blankets. A final relevant factor concerns the alignment and positioning of the plates and ink rollers. Improper adjustment can cause color misregistration and the

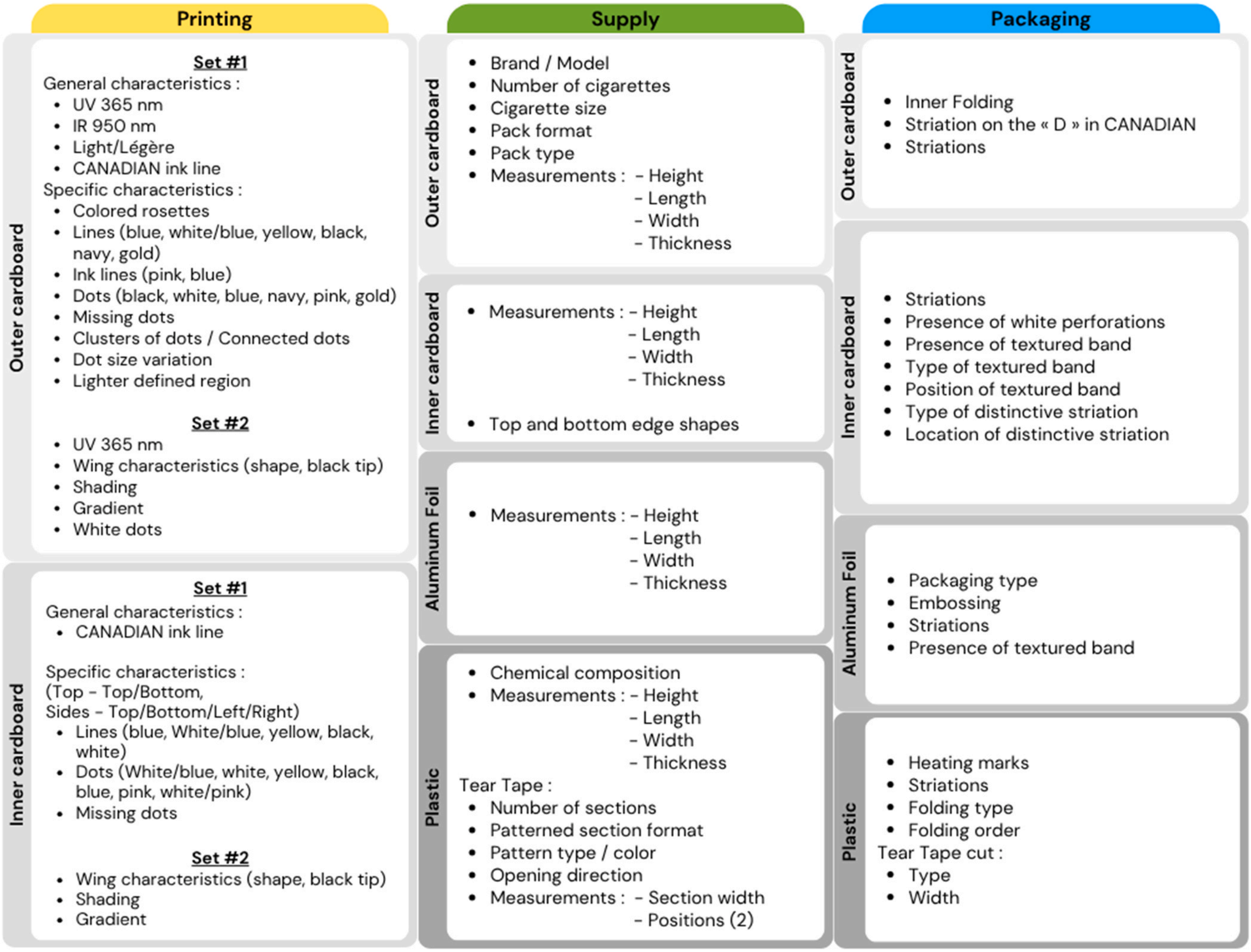


Fig. 3. Summary of component characteristics by class for both cigarette pack sets.

presence of halos, resulting in a blurred printed image [39]. As long as the printing system is not readjusted, the misregistration remains reproducible.

Thus, several factors related to the printing system and print output prove relevant from a forensic profiling perspective, allowing the evaluation of potential links between packs that may have been produced on the same printing system.

3.1.2. *Supply characteristics*

This class includes more general characteristics associated with the raw materials used to manufacture the cigarette packs. These materials are supplied to the manufacturer by one or more providers, typically in the form of reels for most components (aluminum foil, plastic film, tear strips). Once installed on the machines, the reels are cut and folded to form the packaging according to the required format. The thickness and chemical composition of the materials are relevant characteristics for establishing potential links related to the raw materials. For example, significant differences in the thickness of materials between cigarette packs of the same brand and model may suggest different manufacturers, the use of different suppliers, or a change of supplier by the same manufacturer (c.f. Fig. 4 – E). For plastic wrapping, tear strips are also supplied separately, in reels distinct from the plastic film. The various patterns or designs of these tear strips are also relevant for establishing links related to raw materials and supply chains (c.f. Fig. 4 – F).

Finally, the measurements of the components are also considered, although they are generally standardized according to the pack format and the number of cigarettes it contains, which limits their discriminating power from a forensic profiling perspective (c.f. Fig. 4 – G).

3.1.3. *Packaging characteristics*

The manufacturing of cigarette packs involves a rapid sequence of automated steps carried out by various mechanisms and machines. Each stage of the process can leave traces or characteristics on the packs, whether through the folding and handling mechanisms or their movement through gear and roller systems. The adjustment of these mechanisms and the parameters programmed into the machine by the manufacturer also influence certain characteristics of the cigarette packs, such as the shape of the cuts or the folding sequence of the different components (c.f. Fig. 4 – H, I). Additionally, certain manufacturing steps can generate distinctive striations, such as those observed on the inner cardboard (c.f. Fig. 4 – J). When these traces are reproducible, their presence on multiple packs may suggest production on the same machine.

The embossing pattern on the aluminum foil is another characteristic specific to the manufacturer (c.f. Fig. 4 – K). Typically, the embossing roller remains the same within the machine, unless it reaches the end of its useful life due to wear, which can take several years. Therefore, the embossing pattern is a relevant characteristic from a forensic profiling perspective.

Thus, packaging-related characteristics are particularly relevant, as they result directly from the operation and settings of the machine used, establishing a direct link between the cigarette packs, their

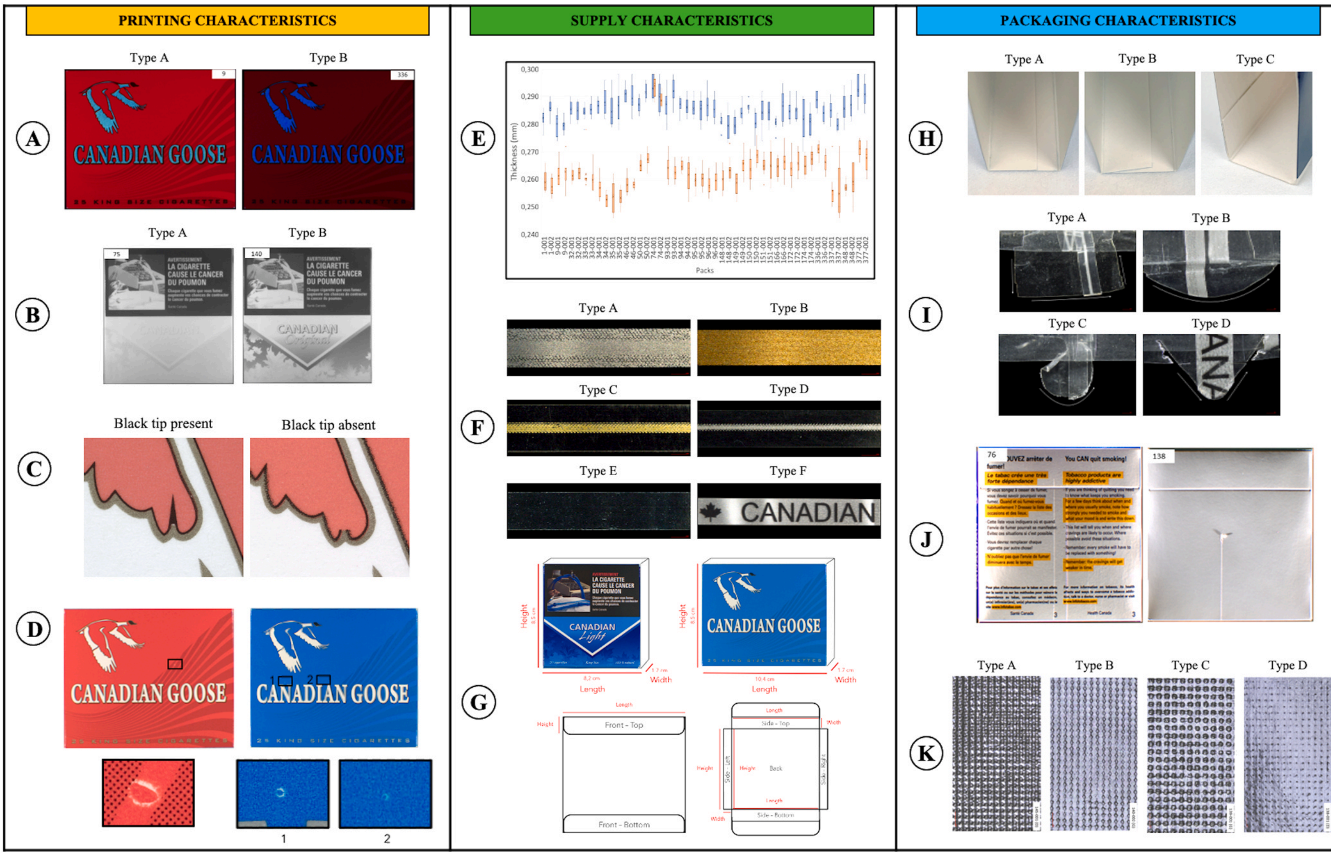


Fig. 4. Examples of characteristics observed and analyzed. (A - Reactions under UV light: grayish appearance (Type A) vs. blue appearance (Type B), suggesting different inks used in the printing process; B – Reactions under IR light. Varying degrees of response, also suggesting different inks used in the printing process; C – Differences in printing patterns of Canadian Goose™ packs: one model shows a black tip on the wing, the other does not, suggesting the use of different printing plates (different manufacturers?); D – Examples of printing defects caused by the printing system; E – Example of a cardboard thickness measurement graph. Thickness was measured for each component (cardboard, aluminium foil, plastic). Measurements are displayed as boxplots. The X-axis represents individual packs, and the Y-axis shows thickness (0,240 – 0,300 mm). Blue corresponds to the outer carton of Canadian Goose™ packs; orange corresponds to the inner carton; F – Examples of different tear tape patterns observed; G – Examples of material dimension measurements; H – Differences in outer cardboard folding: Types A and B observed in Set #1, Type C in Set #2; I – Examples of different tear tape cuts observed. The pull tab used to open the plastic wrapping has various shapes, which are determined by the manufacturer; J – Example of packs showing distinctive striations. Two examples observed are shown (left: two long striations; right: a single distinctive striation). These striations are produced during the manufacturing process; K – Examples of aluminum foil embossing. Four types observed are presented. The embossing pattern is applied during production and is determined by the manufacturer).

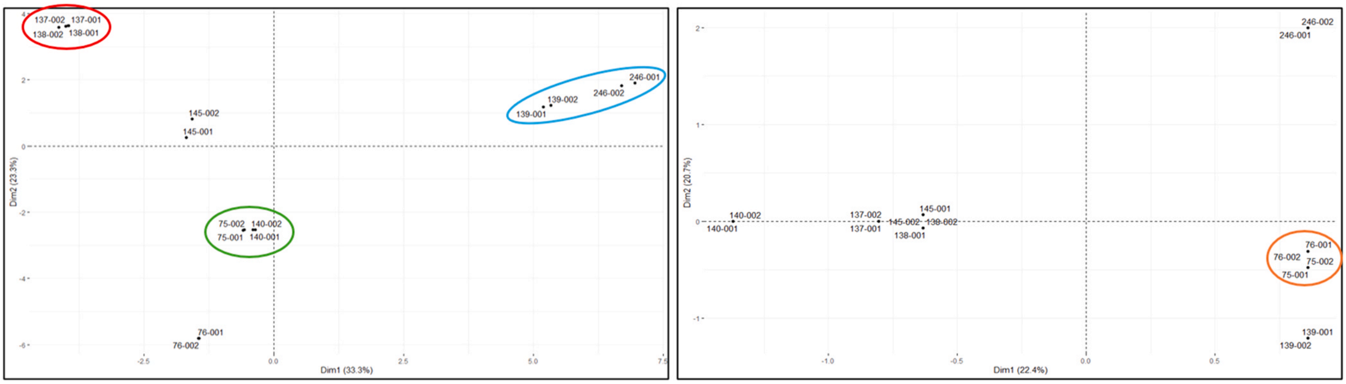
manufacturing process, and potentially the manufacturer.

3.2. Analyses of relevant variables

A first analysis was performed using the complete dataset, including both groups of packs and all characteristics from the three classes (supply, packaging, printing). The FAMD outputs are graphical projections of the samples within two latent dimensions and, similarly to PCA, permits to visualize the variables with the most influence on the separation, that are accurately representing the variability within the dataset. The selection of relevant variables for subsequent analyses was based on both statistical results from the FAMD and the observations made during data collection and analysis. The three previously described selection steps were applied. During the analyses, it became clear that removing variables causing intra-variability between the two packs of the same carton was particularly important. Indeed, this selection reflects the main limitation encountered in the study, that is, the limited number of packs available to evaluate intra-variability. As noted previously, the number of packs was limited due to legal constraints on the transfer of illicit products. With only two packs representing each carton, it was difficult to fully assess the intra-variability within cartons. Therefore, when a difference was observed between the two packs from the same carton, creating separation in the analyses, the concerned variable was excluded to limit the impact of unmeasurable variability. Finally, after the selection process, the total number of variables was reduced from 240 to 45 characteristics.

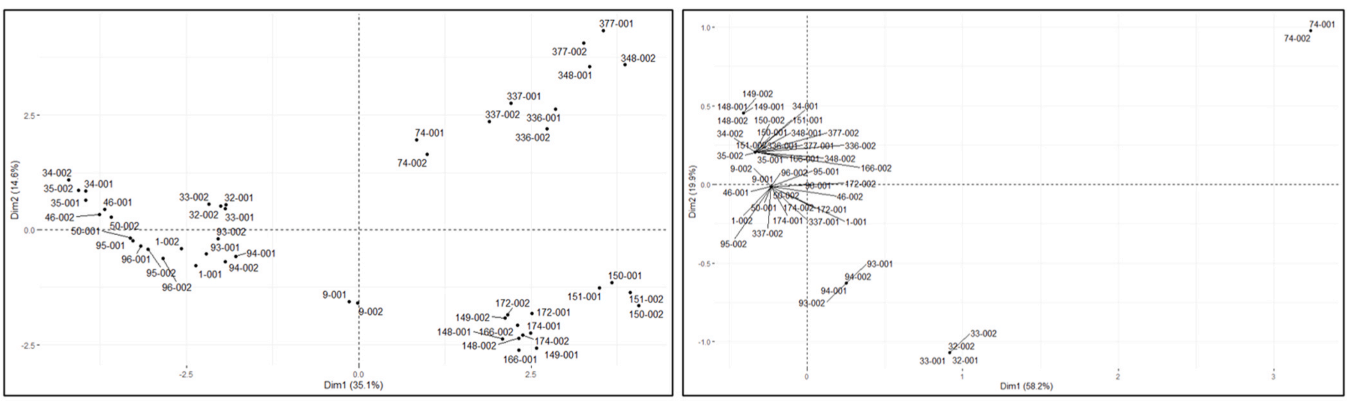
The two sets of packs were then analyzed separately, and characteristics related to supply and packaging were combined into one analysis, while printing-related characteristics were analyzed separately. This decision was made to avoid potential bias from design-related characteristics influencing separation caused by other manufacturing factors and would therefore permit to highlight similarities between packs independently of their brand and model, based solely on their production traces. The FAMD results illustrating the projection of packs within the primary dimensions are presented in Fig. 5 and Fig. 6.

For Set 1, the analysis of supply and packaging characteristics identified a single distinct group of packs sharing the same manufacturing characteristics, which is circled in green in Fig. 5. Interestingly, this group included packs from different models (Canadian Light/Original). Although other packs shared most of their characteristics, they were not grouped due to differences in characteristics with greater weight in the separation process. For example, packs 137 and 138 in Fig. 5 (red) initially appeared to form a group but were later separated due to a difference in the tear tape pattern. While this difference does not demonstrate in itself that the packs have (or have not) a different origin, it allows for the formulation of hypotheses (e.g.,



A B

Fig. 5. Projection of Packs from Set #1 by FAMD Based on Relevant Variables from (A) the Supply and Packaging Classes (B) the Printing Class. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).



A B

Fig. 6. Projection of Packs from Set #2 by FAMD Based on Relevant Variables from (A) the Supply and Packaging Classes (B) the Printing Class.

different supply sources, suppliers, or manufacturers) that, combined with standard investigation processes, will help the investigation move further. Packs 139 and 249 (blue) also shared several characteristics, however, differences in characteristics directly related to the machine, such as the embossing and the textured bands pressed into the cardboard, resulted in their separation.

For the printing class, although the FAMD projection appears to show proximity and similarities between certain packs, all packs were ultimately separated in the supplementary dimensions, as none shared all the same printing characteristics. The variables contributing to the clustering of packs in the principal dimensions were still reviewed to assess their relevance. For example, packs 75 and 76 share several characteristics but diverge in the supplementary dimensions due to differences in ink lines, ink reactions under UV light, and whether the model was translated.

For the FAMD results of Set 1, the difference between the groups obtained from the two analyses suggests that the packs grouped by raw materials and packaging (packs 75 and 140) did not follow the same printing process, possibly due to a change in procedure or the use of different printing systems.

For Set 2, the analysis of supply and packaging characteristics resulted in eight distinct groups, some of which included both red and blue pack models, demonstrating that even though they are from different models, they share common production traces. The discriminating characteristics responsible for the differentiation of pack groups include embossing of the aluminum foil, tear tape pattern, distinctive striations and folding. The analysis of printing characteristics identified five groups. The group separation in this analysis is primarily based on shading, print template and UV ink reaction. Comparing the results of both analyses, two groups comprising packs from different cartons remained in close proximity, suggesting a shared production line. Additionally, some groups demonstrating particular printing characteristics included packs from cartons that were separated by the supply and packaging analysis, indicating similar printing processes followed by distinct production phases. Certain packs that were not grouped in the supply and packaging analysis were grouped with others based on their printing characteristics. Only the packs from one specific carton remained isolated in both analyses, showing no links to other packs.

The groups identified through the FAMD analyses are presented in Fig. 7. The diagram illustrates the connections between the different cartons of cigarette packs, whether from Set #1 (blue) or Set #2 (grey). It also highlights the packs that were not grouped, either based on the analysis of supply and packaging characteristics, the printing analysis, or both.

By considering the three classes of characteristics, printing, supply, and packaging, multiple links can be inferred among the analyzed cigarette packs. This framework allows for the formulation of various hypotheses (Fig. 8). For instance, hypothesis 1 addresses two packs sharing common characteristics across all three classes. Hypothesis 8 represents the opposite case, in which two packs share no common characteristics in any of the three classes. All intermediate scenarios, where one or two blocks show overlapping characteristics between the packs, are visually illustrated in hypotheses 2–7.

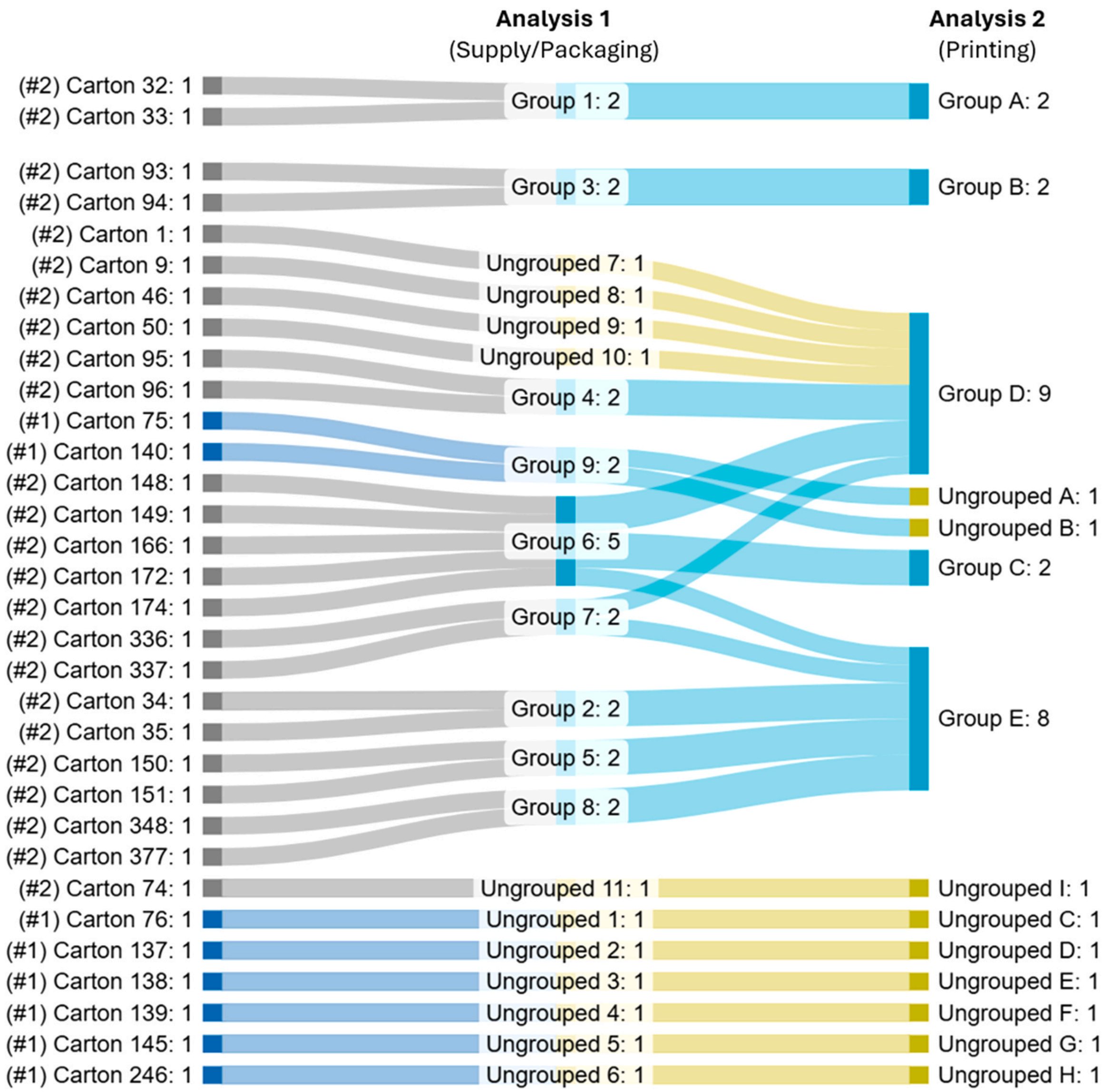


Fig. 7. Groups identified through FAMD analyses for all packs. Graph created by Sankeymatic.com. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

3.3. Comparison with seizure data

The statistical analysis results highlighted packs that share or differ in their manufacturing characteristics. These results and the identified groups were later compared with seizure data provided by police forces. It is important to note that these data were obtained and used only within this part of the project. This comparison aimed to assess potential correspondences between the groups obtained through forensic profiling and the operational seizure contexts, thus supporting the formulation of hypotheses regarding the manufacturing of the seized cigarette packs. It is important to recall that the exact manufacturing processes used by illicit manufacturers are unknown. They may vary from one manufacturer to another, possibly involving different processes and machinery than those used in the legal market. Nevertheless, the hypotheses were formulated based on our knowledge of legal cigarette production.

For this task, no other information was available except that they were eventually seized at the same time and location. It is important to note that seizure data does not provide information on the production conditions. The fact that certain packs were seized together does not necessarily mean they originate from the same manufacturer. An individual subjected to a seizure may have sourced products from different locations or manufacturers. Furthermore, the precise circumstances of the seizures (such as location or context) are unknown.

Although the exact origin of the packs, whether they come from the same manufacturer or not, remain unknown, the comparison process still provides additional intelligence related to contraband cigarette packs. No links can be confirmed, but the comparison enables the development of various hypotheses or the corroboration of existing investigative hypotheses. This demonstrates how forensic intelligence can complement operational information and help prioritize law enforcement resources.

The examples presented below illustrate some of the results obtained from the analyses and the hypotheses derived from them. It is important to note that these examples and explanations reflect selected cases and do not represent an exhaustive overview.

Example 1. Packs seized together share identical manufacturing characteristics, suggesting they were likely produced and distributed as part of the same batch.

A seizure carried out in August 2015 included four Canadian Goose™ cartons: two red (32, 33) and two blue (34, 35). Analyses of supply,

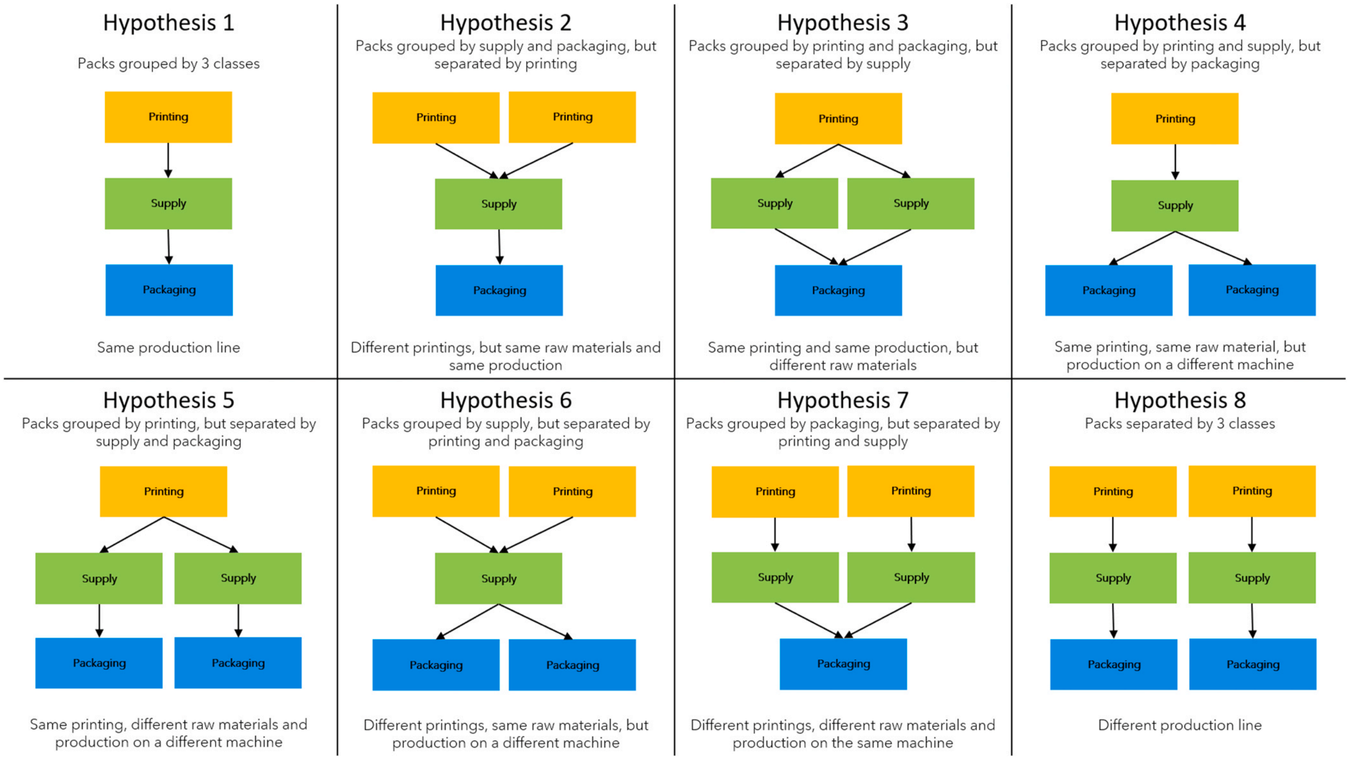


Fig. 8. Potential Hypotheses Depending on Whether Packs Are Grouped Based on Manufacturing Characteristics in the Three Classes.

packaging, and printing characteristics indicated that cartons of the same model likely followed a common production chain and were distributed together. However, differences observed between the red and blue cartons suggest that they originated from distinct production chains and were subsequently brought together, either at the point of purchase or during distribution.

Example 2. Some groups include packs from different seizures, supporting hypotheses of potential links between production networks or a shared origin, such as the same manufacturer.

The results of the three-class analyses, for example, grouped together Canadian Goose™ packs from carton 172 (blue model) and carton 174 (red model). These two cartons were not seized together: carton 172 was seized in July 2017, whereas carton 174 was seized in September 2017. The hypothesis of a common production chain or the same manufacturer can be raised, not only due to the shared characteristics but also given the relatively short time interval.

Example 3. Certain individually seized packs do not cluster with others, suggesting they originate from a distinct production line, possibly linked to a different manufacturer.

Carton 74 (Canadian Goose™, red model) was seized individually in May 2014 and represents the oldest seizure among the data. Analyses indicated that this carton had supply, packaging, and printing characteristics clearly distinct from those of other cartons. Consequently, carton 74 was not grouped with any other carton, suggesting that it may have followed a different production chain. The time interval between this seizure and others, which occurred between 2015 and 2018, also allows for hypotheses regarding the evolution of a production chain within the same manufacturer.

It should be emphasized that the data analysed in this study were obtained under specific constraints, as mentioned previously. Coupled with the inherently exploratory nature of forensic intelligence analysis, in which hypotheses are openly inferred for investigative purposes instead of strictly proposed for evaluation, the strength of associations is to be assessed with other investigative links outside the province of the forensic scientist. Indeed, the findings should be interpreted within a forensic intelligence framework, as informative hypotheses intended to guide investigative reasoning.

3.4. Forensic intelligence procedure

Based on the results obtained, it is relevant to propose an optimized procedure (Fig. 10) for applying forensic profiling methods in operational contexts, along with recommendations for structured management of observed characteristics.

The optimized procedure begins with the systematic observation of cigarette packs, documenting all relevant characteristics across the three classes (supply, packaging, and printing). A selection of the most relevant variables for forensic profiling must then be performed. To guide this selection, two key factors were established to determine the characteristics with the most weight for inferring potential links in production: **selectivity** and **temporal stability**. **Selectivity** refers to the rarity and prevalence of a characteristics within the dataset: the rarer it is, the more likely it is associated with a limited number of packs. **Temporal stability** refers to the expected reproducibility of a characteristic based on its source. A characteristic linked to materials or machine components that are rarely replaced has higher discriminating power than one associated with frequently replaced elements. Thus, a characteristic that is both highly selective and stable over time carries greater weight in supporting a hypothesis of similar production, or even common machinery when the characteristic is directly dependent on the machine itself. Conversely, a common and unstable characteristic has less weight.

This classification was applied to the characteristics observed in this project. It is based on current knowledge of manufacturing processes and considers the relevance of each characteristic, its known source, diversity, the component on which it appears, and its class (supply, packaging, printing). Fig. 9 and 10 presents the so-called general characteristics, selected for their ease of coding in a database and their discriminating potential, as identified during the selection process. The term "general" refers to characteristics that may be common across

Class	Characteristic	Selectivity	Stability
Printing	UV Reaction (365 nm)	+ +	+ +
Printing	IR Reaction (950 nm)	+ +	+ +
Printing	Ink Misalignment (CMYK)	+	+ +
Supply	Pack Format (OC)	+	+ + +
Supply	Thickness Measurements (OC / IC / AF / PL)	+	+ +
Supply	Tear Tape Type (PL) (Number of Sections, Format of the Colored Section, Pattern, Color)	+ +	+ +
Packaging	Inner Folding (OC)	+	+ + +
Packaging	Unconfirmed Characteristics (IC) (Indented marks, textured pattern (type/position), distinctive striae (type/position))	+ + +	?
Packaging	Packaging Type (AF)	+	+ + +
Packaging	Embossing Type (AF)	+ +	+ + +
Packaging	Folding Type / Order (PL)	+	+ + +
Packaging	Type of Tear Tape Cut (PL)	+ +	+ + +

OC : Outer Cardboard IC : Inner Cardboard AF : Aluminum Foil PL : Plastic

Fig. 9. Selectivity and stability of relevant characteristics.

multiple models.

In Fig. 9, selectivity and temporal stability are represented using one to three plus signs (+):

- (+) indicates a frequent and unstable characteristic,
- (++) indicates an intermediate level,
- (+++) indicates a rare and highly stable characteristic.

Characteristics related to the inner cardboard could not be assessed for stability due to uncertainty regarding their source. However, they were retained for their high discriminating potential, as they are directly linked to production machinery and may indicate a common origin if their source is identified.

Once relevant variables are selected, the optimized procedure continues with statistical analysis of the database, considering only general characteristics. By limiting the analysis to these characteristics, it is possible to analyze all three classes (supply, packaging, and printing) without introducing bias linked to brand, model, or design elements. This step enables the grouping of both new and existing packs within the database. The position of new packs within the FAMD dimensions determines their similarity or distinctiveness compared to existing groups, allowing verification of shared manufacturing characteristics.

After a first analysis of the relevant characteristics using statistical tools that aims to identify the packs most similar to the unknown, a more specific detail-level comparison can be realized with the packs located near the studied sample in the FAMD projection. Since detail characteristics are associated with design elements or are specific to a brand or a model (e.g., printing defects, differences in print layout, or other distinctive features), the packs are analysed sequentially to identify the characteristics relevant to the cluster being examined. These characteristics cannot be integrated into the first analysis due to their complexity and variability. In fact, they are tied to brand, model, or design, which would introduce bias into the statistical analyses and lead to comparisons of non-equivalent elements.[1] For this reason, detail characteristics must be analysed on the real physical packs whenever available (rather than virtual profiles) and compared manually, following the ACE-V methodology (Analysis, Comparison, Evaluation, and Verification), after the statistical analysis. These characteristics have higher selectivity and greater potential for discrimination than general characteristics. This manual step provides a secondary validation of the groups established through general characteristics, either reinforcing or questioning the observed links.

On average, the complete observation of general characteristics following this optimized procedure requires approximately 30 min per

[1] For example, the presence or absence of the black tip on the goose's wing in the design of Canadian Goose™ cigarette packs cannot be compared to those of the Putter's™ or NexX™ brands, since the designs are entirely different. In fact, considering this absence as a shared characteristic between Putter's™ or NexX™ packs would artificially create an unjustified link.

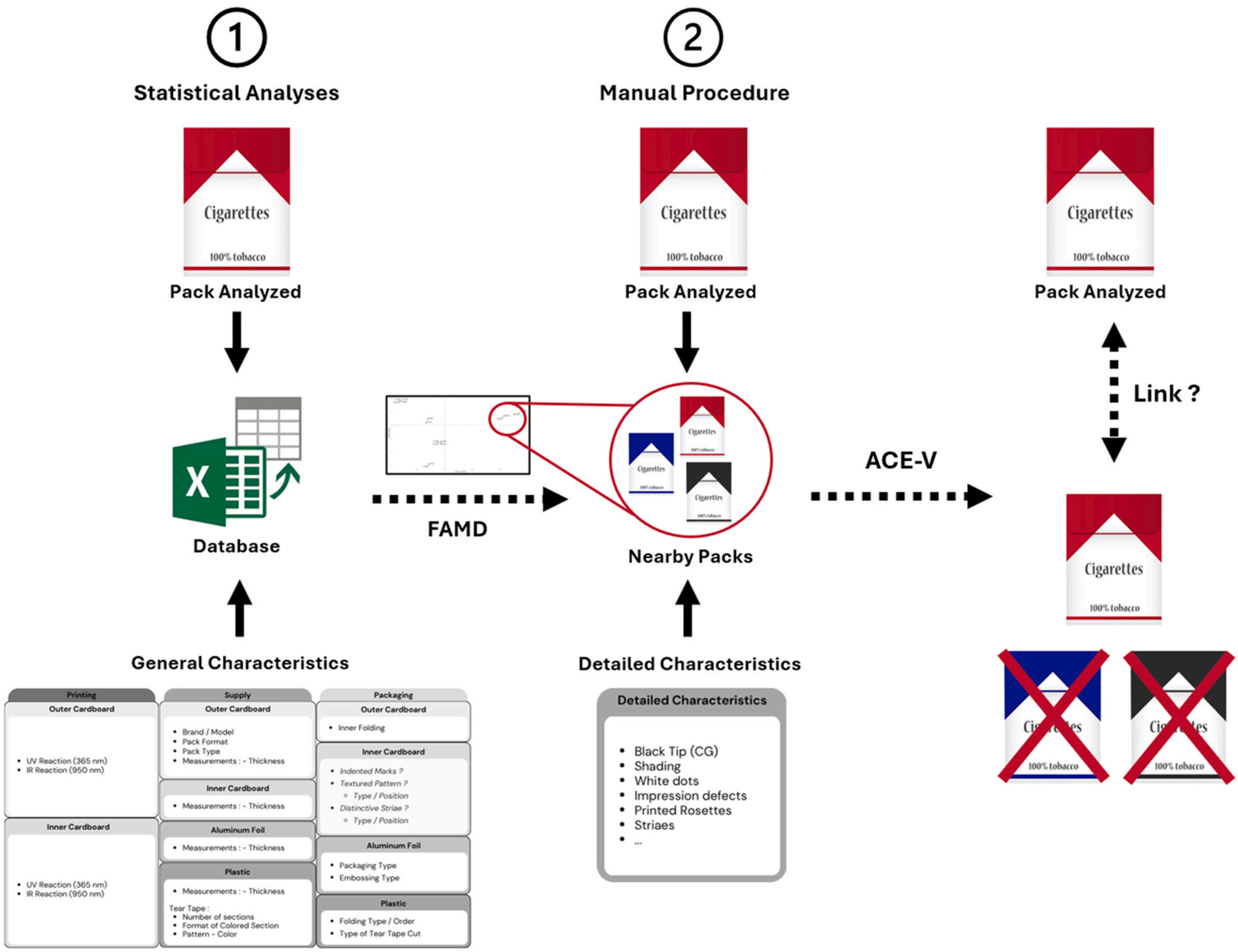


Fig. 10. Overview of the Proposed Optimal Procedure.

pack, with rapid database coding. The analysis of detailed characteristics takes longer, particularly for packs from previously unstudied brands or models, as relevant characteristics must first be defined.

This proposed procedure represents an early stage in the development of a structured operational procedure and will require further verification in the future, through the collaborations in place, to assess both the strength of the links and the operational benefits. Nevertheless, the following case example, inspired by data and first exchanges with our collaborator, illustrates the potential of the proposed procedure and its practical outcomes in a real investigation. During an investigation, two separate seizures of cigarette packs suspected of being contraband were carried out a few weeks apart: the first (Seizure A) consisted of 10 cartons of the brand Canadian Light™ intercepted in a vehicle during a routine operation, and the second (Seizure B) included 14 cartons of the same brand seized from the residence of an individual suspected of drug trafficking. A sampling procedure was conducted, with two packs per carton selected for analysis. After a complete observation and coding of the general characteristics of the packs according to the three classes (supply, packaging, and printing), the data were integrated into the existing database and projected into the factorial space of the FAMD. The results showed that the packs from Seizure B clustered with those from Seizure A, suggesting a potential manufacturing link between the two lots. Interestingly, this cluster also showed proximity to another group already present in the database, consisting of packs seized the previous year in the same region. A manual comparison of detailed characteristics using the ACE-V method was then performed on the packs, which revealed several common elements, particularly in the carton printing (e.g., a recurring defect under the logo, identical distinctive features related to the model, etc.). These concordances, observed both between Seizures A and B and with the pre-existing group, strengthened the hypothesis of a shared production line or a common illicit manufacturer. When these results were combined with investigative information, investigators were able to link individuals and gain a better understanding of the criminal tobacco smuggling network in which they were operating.

By identifying possible production links between geographically and temporally distinct seizures, this method enables law enforcement agencies to group seemingly isolated events, to more effectively direct investigative resources toward priority targets, and to better understand the structure of criminal networks. Furthermore, highlighting similarities between seizures and groups already recorded in the database can help anticipate distribution routes, prevent the establishment of new points of sale, and support the strategic planning of dismantling operations.

In this way, the structured procedure provides a rigorous and adaptable framework for applying forensic profiling in investigative contexts, maximizing the discriminating potential of observed characteristics of contraband cigarette packs to establish production-level links. Thus, the information generated through this forensic approach becomes a valuable decision-support tool to disrupt tobacco smuggling.

4. Conclusion

This project presents a forensic profiling approach applied to contraband cigarette packs, rooted in forensic intelligence principles. By recognizing that the manufacturing process of cigarette packs reflects specific production methods, and potentially identifies the manufacturer, the comparative analysis of material traces, raw materials, printing processes, and packaging characteristics emerges as a promising tool for establishing links between seizures. These links provide information regarding the networks involved in raw material supply, production, and distribution of tobacco smuggling, through the understanding of traces produces throughout these steps. This preliminary study further examines how forensic profiling can aid law enforcement and support measures to prevent and disrupt such illicit activities.

The study first enabled a systematic observation of the manufacturing characteristics of seized contraband cigarette packs provided. Observed characteristics were classified based on their association with raw materials (i.e., cardboard, aluminum, plastic), packaging processes, or printing processes. A data processing and selection process was then applied to reduce the number of variables, retaining only those with the greatest weight for comparing and evaluating variability in pack characteristics. Several multivariate statistical analyses were performed, allowing for the grouping of certain packs based on their manufacturing similarities and the development of hypotheses regarding production chains. Finally, comparing these groups with seizure data enabled exploration of possible links between packs seized together or separately. Based on these results, several production process hypotheses were formulated. These hypotheses are based on our knowledge of legal cigarette manufacturing process, which can be updated through new information acquired on this illicit market (e.g., dismantling of a lab, seizure of a printer, etc.).

The observations, analyses, and hypotheses developed within this project represent an advancement in understanding the networks involved in tobacco smuggling. The systematic approach developed, and the hypotheses formulated provides avenues for investigating the illegal production chain. This study represents a first step in applying a scientific approach to tobacco smuggling, but it requires further expansion. To address the main limitation, the restricted number of samples, the project will continue with the integration of additional packs through new national collaborations. The analysis of complete cartons will notably enhance the assessment of characteristic reproducibility, as well as inter- and intra-variability.

Additionally, new avenues will be explored, including chemical analyses of tobacco and the development of a database coupled with semi-automated statistical tools, enabling practitioners to systematically compare seized packs and quickly identify similarities. These tools could strengthen investigative capabilities while serving as a relevant resource in judicial contexts.

CRediT authorship contribution statement

Laurie Caron: Writing – original draft, Visualization, Software, Methodology, Formal analysis, Conceptualization. **Frank Crispino:** Writing – review & editing, Project administration, Conceptualization. **Cyril Muehlethaler:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of Competing Interest

There are no conflicts of interest to declare from the authors.

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