



REVIEW OF FORENSIC METHODS FOR COLLECTION AND ANALYSIS OF TYRE AND FOOTPRINT IMPRESSIONS AT EVENT SCENES

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ABSTRACT

Tyre and footprint evidence linking vehicles, persons and event scenes can be important, but their significance relies on systematic recovery and interpretation. The present review gathered research on tyre and footprint evidence collection, recovery, analysis using a structured search of literature and systematic comparison of information on methods and outcome measures. The review addressed the need for systematic recovery, analysis accuracy and evidential reliability. Findings indicated photography, measurement, casting and Structure from Motion allow feature preservation, and digital applications contribute to feature recognition and classification. Limitations exist in impression quality, examiner judgement, and error and random match rates. The review identified methods ideally suited to integrated, validated applications and recommends standardised recovery, better validation, and expansion into relevant African research.

Keywords: Casting, Impression, Photography, Recovery, Structure from Motion

Introduction

Tyre and footprint tracks are significant forms of impression evidence that may be recovered from the scene of an event in which movement of persons or vehicles has resulted in impressions being left on a surface. Footprint evidence can consist of class characteristics related to footwear manufacture, size, tread pattern and design, as well as any randomly acquired characteristics associated with wear and damage. Similarly, tyre impressions are useful for reflecting design features such as tread pattern, tyre size and dimensions, as well as other random features. Impression evidence continues to be significant to forensic examinations, and contemporary research continues to consider the recovery, comparison, interpretation and scientific evaluation of footwear marks and tyre impressions (Charron et al., 2023). Recoveries of impression evidence have been shown to benefit from the use of digital and three-dimensional approaches (Larsen et al., 2021; Venkatasubramanian et al., 2021).

Importance of Track Evidence in Forensic Investigation

The forensic significance of tyre and footprint impressions is primarily related to movement, association and the potential connection between individuals, footwear, vehicles and the scene of events. A good quality footprint impression can contribute to the construction of information regarding the footwear type and comparison of questioned impressions to a known footwear, while tyre impressions may contribute to the construction of knowledge on whether a given vehicle could have been present at a scene. Footwear evidence has also been linked to case outcomes. Wuullenweber et al. (2021), for example, in a study of 445 police recorded cases,



found a positive correlation between footwear evidence and the subsequent charging of suspects in volume crime cases relevant to forensic footwear work. Recent findings have provided increased evidence to underpin tyre examination. Richetelli et al. (2024), for instance, found that the evidence provided by tyre impressions could help to connect vehicles to scene or secondary locations and contribute to the construction of the chain of events.

Statement of the Problem

Although tyre and footprint evidence can be a valuable investigative tool, it poses forensic challenges in the way it is recovered, analysed and interpreted. The quality of an impression is influenced by the type of substrate and environmental conditions, movement of the vehicle or person, surface contamination and disturbance of the scene. Interpretation of the impression can be affected by the quality of the impression and the subjective judgement of the examiner. Austin-Hicklin et al. (2022) discovered that in some comparisons some footwear examiners failed to reach accurate conclusions and that differences in decision making when considering if an impression is suitable for comparison varied significantly. Richetelli et al. (2024) found that decisions regarding tyre examination should be empirically tested for accuracy and consistency. These issues suggest that a current analysis of the methods used to recover and examine tyre and footprint impressions and the probative value that can be assigned to their conclusions is significantly relevant and important.

Aim and Objectives

The aim of this review is to examine forensic methods for the collection and analysis of tyre and footprint tracks in event scenes. Specifically, the review:

- i. examines the nature and forensic importance of tyre and footprint track evidence;
- ii. evaluates methods used for the collection and preservation of such evidence;
- iii. reviews the principal approaches used in their forensic analysis and comparison; and
- iv. assesses the reliability, limitations and evidential significance of findings obtained from tyre and footprint track examinations.

Conceptual Overview

Tyre Track Evidence

Tyre track evidence is formed by impressions made when a vehicle tyre contacts a surface and may capture some of the tread pattern of the tyre as well as other characteristics acquired through wear and damage in certain circumstances. The characteristics visible in impressions can include information on the pattern, dimensions, wear characteristics and others which can contribute to establishing the possibility that a certain tyre might have created a questioned mark. Richetelli et al. (2024) reported that tyre impression evidence can be used to link secondary scenes and vehicles with an incident, as well as shed light on the sequence of events surrounding an incident. Such evidence can have tremendous scientific power, although the value is influenced by the quality of the impression obtained and the level of observable features which can be confidently compared. The 2023 International Association for Identification standard provides guidance on the examination and documentation of footwear and tyre impression evidence which facilitates consistency in the field (International Association for Identification, 2026).



Footprint Track Evidence

Footprint track evidence is formed by impressions left by footwear or bare feet on a surface. In footwear examination, they may have class characteristics like outsole structure, dimensions and pattern arrangement, along with other features resulting from wear or accidental damage. Kaur and Sodhi (2025) noted that impression evidence can be used to tie a source of footwear to a scene and can support inference on the movement in an event. The evidential information present in footprints is therefore not limited to their outline, but can also include tread design, arrangement and patterning, wear features and randomly acquired characteristics. Scholars have become increasingly concerned with the role of quantitative and computational analysis in the examination of these facets. Lee et al. (2024) produced a computerbased automated alignment procedure for matching footwear impressions with common class characteristics and highlighted the benefit of computational methods in footwear evidence.

Categories and Features of Track Evidence at Event Scenes

Impressions found at event scenes may generally be two dimensional marks, three dimensional impressions or imprints that need to be enhanced before their features are clearly identifiable. Two dimensional impressions are created when material such as blood, dust or another substance is transferred from one surface to another. Three dimensional impressions can be made when a relatively soft surface is deformed by footwear or tyres, thereby capturing depth as well as surface pattern information. The Shoe Case data set created by Tibben et al. (2023) exemplifies the broad range of different types of footwear impressions that may be detected including in full and partial impressions in blood and dust on a variety of flooring surfaces, which are recovered in different ways. Kaur and Sodhi (2025) identified class characteristics and features derived from wear as significant elements of footwear impressions. Such variations in impression characteristics dictate that documentation and preservation techniques must be adapted to the physical properties of the impression.

Potential and Limitations of Track Evidence

Tyre and footprint tracks are important because they contribute associations to a scene that connect a tyre or footwear to an event. Their evidential value, however, should not be automatically assumed to be unique. The ability of an impression to contribute to the evidential matrix depends on impression quality, the presence of distortion, the level of pattern completeness, surface condition and availability of comparative characteristics. Kellett et al. (2024) in a systematic review of footwear comparison research found much of the work focused on impression recovery and enhancement, with comparatively little emphasis on the process of interpretation and the features which underpin comparative evaluations. The need for more transparent, thorough and consistent ways of expressing the evidential value of footwear comparison was identified by the review. Tyre research has similar implications, with Richetelli et al. (2024) concluding that definitive tyre exclusion and identification decisions were generally accurate, while classification decisions must be approached with caution. The strength of track evidence therefore lies in its ability to establish contributory links, though these are more reliable when the impression is of high quality, the comparison base is adequate, and the comparison methods are supported by empirical evidence and are applied cautiously.



Methods for Collection of Tyre and Footprint Tracks

Scene Documentation and Photography

Documentation of the scene prior to disruption of any tracks should include overall photographs of the event scene, close-up and medium range photographs illustrating identifying characteristics of a track as well as comparison photographs with an included scale and an angle designed to prevent perspective distortion. Research by the American Society of Trace Evidence Examiners recommends photographs before lifting, casting and chemical processing while as needed to enhance facial features. The ANSI/ASB (2021) also provides guidelines for the photographic recording of tyre and footwear impressions for comparison purposes, while the 2020 Best Practice Recommendations for tyre and footwear impression evidence recommends the same. NIST (2023) further recommends photographic documentation of impressions prior to recovery to preserve detail.

Measurement and Pattern Recording

Recording of impressions provides the impression pattern that is essential for comparison. Information such as the location and orientation of all impressions, directional travel and measurements including the width between impressions and the shoe print wheelbase for footwear and the track width and presence of interaction for tyres should be obtained. Rotation and interrelationship of impressions may also be used. The ANSI/ASB Standard 137 (2023) underlines the importance of recording observations to be used for comparison with other impressions, and the Shoe Case dataset created by Tibben et al. (2023) highlights the need for records of impression type, substrate, characteristics and imaging parameters.

Collection or Recovery of 2D Impressions, 3D Impressions and Casts

As illustrated by Tibben et al. (2023), Two dimensional impressions can be recovered through various lifting and enhancement techniques including gel lifting and electrostatic lifting, depending on the impression surface and substrate. This supports the potential practical application of gel lifting for footwear impressions and photographically capturing impressions in blood. The collection of three-dimensional impressions on soils, sand and other loose substrates is typically achieved through casting with dental stone. Pouring and separating the cast within a prescribed time frame should be carried out (ANSI/ASB Best Practice Recommendation 126 (2020)), leaving no blowout or surface detail. Contemporary forensic practice advises photographing fragile impressions before casting.

Handling and Transportation of Impression Evidence

Impression preservation is particularly time critical immediately after collection because damage can occur to impressions and casts through mishandling, exposure to moisture or contamination, and inappropriate storage and transport. When handling casts, they should be adequately dried before transportation and properly packed to prevent breaking and damage. Lifted impressions should also be firmly supported with no distortion. For evidence image files and records, relevant information should be stored to facilitate later review (ANSI/ASB Standard 137 (2023)). Attention to detail in packaging, labelling and transportation of impression evidence is therefore of paramount importance in preservation efforts.



Forensic Analysis of Tyre and Footprint Impressions

Visual and Pattern Examination

Forensic evaluation begins with visual inspection of a recovered impression to determine whether it is suitable for comparison and to identify any visible qualities and patterns. Park and Carriquiry (2020) explained that traditional footwear analysis heavily relies on visual comparison of questioned and known impressions, particularly in circumstances where class characteristics and randomly acquired characteristics are visible. Visual comparison is important because smudges, poor impressions and background noise can hide useful features, meaning quality impressions are essential.

Comparative Examination and Individualisation

Examining for a match between a questioned impression and a known item of footwear or tyre involves assessing the size, design, and pattern of the impression followed by examination of more individual characteristics arising from wear and damage. Park and Carriquiry (2020) demonstrated that comparison of two-dimensional footwear impressions using computer algorithms can distinguish impressions even when footwear of similar brand, size and model is used. Objective comparison algorithms are intended to assist, rather than replace, forensic examination.

Tyre Track Analysis

Tread pattern, dimensions, damage, wear and other characteristics that may assist comparison of a questioned tyre impression with a known can be considered during tyre analysis. Impressions can also be evaluated with respect to their sequence in order to help vehicle movement. Evaluation of tyre impression similarity is moving towards a reliance on quantitative measures rather than subjective visual assessment. Swofford and Champod (2021) stated that algorithms for comparison of impression evidence should be verified before routine use in forensic casework.

Footprint Analysis

Impression analysis is primarily based on outsole pattern, measurement or size, wear, damage and other visible factors that may help comparison of a questioned impression with a known sample. Even incomplete impressions can still contain good information when significant similarity remains. Tibben et al. (2023) published a collection of the types of footwear impressions that can be found in simulated scene conditions including complete and partial blood impressions and dust impressions. The ShoeCase dataset is freely available for further research.

Digital and Computer-Enhanced Analysis

Digital comparison methods are starting to convert impressions into measurable images, which can then be manipulated, compared and combined. Park and Carriquiry (2020) created a method of assessing the similarity between two-dimensional footwear impressions based on object edges, the maximum clique matching algorithm and the random forest classifier. The authors found their approach offered better discrimination between matching and non-matching impressions. Computer-enhanced analysis therefore provides a means of enhancing judge jury decision, as well as improving consistency.



Emerging Technologies in Track Evidence Analysis

Recent advances in analysis include the use of machine learning, computer vision and automated image segmentation. Li et al. (2024) was able to apply edge detection to address a serious problem in impression comparison: overlap of two shoeprints. Their use of deep learning enabled the individual shoeprints to be correctly detected despite major areas of overlap. Swofford and Champod (2021) suggested computational algorithms should only be used once they have been appropriately validated. These innovations may lead towards more scientific analysis of track evidence.

Interpretation and Evidential Significance

Linking Tracks to Persons, Vehicles and Event Scenes

Tyre and footprint impressions can link a questioned impression to a specific item of footwear or a vehicle and the associative evidence can be found linking the impression to its location. Richetelli et al. (2024) concluded that tyre examination may support linking a vehicle to a scene or secondary location and may also support reconstruction of elements of events. Kellett et al. (2024) found that interpretation of footwear may involve evaluating the features within the questioned mark and determining if there is sufficient evidentiary support to compare the given mark with the known footwear. The overall context of the impression should be considered, rather than making interpretation of a track an independent source of evidence of the presence of a person or vehicle.

Reliability and Accuracy in Track Examination

Empirical research has shown potential for relatively high accuracy rates. Richetelli et al. (2024), in the first black box study of tyre examination, derived a total of 238 comparison decisions from 17 tyre examiners and trainees. A correct identification decision was reported in 96 percent of cases, and a correct exclusion decision in 89 percent, though the researchers note that the small sample size means more precision is necessary. Richetelli et al. (2024) show that tyre examination is capable of generating high reliability decisions, but such reliability should be established empirically rather than assumed on examiner expertise alone.

Sources of Error and Factors Influencing Interpretation

Quality and dimensionality of tracking quality can influence interpretation significantly. Richetelli et al. (2024) found a negative correlation between impression quality and conclusions of class association, and a positive correlation between dimension of impression and conclusions of definitive decision. In footwear examination, Kellett et al. (2024) found interpretation to be an area for further focus, particularly in terms of describing the significance of characteristics of footwear marks. Wear can influence interpretation and just like pathologist experience it is now known that outsole features may change over time, Richetelli et al. (2025) found that footprints' features changed over a 24-week footwear training programme, so features should not necessarily be assumed constant.

Limitations and Challenges in Track Examination

A significant limitation is the continued requirement for transparent and consistent presentation of the significance of comparison decisions. Kellett et al. (2024) finding shows that there was



relatively little research on interpretation. The review highlighted a need for research to develop robust methods to express the result of comparison and sources of uncertainty. Richetelli et al. (2024) similarly recognize that the relatively small number of tyre examiners recruited in their study limits the accuracy with which the data can be applied. These limitations highlight how track evidence should be approached with caution, taking account of all the factors involved.

Empirical Review of Relevant Studies

Lin et al. (2022) in the study titled 'A Simulated Crime Scene Footwear Impression Database for Teaching and Research Purposes', aimed to facilitate robust evaluation of footwear collection, enhancement and comparison methodology through the creation of a publicly available database. Through enhancement of 597 impressions, across several substrates, matrices and methods, the study found that publicly available data could facilitate research and training. The study's major strength was methodological variety and open data access, though simulated impressions may not accurately represent complex casework. They recommended creation of additional datasets for research and training use.

Tibben et al. (2023) study titled 'ShoeCase: A Data Set of Mock Crime Scene Footwear Impressions', also aimed to provide research-grade, reproducible footwear evidence. Through collection of 936 impressions from trained participants, across multiple footwear, matrix, flooring and method combinations, the study established the importance of open-access empirical data but offered large dataset and emphatical intents on reproducibility. Its major strength was breadth of use, though it was limited to two footwear models. They recommend the 'ShoeCase' dataset as an empirical resource for quantitative comparison method development and testing.

Richetelli et al. (2024) in 'Accuracy and Reproducibility of Forensic Tire Examination Decisions', examined examiner grouping decisions for tire comparison through 238 combinations made by 17 participants. Definitive matches were correct in 96% of cases, whereas exclusions were correct in 89%. The strength of the study was empirical examination of tyre comparison. The small sample size allowed for only broad conclusions and they recommend continued findings validation and standardisation.

Finally, Lee et al. (2024) study titled 'An Automated Alignment Algorithm for Identification of the Source of Footwear Impressions with Common Class Characteristics', developed and tested an automated comparison method of Iterative Closest Point alignment and random forest classification. Comparison performance was improved using impressions from the same shoe. The major difference from the database studies was a computational focus, similar to the artificial creation of impression collections, though agreeing that objectivity can improve comparison. They recommended further validation of the method with large, diverse collection of impressions.



Findings of Studies Reviewed

The findings are presented as comparative data from the selected studies.

Tyre Impression

Table 1: Review on Collection and Recovery Methods in Tyre Impression

Study	Sample / evidence	Collection or recovery method	Recorded variables
Arya, Gupta and Singla (2022)	20 motorbikes, 10 new tyres and 10 old tyres	Tyre impressions produced on medium black and red soil at 10, 20, 30, 40, 50, 60 and 70 km/h	Tread depth, speed, gross vehicle weight and tyre age
Günay-Yılmaz, Ibram and Nabiye (2022)	Clean tyre tracks and dirty or fragmented tyre track images	Digital acquisition of complete and fragmented track images	Tread pattern and local image features
Jiang et al. (2023)	Tyre pattern images and tyre indentation marks	Digital image acquisition of tyre patterns and indentation marks	Pattern regions and image features
Girish and Manchegowda (2024)	2,693 tyre impression photographs from 22 tyre classes	Photographic collection followed by denoising, normalisation and enhancement	Texture, morphology, statistical image characteristics and SSIM
Richetelli et al. (2024)	77 questioned impression and known tyre comparison sets	Digital images representing casework type questioned impressions and known tyres	Impression quality, dimensionality and corresponding tyre characteristics

Table 2: Review on Analytical Methods in Tyre Impression

Study	Analytical method	Main quantitative finding
Arya, Gupta and Singla (2022)	Pearson correlation and Mann Whitney U test	Old tyre depth versus speed: $r = -0.871$, $p < .001$; new tyre depth versus speed: $r = -0.734$, $p < .001$; old versus new tyre depth: $U = 1461.50$, $p < .001$
Günay-Yılmaz, Ibram and Nabiye (2022)	Scale Invariant Feature Transform (SIFT) and template matching	Higher recognition performance than the state of the art methods for clean and dirty track fragments
Jiang et al. (2023)	Bilateral Segmentation Network, semantic segmentation and few shot learning	Semantic segmentation increased overall classification accuracy by approximately 4%
Girish and Manchegowda (2024)	Mask based segmentation, texture and morphological features, VGG19 and Structural Similarity Index Measure (SSIM)	95.3% classification accuracy; 80% training and 20% testing
Richetelli et al. (2024)	Human comparative examination using a multi level conclusion scale	68% class associations, 21% definitive decisions, 8% probable decisions and 3% neutral decisions; 96% of definitive IDs and 89% of definitive exclusions agreed with ground truth

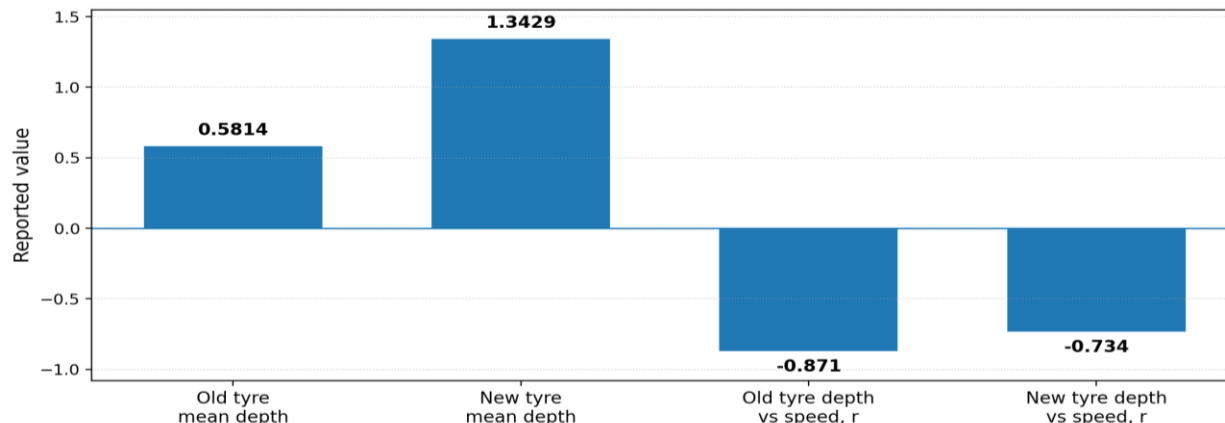


Figure 1: Tyre tread depth relationship with vehicle speed (Mean values are reported measurements; correlation values show the direction and strength of the speed relationship.)

Source: Arya, Gupta and Singla (2022)

Table 3: Review on Tyre Impression Methods with Reported Effectiveness

Examination stage	Method	Reported effectiveness
Physical impression measurement	Taper gauge measurement of tread depth	Significant old versus new tyre difference, $U = 1461.50$, $p < .001$
Image feature extraction	SIFT	Higher recognition performance than comparison methods
Pattern segmentation	Bilateral Segmentation Network	Approximately 4% improvement in classification accuracy
Deep learning classification	VGG19 with SSIM	95.3% accuracy
Forensic examiner comparison	Multi level human conclusion scale	96% correct definitive IDs and 89% correct definitive exclusions

Footprint Impression

Table 4: Review on Collection and Recovery Methods in Footprint Impression

Study	Sample / evidence	Collection or recovery method	Recorded variables
Larsen and Bennett (2021)	5 shoes producing 3D impressions in sand and soil	Traditional casting, 2D photography and Structure from Motion (SfM) photogrammetry	Class characteristics, randomly acquired characteristics and depth information
Budka et al. (2021)	Digitised footwear impression images	Greyscale image preparation at different resolutions and aspect ratios	Footwear descriptors and image resolution effects
Smale and Speir (2023)	More than 160 simulated blood impressions on tile	Blood deposition on tile followed by impression imaging; 759 RACs identified	RAC size, position and geometry
Smale and Speir (2024)	Dust impressions on paper and tile	Dust deposition with tile impressions lifted using gelatin or Mylar film	RAC position, size and geometric similarity
Xie et al. (2024)	3D footwear impressions in soil	Rigid polyurethane foam casting compared with plaster of Paris	Recovered characteristics, dimensional stability and compressive strength

Table 5: Review on Analytical Methods in Footprint Impression

Study	Analytical method	Main quantitative finding
Larsen and Bennett (2021)	Grid comparison and UK footwear tread descriptors	SfM provided superior visualisation of class and randomly acquired characteristics in some impressions



Budka et al. (2021)	Deep multilabel Convolutional Neural Network (CNN)	Learnable preprocessing with multiple interpolation methods outperformed single interpolation; preserving aspect ratio produced a considerable accuracy increase
Smale and Speir (2023)	Visual comparison and percentage area overlap modelling	Non zero RAC random match frequency occurred in 3.4% to 34% of shoes depending on the feature criterion
Smale and Speir (2024)	Visual comparison and percentage area overlap modelling	Non zero RAC random match frequency occurred in at least 3.1% and up to 32% depending on feature size
Xie et al. (2024)	Comparative examination of recovered casts and material testing	Polyurethane dimensional change: 0.1% to 0.13% length and width; 0.2% to 0.22% thickness

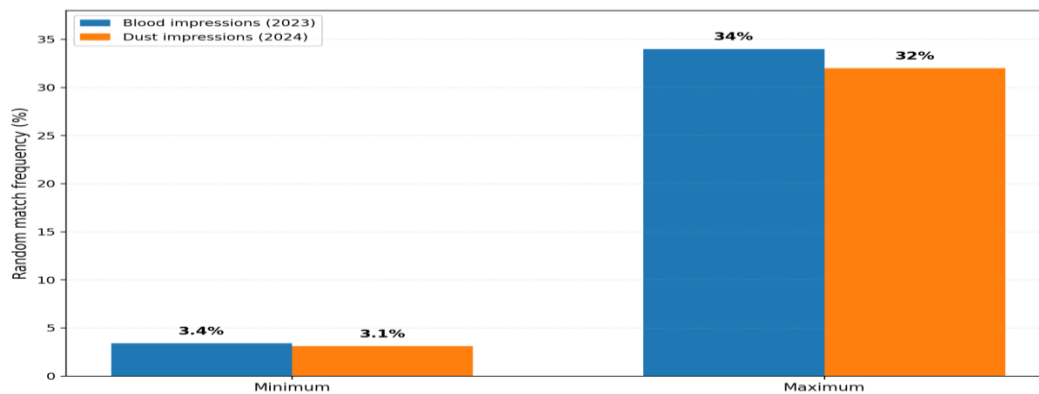


Figure 2: Estimate of the Random Match Frequency of Acquired Characteristics in Footwear: Part I & II

Source: Smale and Speir (2023, 2024).

Table 6: Review on Footwear Impression Methods with Reported Effectiveness

Examination stage	Method	Reported effectiveness
3D recovery	Structure from Motion photogrammetry	Superior visualisation of class and randomly acquired characteristics in some impressions
Image preparation	Learnable preprocessing with multiple interpolation methods	Better performance than single interpolation
Image geometry	Aspect ratio preservation	Considerable increase in classification accuracy
RAC analysis	Percentage area overlap modeling	Empirical RAC random match frequencies established for blood and dust impressions
3D casting	Rigid polyurethane foam	0.1% to 0.13% dimensional change in length and width; 0.2% to 0.22% in thickness



Table 7: Comparative Review from the Studies

Evidence stage	Tyre impressions	Footprint impressions
Collection / recovery	Controlled photography plus physical measurement	SfM photogrammetry for 3D impressions, supplemented by casting
Feature preservation	Tread depth, tread blocks, grooves and image texture	Sole pattern, depth, wear and randomly acquired characteristics
Digital analysis	SIFT, semantic segmentation, VGG19 and SSIM	CNN classification, image preprocessing and similarity modelling
Quantitative performance	95.3% reported classification accuracy with VGG19	RAC frequency empirically estimated; SfM produced superior visualisation in tested conditions
Human examination	96% correct definitive IDs and 89% correct definitive exclusions	RAC comparison demonstrated measurable occurrence of similar characteristics in unrelated footwear
Most strongly supported recovery approach	Photographic documentation plus dimensional measurement	SfM photogrammetry, with physical casting retained for 3D preservation

Discussion of Findings

The findings reviewed suggest that the most reliable tyre and footprint track examination depends on recovery quality and on the appropriateness of the chosen analytical method to the recovered impression. The evidence supports that physical measurement, digital processing and examiner interpretation each provide different types of information and are most effectively used in combination rather than independently.

As summarised in Table 1, tyre evidence is most reliably recovered by controlled photograph supported by physical measurement and digital acquisition. Arya, Gupta and Singla (2022) demonstrated the effects of speed, age and weight on tyre depth, while Günay-Yılmaz, Ibram and Nabiyevev (2022) showed that SIFT and template matching can successfully recognise both clean and contaminated tyre fragments. Richetelli et al. (2024) also showed that impression quality and dimensional dimensions influence the decisions of tyre examiners. The review confirms that a combination of physical measurement and high-quality digital photograph is the most appropriate recovery method because measurement gives quantitative information while digital image preserves pattern information which can then be compared.

Table 2 demonstrates that computational analysis can enhance pattern recognition. The high recognition rates obtained by Günay-Yılmaz, Ibram and Nabiyevev (2022) using SIFT and template matching confirm the usefulness of feature-based matching, while Jiang et al. (2023) and Girish and Manchegowda (2024) found better recognition of pattern when semantic segmentation and VGG19 were used respectively. The results suggest that computer assisted pattern classification is useful, although Richetelli et al. (2024) showed that examiner response-based interpretation still involves uncertainty. The review considers computer aided methods as useful supplementary assistance rather than capable of establishing individualisation.

The clearer evidence of mechanical factors affecting tyre impressions illustrated in Figure 1 establishes that the depth of impression is largely affected by age of tyre and by speed of vehicle. The mean depth of new tyres is more than twice that for old tyres, at 1.3 compared to 0.6, while



underlying means of 1.3429 and 0.5814 show that the mean new tyre depth was over twice that for the old tyres. Similarly, the correlation of about -0.9 for old tyres and about -0.7 for new tyres shows strong inverse relationships between increased speed and decreased depth. The general trend indicates that increased speed decreases impression depth with the effect being stronger for old tyres. Both these reported correlations (-0.871 and -0.734 , $p < .001$) were highly significant and confirmed that the result was not a random fluctuation. Mann Whitney test $U = 1461.50$ and $p < 0.001$ confirmed a significant difference between old and new tyre depth impression. Arya, Gupta and Singla (2022) support that impression depth is useful for determining scene situation and tyre condition, but that depth impression is influenced by speed and by tyre characteristics, which concurs with Richetelli et al. (2024) observation that impression class and pattern dimensions affect tyre examiner decision. Further, Günay-Yılmaz, Ibram and Nabiyevev (2022) showed that pattern features still have a role in recognising impressions where contamination or damage occurred. The review therefore finds the impression of tread depth to be a supportive feature rather than an individualising one.

Table 3 additionally demonstrates that different methods of tyre examination serve complementary rather than competitive purposes. Physical measurement characterises measurable features, while SIFT-based pattern recognition aids partial recognition. Segmentation isolates the relevant tread area from the overall pattern, and VGG19 automated classification. The 95.3% accuracy reported by Girish and Manchegowda (2024) and 4% improvement by Jiang et al. (2023) indicates the usefulness of computational pattern classification, while Günay-Yılmaz, Ibram and Nabiyevev (2022) supports the value of feature-based matching, but the 96% accuracy and 89% accuracy for positive ID and exclusion respectively reported by Richetelli et al. (2024) emphasizes that the examiner decision cannot be replaced entirely by automated recognition. The review accordingly finds that computer-based tools are best used as support systems for layered tyre comparisons.

As demonstrated in Table 4, the evidence indicates that footwear evidence relies heavily on maintaining three-dimensional information. Larsen and Bennett (2021) establish that Structure from Motion 3D visualisation enhances examination of class and anacrusis features in various impressions. Xie et al. (2024) demonstrate the importance of physical recovery, with rigid polyurethane producing only between 0.1%- and 0.13%-dimensional alteration of length and width and 0.2% and 0.22% difference in thickness. The review supports combining these two methods, with Structure from Motion providing a detailed digital representation of the evidence and casting producing a more stable physical recovery.

Table 5 further demonstrates that footwear examination benefits greatly from preserving the geometry of the image, careful image processing and quantitative comparison. Preserving the aspect ratio of the imaged impression significantly increased accuracy of classification (Budka et al., 2021), suggesting that distorted images can negatively influence computer aided recognition. Smale and Speir (2023, 2024) confirmed that acquired features may occur in some unrelated footwear samples, making comparable frequencies crucial to identifying an impression even as acquired features. Wen, Curran and Wevers (2023) report that the computer aided system retrieved 82% of footwear image impressions correctly within the top 1% ranked match and



88.99% within the top 20% matches. The review suggests that geometry of the image can be protected without distortion and that quantitative comparison can be used to assist investigations, but that the assumption that a computer-based match equates to the source remains unsuitable.

The evidence more clearly outlined in Figure 2 confirms that the maximum random match frequency of acquired features can reach as high as 34% for blood and 32% for dust impressions when features of different sizes are used. This similarity in the maximum maximums across examples of different impression types implies that overall chance matches are not limited to a particular medium. At the same time, the fact that the minimum values are much lower at around 3% (3.4% and 3.1%) shows that changes in the number of features used as basis for the match greatly impacts the percentage. This conclusion suggests that the size and the number of characteristics used in an RAC will influence its evidential significance. Smale and Speir (2023, 2024) explicitly warn these absolute RAC values are also impression-specific and should not be confused with the overall likelihood of a random match in the impression population. The pair further observed that non-acquired positional or geometric similarities may sometimes occur between unrelated footwear in both blood and dust impressions. The review finds it necessary to use the empirical random match frequency for the number of features in an RAC to avoid overestimating the impact of direct comparison.

Furthermore, as described in Table 6, the most effective approach combines three-dimensional recovery, clean image processing and quantitative comparison. Larsen and Bennett (2021) endorse Structure from Motion digital visualisation, Budka et al. (2021) support value of preserving image aspect ratio, and Xie et al. (2024) support the stable dimensional recovery of rigid polyurethane castings. The review considers the two digital recovery methods as provides of different information rather than competitors.

Lastly, as summarised in Table 7, different tyre and footwear evidence each require specific emphasis within an overall forensic procedure. Tyre evidence benefits most from physical measurement, controlled photography and pattern recognition aided by computer analysis, as demonstrated by Arya, Gupta and Singla (2022), Günay-Yılmaz, Ibram and Nabiyevev (2022), and Girish and Manchegowda (2024). Footwear evidence depends more on physical recovery of evidence, image processing and comparison of acquired features, as demonstrated by Larsen and Bennett (2021), Budka et al. (2021), and Smale and Speir (2023, 2024). This review concludes that a combined approach, considering recovery quality, analytical method and evidential interpretation as a whole, will be most scientifically supportable.

The evidence considered thus far, therefore, favour physical measurement and digital recovery of tyre impressions and three-dimensional recovery and casting of footwear impressions. Computation continues to be useful in classification, retrieval and feature comparison, however, the results of Richetelli et al. (2024) and Smale and Speir (2023, 2024) show why their outputs must be handled with care from the forensic perspective. This review maintains that reliable track evidence is established not by a single method being 'best', but by suitable recovery, verified analysis and judicious interpretation of what the retrieved features are truly capable of illustrating.



Conclusion

Tyre and footprint tracks can be valuable event scene evidence with appropriate documentation, collection, preservation and analysis. Reviewed literatures shows photographs can document event scene evidence and allow for measurement and comparison using simple computerised image processing, Structure from Motion photogrammetry, casting and physical measurement, Scale Invariant Feature Transform, dimensional segmentation and convolutional neural networks and similarity measures to enhance evidence preservation and comparison. Interpretation however, can still be affected by variation in impression quality, environment, wear, tyre and footwear, examiner judgement and limited empirical estimates of evidential values complicating conclusions. Reliable track evidence investigation therefore require validated methods and balanced interpretation rather than a one method fits all approach.

Recommendations

The following recommendations are made based on the findings of this review.

- i. Forensic practitioners and analysts should integrate recording by systematic photographs and dimensional measurement with systematic collection via appropriate casting or photogrammetry in order to preserve the maximum evidence for analysis and comparison.
- ii. Forensic laboratories should strengthen validation, quality assurance and practitioners' competency in digital methods.
- iii. Future research should improve understanding of measurement and data processing methods, establish error rates, random match frequencies and reliability in Nigeria and Africa for both casual and intentionally deposited tracks.

Contributions to Knowledge

This review presents mostly recent research and literature on digital and physical collection, preservation and analysis of tyre and footprint impressions and how digital and physical methods can be combined to preserve and compare impressions. It highlights needs for research, validation, standardisation and practitioners' training, particularly in Nigeria and Africa.



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Appendix
List of Abbreviations

2D	Two Dimensional
3D	Three Dimensional
CNN	Convolutional Neural Network
RMF	Random Match Frequency
RAC	Randomly Acquired Characteristic
SIFT	Scale Invariant Feature Transform
SfM	Structure from Motion
SSIM	Structural Similarity Index Measure
VGG19	Visual Geometry Group 19 Layer Convolutional Neural Network