Academic Education Publishing House

Industry Science and Engineering Vol. 3 No. 4, 2026

Research on Identification of Rider-Passenger Relationship in Two-Wheeler Traffic Accidents Based on Kinematics and Trace Examination

Feng Qin[1,2], Danju Huang[3]

[1]*Experimental Center of Hubei University of Police, Wuhan, Hubei, China*

[2]*Hubei Sanzhen Forensic Identification Center, Wuhan, Hubei, China*

[3]*Wuhan Vocational College of Police Officers, Wuhan, Hubei, China*

Abstract: In the analysis of two-wheeler traffic accident patterns, a three-dimensional integrated identification system for driver-passenger relationships, namely "trace–motion–injury", is established through systematic analysis of core elements such as the motion state of two-wheelers, distribution patterns of traces, the relationship between receiving surfaces and trace-forming objects, injury mechanisms and causative instruments. The entire accident process is reconstructed based on kinematic principles, with kinematic analysis as the core to achieve dynamic reconstruction of the full accident sequence. Combined with the structural characteristics and operational features of two-wheelers, multi-dimensional fitting is carried out from the perspectives of trace formation mechanism, vehicle running trajectory and injury formation logic, thereby realizing precise trace examination and correlation verification. Finally, the actual rider of the two-wheeler is scientifically determined. This method proposes a multi-dimensional fitting identification approach, providing reliable technical support and practical reference for the identification of driver-passenger relationships in complex two-wheeler traffic accidents.

Keywords: Traffic Accident; Two-Wheeler; Driver-Passenger Relationship; Driver

1. Introduction

In traffic accidents involving two-wheeled vehicles, accurate determination of the rider-passenger relationship is a key prerequisite for assigning accident liability and characterizing the case. In such accidents, factors such as vehicle instability, occupant ejection, and trace destruction often make the rider-passenger relationship difficult to determine directly. It is therefore necessary to integrate multidisciplinary knowledge from trace evidence science, kinematics, forensic medicine, and related fields, reconstruct the dynamic process of the accident through correlation analysis of vehicle traces, road-surface traces, and human injuries [1,2], and ultimately form a complete chain of evidence to clarify the rider-passenger relationship. Based on a specific case, this paper elaborates a method for determining the rider-passenger relationship on a two-wheeled vehicle from the perspective of kinematic analysis [3,4].

2. Basic Accident Information

An unplated two-wheeled motorcycle carrying Li and an unidentified person lost control while traveling through a curved road section and fell into a roadside ditch, resulting in the unidentified person dying at the scene, Li being injured, and the vehicle being damaged.

Key information at the accident scene: Road conditions: the road ran north-south, and the accident section was a right-hand curve. The pavement was dry asphalt, with a roadway width of 5.0 m and a shoulder width of 1.3 m. On the east side of the road there was a concrete ditch 65 cm wide and 40 cm deep, which was the core contact area of the accident. Vehicle status: after the accident, the unplated two-wheeled motorcycle stood upright in the ditch with its front facing south and rear facing north (Figure 1), and the body as a whole remained in an upright posture. Occupant positions: Li and the unidentified person were both located in the ditch north of the motorcycle. The unidentified person lay prone on the eastern vertical face of the ditch facing east (Figure 2), with the right foot curled against the western vertical face of the ditch and the cotton slipper from the right foot scattered at the bottom of the ditch. Scene traces: obvious scrape marks were present along

the upper edge of the western vertical face of the ditch. On the west side of a tree approximately 80 cm east of the eastern vertical face of the ditch, a scrape mark was found at a height of 60 cm above the ground (Figure 3). Tire braking marks running from north to south were visible on the pavement east of the geometric center of the road, and tire marks were also found on the eastern roadside slope (Figure 4). These traces constituted key clues to the vehicle's travel and loss-of-control trajectory.

Figure 1. Scene Posture of the Two-Wheeled Motorcycle

Figure 2. Scene Posture of the Unidentified Person

Figure 3. Tree Trace on the Vertical Face East of the Road

Figure 4. Tire Traces of the Two-Wheeled Motorcycle

3. Trace Examination

3.1 Examination of Human Injuries

3.1.1 Injury characteristics of the unidentified person (Deceased)

The body length was 182 cm. Bleeding was observed from the mouth, ears, and nose, and a swelling was seen in the occipital region. Poor resistance of the right chest when pressed suggested possible rib fractures. Multiple contusions from the left knee to the ankle, accompanied by an open fracture above the ankle, were observed (Figure 5), with the injury range concentrated on the lateral and distal portions of the left lower limb. Strip-like contused abrasions were seen on the medial side of the left lower leg, and contusions were present on the back of the right hand. The injuries were multi-site and compound in nature, consistent with mechanisms of collision, compression, and friction.

3.1.2 Injury characteristics of Li (Injured Pesron)

Craniocerebral injuries: contusions and lacerations of the frontal lobe, left temporal lobe, and centrum semiovale, as well as traumatic subarachnoid hemorrhage, with injuries concentrated on the left side of the brain. Skeletal injury: fracture of the left radius, with the injury site associated with upper-limb support and protective movement. Overall, the injuries showed the characteristics of being concentrated anteriorly and predominantly on the left side.

3.2 Vehicle Trace Examination

The vehicle was fitted with a sunshade canopy, the rear side of which was fixed to the front side of the rear box. It remained intact after the accident and showed no collision marks. The key traces on the vehicle body were distributed as follows [5]:

1. Front crash bar: a collision depression deformation was present at the right front portion, approximately 32 cm above the ground, formed by hard contact. Horizontal linear scrape marks were present on the left front crash bar at heights of 30-60 cm above the ground; the trace direction was from front to rear, consistent with the formation characteristics of lateral friction.
2. Front fairing and front guard panel: scrape marks were present on the left side of the front fairing within the range of 30-60 cm. Collision marks were observed on the left side of the front guard panel at heights of 60-64 cm above the ground, with red primer exposed. The marks showed an oblique linear form that was higher at the front and lower at the rear (Figure 6 and Figure 7). These traces lay on the same line as the trace of the left passenger foot peg (Figure 8), forming a continuous contact-trace chain.
3. Passenger foot peg and crash bar: the left passenger foot peg was compressed inward and deformed, and scrape marks were visible on the crash bar below the foot peg (Figure 9).
4. Handlebar and sunshade canopy: the end of the left handlebar was damaged, with soil adhering to the damaged area. Scrape marks running from front to rear were observed on the left edge of the sunshade canopy at a height of approximately 153 cm above the ground (Figure 10).
5. Trace alignment verification: when the front and rear traces on the left side of the vehicle

were aligned with the traces on the eastern vertical face of the ditch, the left rear passenger foot peg was located approximately 4 cm below the upper plane on the east side of the ditch. This indicated that this part had scraping contact with the eastern vertical face of the ditch during the accident (Figure 11 and Figure 12).

Figure 5. Injury to the Left Ankle of the Unidentified Person

Figure 6. Trace on the Left Front Guard Panel of the Motorcycle

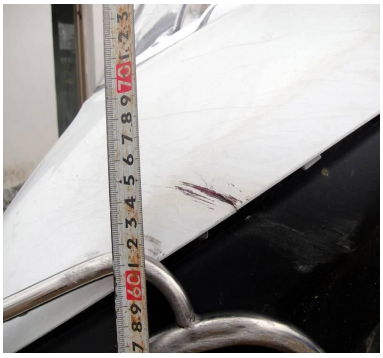

Figure 7. Trace Higher at the Front and Lower at the Rear

Figure 8. Relationship between the Left Front Guard-Panel Trace and the Left Rear Foot-Peg Trace

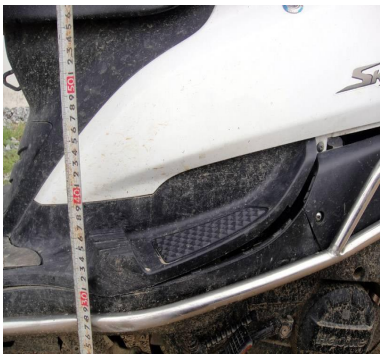

Figure 9. Trace on the Left Passenger Foot Peg

Figure 10. Trace on the Left Side of the Sunshade Canopy

4. Analysis of the Rider-Passenger Relationship

4.1 Analysis of Trace Correlation and Formation Mechanisms

Based on the correspondence between vehicle traces and scene traces, and in combination with kinematic principles, the contact process between the vehicle and objects at the scene can be reconstructed as follows:

1. Collision depression on the right front portion of the crash bar: its morphology and height completely matched the upper edge of the western vertical face of the ditch. This was consistent with the formation characteristics of hard contact between the right front part of the vehicle and the ditch edge when the front wheel fell into the ditch, proving that the vehicle first contacted the western side of the ditch during its initial loss of control.

2. Oblique linear trace on the left side of the front guard panel: the oblique feature, higher at the front and lower at the rear, and the connecting line between this trace and the left passenger footboard matched the trace on the

eastern vertical face of the ditch. Considering the angle between the vehicle's travel direction and the ditch, this trace could be determined to have been formed by collision between the left front guard panel and the eastern vertical face of the ditch as the vehicle fell to the left after the front wheel entered the ditch.

3. Horizontal scrape marks on the left front crash bar and front guard panel: the trace direction was from front to rear, consistent with the sliding trajectory after the vehicle tipped over. This matched the formation mechanism of continuous friction between the left side of the vehicle and the eastern vertical face of the ditch after the vehicle fell to the left, further verifying the dynamic process of left-side vehicle contact.

4. Scrape marks on the left edge of the sunshade canopy: the scrape marks at a height of 153 cm above the ground matched the position and direction of the scrape marks at a height of 60 cm on the west side of the tree east of the ditch. This proved that, when the vehicle fell to the left, the left side of the sunshade canopy scraped laterally against the tree, supplementing a key node in the vehicle's overturning trajectory.

4.2 Reconstruction of the Accident Process from a Kinematic Perspective

Based on the braking traces at the scene, vehicle traces, and occupant positions, the entire accident process was decomposed using kinematic principles:

4.2.1 Braking and Loss-of-Control Stage

The tire braking marks on the pavement east of the road indicated that the rider took braking measures after detecting danger. However, under the effect of centrifugal force on the curved road section, the vehicle still shifted to the left, and the front wheel eventually slid into the ditch on the east side. At this moment, the vehicle's travel direction formed a small angle with the ditch. After the front wheel entered the ditch, the right passenger foot peg was supported by the western vertical face of the ditch, causing the vehicle to assume an unstable posture of front-low/rear-high and right-supported/left-suspended.

4.2.2 Collision and Tipping Stage

After the front wheel fell into the ditch, the right front portion of the crash bar collided with the upper edge of the western vertical face of the ditch, producing the first contact point. Because the vehicle was unstable, its center of gravity shifted, and inertia acted on it, the vehicle began to tip to the left. During this process, the left front crash bar and the left front guard panel continuously scraped against the eastern vertical face of the ditch, forming an oblique collision mark on the left front guard panel. Meanwhile, the left side of the sunshade canopy contacted the tree east of the ditch, forming scrape marks on the west side of the tree.

Figure 11. State of the Motorcycle during the Accident

Figure 12. Relationship between the Left Rear Foot Peg and the Vertical Face

4.2.3 Ditch entry and uprighting stage

The vehicle continued moving forward, and the rear wheel gradually fell into the ditch. The 40 cm depth of the ditch matched the wheel track and height of the vehicle, allowing the vehicle to return to an upright posture after entering the ditch and finally stop with its front facing south and rear facing north. This process explains why the vehicle could remain upright and why the vehicle-body traces aligned accurately with the traces on the vertical face of the ditch.

4.2.4 Occupant-vehicle separation stage

During the dynamic process of vehicle tipping and ditch entry, the occupants separated from the vehicle under inertia. Because the rider was positioned at the front of the vehicle, with the center of gravity closer to the front, the throwing distance at separation was shorter. During the process in which the unplated two-wheeled motorcycle rolled to the left and then fully entered the ditch before returning to an upright posture, the rear-seat occupant's body center of gravity shifted to the left and could not move synchronously to the right with the motorcycle as it returned to the upright posture. As a result,

the rear-seat occupant separated from the left side of the motorcycle's rear seat without being blocked by the sunshade canopy. The distorted posture of the unidentified person at the accident scene was consistent with the occupant-vehicle separation characteristics of a rear-seat occupant on this vehicle.

4.3 Corroboration of the Relationship between Human Injuries and Riding Positions

The location and morphology of human injuries are closely related to riding positions. In combination with the accident process derived from kinematic analysis, the rider-passenger relationship can be further corroborated as follows:

4.3.1 Injury corroboration for the rear-seat passenger (unidentified person):

Left lower-limb injuries: the multiple contusions from the left knee to the ankle and the open fracture of the unidentified person corresponded to the inward compression deformation of the left passenger foot peg. Because the left rear passenger foot peg was located 4 cm below the upper plane on the east side of the ditch, the rear-seat passenger's left foot was exactly between the vehicle and the vertical face of the ditch when the vehicle tipped over. It was compressed and rubbed, producing concentrated injuries on the lateral side of the left lower limb, which fully matched the injury characteristics of multiple contusions from the left knee to the ankle accompanied by an open fracture above the ankle.

Head injuries: the injury characteristics of occipital swelling and bleeding from the mouth, ears, and nose were consistent with the formation mechanism in which the rear-seat passenger's head struck the vertical face of the ditch or a tree backward and to the left when the vehicle tipped over. Based on analysis of the distance between the tree and the ditch, the probability that the rear-seat passenger's head collided with the tree was higher, and the degree of injury should have been greater than that of the rider, consistent with the unidentified person's severe craniocerebral injuries.

Medial contused abrasions: the strip-like contused abrasions on the medial side of the left lower leg indicated that this part rubbed against the vehicle's left guard panel or foot peg during separation, further corroborating the contact relationship of the rear-seat passenger when the vehicle tipped to the left.

4.3.2 Injury corroboration for the rider (li):

Craniocerebral injuries: the contusions and lacerations of the left frontal lobe and left temporal lobe were consistent with the rider being located at the front of the vehicle and the head colliding with the vehicle body or the ditch edge when the vehicle fell to the left. Because the rider would instinctively use the left hand for support during the accident, the left radius fracture was consistent with the protective action habit of a person in the riding position and corresponded to the trace of damage and soil adhesion at the end of the left handlebar. The fracture was caused by impact while the left hand was holding the grip, and soil simultaneously adhered to the damaged part of the handlebar.

Comparison of injury severity: although Li's craniocerebral injuries were serious, they did not reach the fatal severity of the unidentified person's injuries. This was consistent with the conclusion from kinematic analysis that the rear-seat passenger suffered more severe injuries, further supporting the determination that Li was the rider.

4.4 Reverse Verification: Excluding the Possibility That the Unidentified Person Was in the Riding Position

By simulating the situation in which the unidentified person was in the riding position and conducting reverse reasoning based on trace and injury characteristics, this hypothesis can be excluded [6]:

4.4.1 Trace contradiction

If the unidentified person had been the rider, the left foot should have been located at the left front part of the vehicle. When the vehicle tipped over, the left foot would have separated the vehicle body from the eastern vertical face of the ditch, preventing continuous scrape marks from forming on the left front crash bar and front guard panel. In fact, however, continuous horizontal scrape marks were present on the left front part of the vehicle, contradicting this simulated scenario.

4.4.2 Injury contradiction

The rider's left foot is located at the left front part of the vehicle body [7]. If the unidentified person had been the rider, the injuries to the left lower limb should have been concentrated in the upper lower leg or around the knee joint, rather than at the ankle and distal portion. However, the unidentified person's injuries were

concentrated from the left knee to the ankle, which was inconsistent with the force-bearing position of a person in the riding position [8]. In addition, medial injuries in the riding position should correspond to inner structures of the vehicle body, but there was no corresponding trace-producing object in the riding position for the contused abrasions on the medial side of the unidentified person's left lower leg, further excluding the possibility that the unidentified person was the rider [9,10].

5. Conclusion

Determining the rider-passenger relationship on a two-wheeled vehicle is a systematic task that requires moving beyond the limitations of single pieces of evidence and constructing a three-dimensional verification system of traces, motion, and injuries. The practice in this case shows that trace examination is the foundation: by accurately aligning vehicle traces with scene traces, the contact points and contact sequence can be identified. Kinematic analysis is the core: by dynamically reconstructing the stages of braking, collision, tipping, and ditch entry, the spatiotemporal evolution of the accident can be restored. Human injury analysis is the key: by verifying the correlation between injury locations and morphology and the riding positions, the final basis for determination can be formed.

In actual work, multidisciplinary knowledge from trace evidence science, kinematics, forensic medicine, and related fields must be skillfully integrated. Attention should be paid not only to the detailed characteristics of individual pieces of evidence, but also to the completeness and logic of the evidence chain. Through systematic evaluation of trace distribution, motion state, injury characteristics, and force relationships, the rider-passenger relationship on a two-wheeled vehicle can be scientifically determined. Using the above methods, this case ultimately determined that Li was the rider of the unplated two-wheeled motorcycle at the time of the accident, while the unidentified person was the rear-seat passenger, providing solid technical support for liability assignment and case handling.

In the future, with technological development, advanced methods such as computer simulation and three-dimensional reconstruction can be combined to further improve the accuracy of kinematic analysis and provide more efficient and scientific solutions for determining rider-passenger relationships in complex two-wheeled vehicle traffic accidents.

Acknowledgments

Hubei Provincial Department of Education Project (B2024200).

References

[1] Ministry of Justice of the People's Republic of China. SF/T 0162-2023 Specification for Identification of Traffic Behavior Patterns of Persons Involved in Road Traffic Accidents. Beijing: China Standards Press, 2023.

[2] Ministry of Public Security of the People's Republic of China. GA/T 944-2011 Specification for Investigation and Evidence Collection for Identification of Motor-Vehicle Drivers in Road Traffic Accidents. Beijing: China Standards Press, 2011.

[3] ZHAO Minghui, LI Lili, FENG Hao. Identification of Traffic Behavior Patterns of Persons Involved in Road Traffic Accidents. Beijing: Science Press, 2019.

[4] WU Ruiliang, HE Huazhang, SU Zhongmei, SUN Yan, et al. Forensic identification of the rider-passenger relationship in a two-wheeled motorcycle under a typical collision pattern: one case report. Chinese Journal of Forensic Sciences, 2018(6): 108-110.

[5] QIN Feng. Research on trace-based judgment methods in traffic hit-and-run cases. Journal of Hubei University of Police, 2018(1): 64-71.

[6] ZHAO Minghui, JIANG Zhenfei, FENG Hao. Identification of bicyclists' riding/pushing status in road traffic accidents. Auto & Safety, 2026(2): 87-92.

[7] LING Zhihui. Application of trace analysis in determining the traffic behavior patterns of bicyclists involved in cases. Road Traffic Management, 2023(9): 48-51.

[8] ZHAO Minghui, JIANG Zhenfei, LI Wei, ZHANG Peifeng. Recognition and application of common road-traffic-accident injuries in forensic identification of traffic behavior patterns. Chinese Journal of Forensic Sciences, 2024(3): 94-101.

[9] XIE Xianqi, JIN Yushi. Identification of a passenger-car driver through analysis of injury characteristics: one case report. Guangdong Public Security Technology,

2017(2): 71-80.
[10]QIN Feng, HUANG Danju. Physical application of key traces in analysis of vehicle collision patterns. Journal of China Criminal Police University, 2018(5): 101-104.