CASE REPORT

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Probability Analysis and the Evidential Value of Bolt Arrangements

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ABSTRACT: The orientation of bolt heads is random because of production or assembly processes. A series of bolts may serve as a means of identification according to orientation.

KEYWORDS: criminalistics, bolts, probability, identification systems

One of the functions of the laboratory in police work is to aid in the "identification" of a person or an object. Identification can be explained as a process in which characteristics held in common are compared (that of the suspect with that of the true perpetrator) to determine whether or not the quality of sameness with another person or thing exists [*1*]. The conclusion regarding identity is reached only when unique characteristics are found to be held in common. The question of which characteristic is unique depends on the frequency of the features of that characteristic in its relevant population.

There have been many discussions in the juridical literature [*2-6*] about the use of the theory of probability in attempts to quantify the "uniqueness" of a characteristic. A commonly used approach is to apply the well-known rule: the probability of two *independent* events happening is equal to the product of their separate probabilities.

No less common are discussions that criticize this method of quantification. The barbs of these criticisms are generally directed at three principal points [*7*].

1. In many instances there is a lack of reliable data as to the probabilities of the different components of the occurrence. Instead, we have the purely subjective estimate of the one calculating the probability. As an extreme example, we can cite the incident in which a judge attempted to estimate the chance of a wallet "being separated" from its owner by means of theft (pickpocketing) as opposed to ordinary loss [*8*]. The judge decided baselessly that the chances were 10% (1:9) in favor of ordinary loss.

2. Criticism has also been leveled against the decisions of "probability estimators" that component parts were independent, despite the absence of a solid basis for these decisions.

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One example is that of "the lucky driver" [7]. In this particular case the judge estimated the probability of finding two wheels of a parked vehicle in a certain position, using the position of the air valves in relation to any chosen reference (the road for instance). His calculation was based on the probability of each wheel separately reaching a certain position. The judge presumed that the movement of each wheel in that same vehicle was independent of the other wheels as far as the position of the valves is concerned. This assumption ignores one's intuitive feeling that since the wheels of a car turn at the same speed the position of each valve is fixed, and thus not totally independent of one other. Although empirically and theoretically it is possible that such an independence really exists, the judge's presumption was unfounded [7].

3. The most serious problem arises when people mistakenly confuse the measure of frequency of features in a certain population with the probability that the accused possessing these features may be the actual perpetrator. In certain instances (such as the presence of fingerprints) where the frequency of the features is so low that they are considered to be unique, the above two questions actually coincide. However, in many other cases where the frequency is not so low, one must be careful to distinguish between them. A well-known example of such confusion is the case of the Collins couple [3], where an estimate was made of the chance of finding a couple with a certain set of features. This estimate was then mistakenly used to indicate the probability that the suspected couple was innocent. Although the frequency of couples possessing such features was one in twelve million, in a sufficiently large population there probably exists several such couples. Thus, the chance of mistakenly choosing the wrong couple is much greater than one in twelve million.

In this work it was shown that an arrangement of bolts can be used as a means of objectively identifying the object in which they are found. This is based on the fact that the position of *each* bolt head in relation to a certain reference line is determined randomly and that the number of possible positions for each bolt head is considerable. In addition, the positions of the *various* bolts within the same arrangement are independent of one another, and therefore, the probability of the occurrence of a certain arrangement can be calculated by the product of the probabilities of the position of each individual bolt. The resulting product is a quantity so high that the presence of a certain arrangement is distinctive enough to be used for identifying the object in which the bolts are found.

The Case

The arrangement of bolts analyzed in this work was found on the coat of the victim of a fatal car accident (Figs. 1 and 2) who was struck by a public bus. The suspected bus driver denied hitting the victim. Various imprints and impressions, including round and hexagonal marks, were found on the coat of the deceased. On examination of the bus' underside it was found that part of the oil sump (lower part of engine crankcase) could have left these marks.

Investigation revealed that at that same time, at least seven additional buses of the same type ("Leyland") had passed the scene of the accident. Since each bus had a similar oil sump, it was necessary to find a way to discriminate among them.

Methods

All eight suspected buses were located and brought to the bus company's central garage. After removal of dirt and grease by a solvent, the bottom of each bus' oil sump was photographed and transparencies were prepared. Photographs and transparencies of the impressions on the victim's coat were also prepared. A random sample of additional buses was also examined.

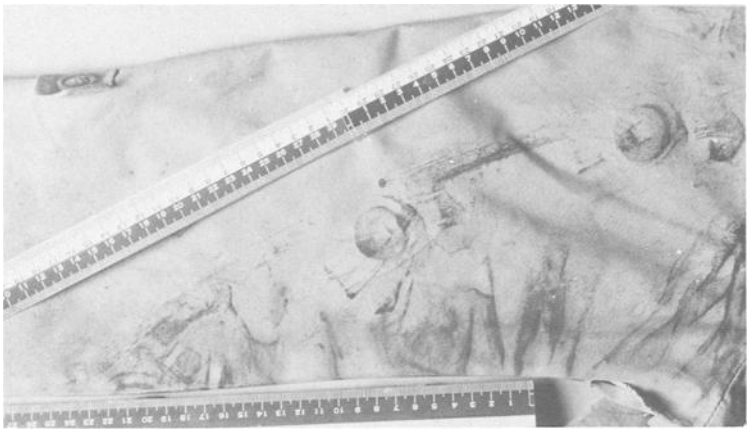

FIG. 1—*Imprints found on the victim's coat.*

Results and Discussion

Figures 3 to 5 depict the relevant part of the oil sump on three of the buses. The top bolt in Fig. 3 has a hexagonal instead of a round head. Except for this difference (which apparently was caused when the bolt was changed in the course of the regular maintenance of the bus), there initially seemed to be a great resemblance among the bolt patterns. However, a second look at Figs. 3 to 5 shows that there are clear differences among the orientations of the bolts. These can be distinguished through the angles (A, A′) created by the two diagonals of the square in the center with a reference line (Fig. 6). An additional aid for defining the orientation is the embossment found on the face of the bolt head.

The fact that the bolt arrangements may be distinguished through the different bolt orientations was in itself enough to solve the question in this specific case, since only one of the eight buses in question matched. However, since all eight sets of bolts were found to be different, we considered the possibility of generalizing and concluding that any such arrangement of bolts is set in an accidental way, since the orientation of each bolt is an inde-

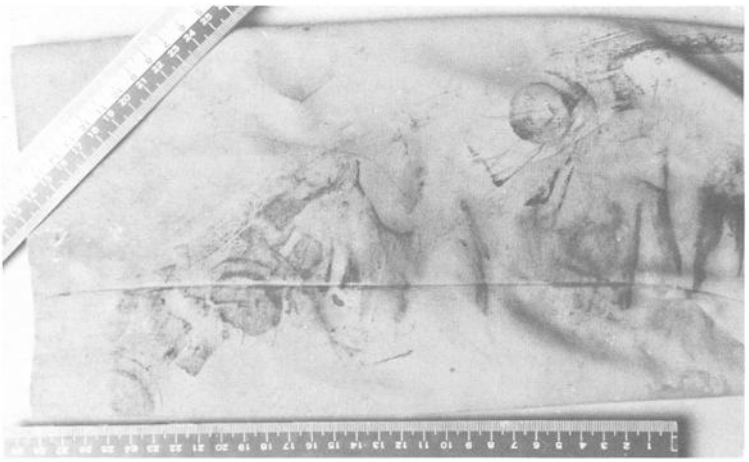

FIG. 2—*Imprints found on the victim's coat.*

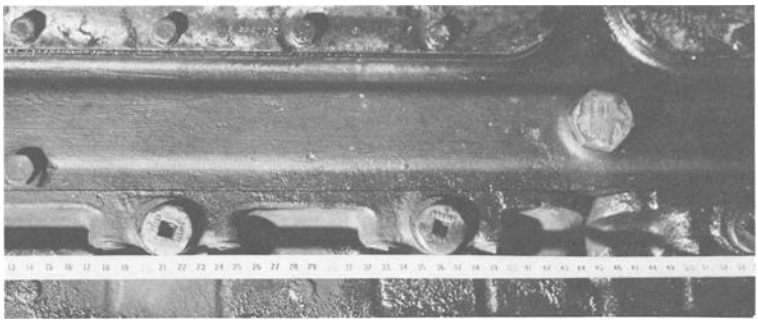

FIG. 3—*Part of the oil sump from one of the eight different buses.*

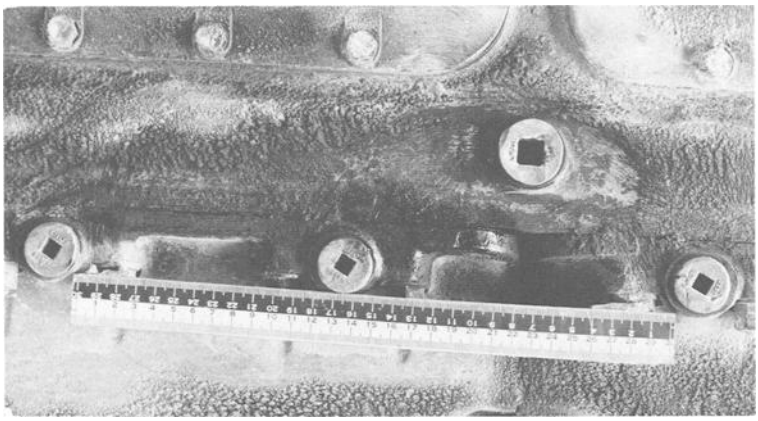

FIG. 4—*Part of the oil sump from one of the eight different buses.*

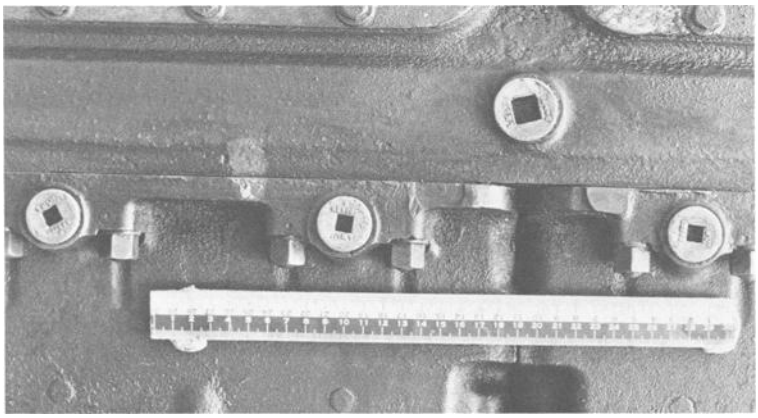

FIG. 5—*Part of the oil sump from one of the eight different buses.*

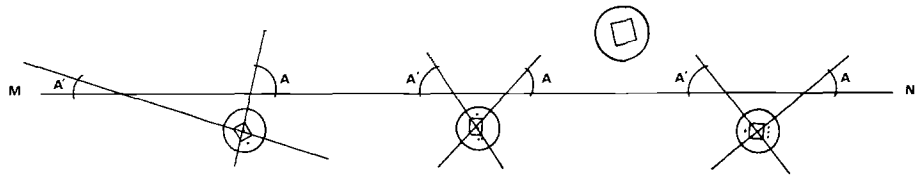

FIG. 6—*Definition of bolt heads orientation· Angles A, A' produced by the intersection of the diagonals (of the square on the bolt heads) with a reference line M N.*

pendent one. Such a generalization requires one to analyze the problem cautiously by using the principles outlined in the introduction.

One might have thought that the presence of standard parts (that is, oil sumps, bolts, and so forth) and the use of assembly line processes would maintain such a high quality control level that each of the bolts would end up with the same orientation. Since they were of the same length, it would be natural to expect that they would have the same length of thread, and that the threading in the holes for the bolts was made identically. On the contrary, the different orientation for each bolt resulted from the randomness of the production and assembly processes.

Microscopic examination of the bolts showed that they were formed in two stages; first, the plastic processing stage in which the blank was created, followed by the machining stage in which the threads were formed. Figure 7 illustrates a scheme for the production of the bolt. The bolt head (the imprint and the square) is formed in the first stage, the thread in the second. The transfer of the bolt from one stage to the other is a random process so that the orientation of the bolt thread does not depend on the orientation of the bolt head. The beginning of the thread may be in any position in relation to the bolt head; therefore, even if the bolts are uniformly tightened, the orientation of each bolt head is random and independent of the position of the others.

The randomness of the orientation of the bolt head is inherent in the assembly process as well as in these production processes. Figure 8 is a schematic illustration of the production of an ordinary washer. The accepted tolerance in the manufacturing process causes a difference in the thickness of the washers, which results in a varying progress in the tightening of the bolt and therefore a different orientation of its head. Figure 9 shows the influence of the thickness of the washer on the orientation of the bolt head. Table 1 illustrates the thickness of ten washers chosen randomly from different oil sumps and the respective difference in the orientation of the bolt heads.

There are of course other random processes which could contribute to the orientation of the bolt head. These, however, may serve only to support further the conclusion that even when there is standardization in production and assembly processes the orientation of each bolt head is randomly fixed and is independent of the orientation of the others.

These empirical observations and theoretical explanations of the independence of the orientation are what make possible an "objective" analysis of the probability of finding a certain orientation of a given series of bolts. The number of geometric positions of a bolt head is of course infinite, but from a practical viewpoint a finite number of positions may be differentiated relatively easily.

A difference of 5° from one position to another is sufficiently clear (see Fig. 10). Thus, the number of possible positions of each bolt is 72 (360:5), and the probability of finding an arrangement of N bolts in a certain orientation is: $72^{**}N$.

As mentioned above, the evidential value of the identification depends on the size of the population of similar arrangements. Since the identification was based on 4 bolts, the probability of finding a bus with a similar arrangement is: 1:26 873 856. If we take into account

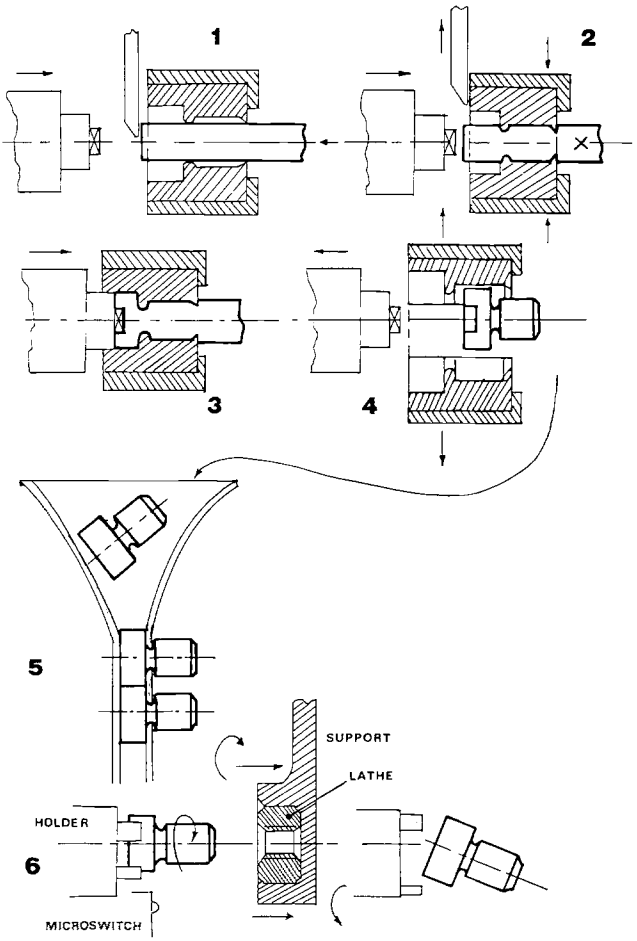

FIG. 7—*Scheme of a possible bolt production technology:* (1) *blank positioned in press,* (2) *initial formation,* (3) *bolt head formed,* (4) *bolt released from press,* (5) *transfer of bolt into "positioning bin," and* (6) *threading stage.*

the number of buses of the same kind having a reasonable chance of passing the same place at the same time, it is clear that there is only a negligible probability that another bus with the same bolt arrangement is the one that struck the woman.

Conclusion

We have demonstrated the evidential value of an arrangement of bolts as a means of identification. When analyzed properly, the probability of finding a bolt in a certain position can be assessed objectively instead of being based on a "subjective" estimation. Since the manufacturing or assembling processes of the bolts are likely to create a random orientation of the bolt heads, the frequency of a certain bolt arrangement can be calculated mathematically. In this respect, identification by means of an arrangement of bolts may have a certain advantage over other "toolmark-type" examinations that are based more or less on the subjectivity of the examiner.

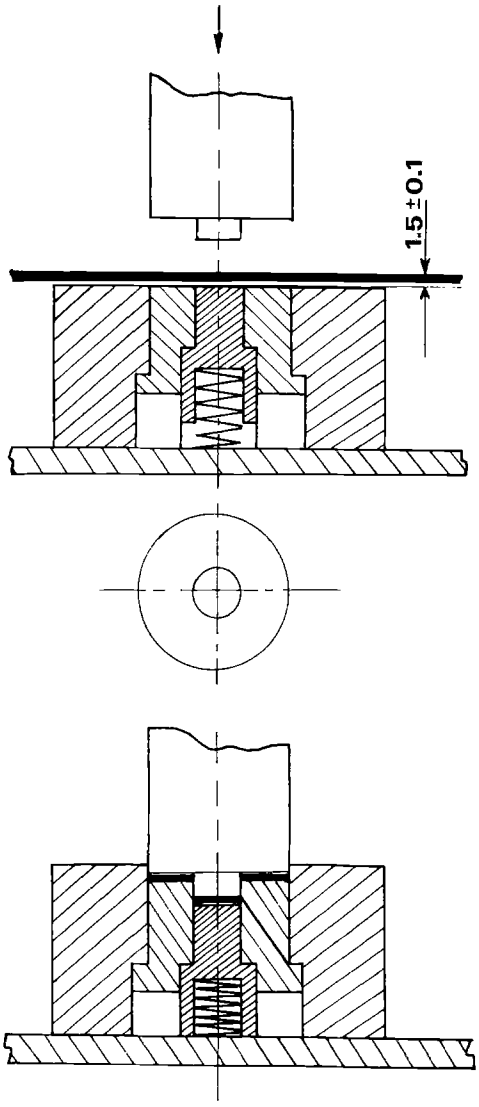

FIG. 8—*Washer production technology.*

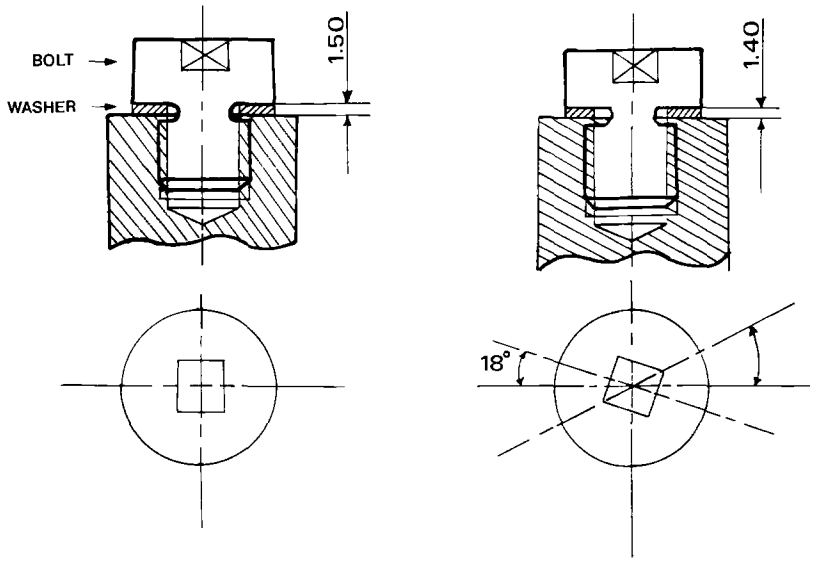

FIG. 9—*Assembly of the bolt and the washer. the correlation between washer thickness on the bolt heads' orientation.*

TABLE 1—*The effect of the thickness of the washer on the position of the bolt.*

No.	Thickness of Washer, mm	Deviation, degrees
1	1.50	0.0
2	1.45	9.0
3	1.49	1.8
4	1.42	14.4
5	1.48	3.6
6	1.33	30.6
7	1.35	24.0
8	1.32	32.4
9	1.50	0.0
10	1.38	24.4

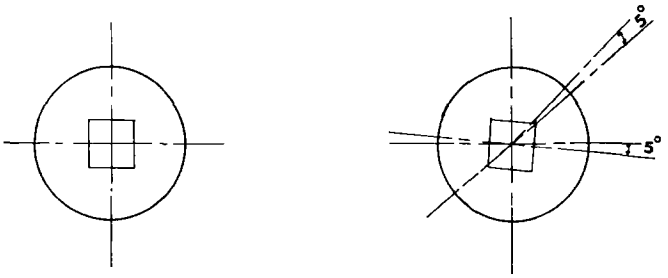

FIG. 10—*Illustration of a 5° difference in bolt head orientation.*

Acknowledgments

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