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Application of Bayes' theorem in assessing recidivism risk in a serial rapist: a case study

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The assessment of recidivism risk among sexual offenders represents one of the most challenging issues in criminological and forensic practice, particularly in cases involving multiple repeat offenders, where available data are often fragmentary and the degree of uncertainty is high. The aim of this paper is to demonstrate the application of Bayes' theorem in the analysis of criminal behaviour and in the formalised probabilistic assessment of the risk of rape reoffending through a case study of a serial rapist sentenced to a long-term term of imprisonment. The study is grounded in a Bayesian inferential framework, in which the recidivism hypothesis is operationalised as a binary outcome: the reoccurrence of rape within a three-year period following release (2029–2032). The individualised baseline probability (empirical prior) was estimated using a beta–binomial Bayesian model based on the offender's criminal history, due to the absence of domestic longitudinal recidivism rates for the specified time horizon. The evidence used for Bayesian updating comprised operationalised risk indicators, including repeated rape following previous releases, escalation of violence, the presence of antisocial personality disorder, impulsivity, and stable modus operandi patterns. Additional empirical data from a domestic study on rape recidivism were used to contextualise the findings. The results of the Bayesian analysis indicate that the posterior probability of recidivism within the three-year period remains exceptionally high (≈0.97–0.99), even under conservative assumptions regarding evidential strength. The findings suggest that the potential protective effects of age and long-term imprisonment, even when considered under a conservative scenario, do not outweigh the strong pattern of prior behaviour and the clinical-behavioural risk factors. In conclusion, the paper demonstrates that Bayes' theorem constitutes a methodologically transparent and practically applicable framework for individualised probabilistic reasoning in forensic risk assessment.

KEYWORDS: Bayes' theorem, rape recidivism, risk assessment, serial rapist, case study, forensic reasoning

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Introduction

Reasoning under conditions of uncertainty represents one of the key methodological challenges of contemporary science, particularly in forensic and criminological research, where decisions are made on the basis of limited, fragmentary, and heterogeneous information. In such a context, probability constitutes a particularly suitable concept for expressing the degree of belief in the truth of specific claims or hypotheses. In Bayesian statistics, it is interpreted as a degree of rational belief based on available information, rather than solely as the frequency of repeatable events (Taroni *et al.,* 2014; Gelman *et al.,* 2014).

This understanding of probability rests on the assumption that conclusions in real-world settings rarely arise from deductive necessity, but rather from plausible reasoning, in which evidence does not permit absolute certainty yet justifies changes in the degree of belief in a given claim. If such changes are required to be logically consistent and to incorporate all relevant data, probability theory may be viewed as a normative framework for rational reasoning under uncertainty (Jaynes, 2003).

The Bayesian approach to statistical inference is grounded in Bayes' theorem, which enables the formal and coherent updating of the probability of a hypothesis in light of new evidence. Within this framework, initial beliefs expressed through prior probabilities are systematically revised as new information becomes available, resulting in posterior probabilities and thereby ensuring a transparent and cumulative process of reasoning (Gelman *et al*., 2014). This approach is particularly well suited to domains characterised by a high degree of uncertainty and the need for individualised assessment, which is typical of forensic practice and the assessment of criminal recidivism risk.

The application of Bayesian reasoning in the assessment of criminal recidivism risk has already been recognised in the contemporary forensic literature. Mokros *et al.,* (2010) demonstrated that multivariate Bayesian classification enables an individually specific probabilistic assessment of violent recidivism risk, whereby combining multiple relevant predictors yields substantially greater predictive value compared with assessments based on single factors. A particular advantage of this approach lies in the explicit incorporation of the base rate of recidivism and the transparent updating of probabilities, which is crucial for informed decision-making in legal and forensic contexts.

Further research indicates that the application of Bayes' theorem is particularly important in the assessment of sexual recidivism risk under conditions of low base rates, where existing actuarial instruments exhibit serious limitations. Wollert (2006) demonstrates that even when discriminatory properties are satisfactory, actuarial models in such populations produce a high proportion of misclassifications and systematically overestimate risk. Under these circumstances, reliance on fixed group probabilities and tabular estimates becomes methodologically limited in individual forensic assessments, whereas the Bayesian framework enables rational and transparent reasoning through the integration of base rates, the evidential strength of available indicators, and the individual characteristics of the case.

This approach is of particular importance in legal and forensic systems in which standardised instruments for recidivism risk assessment and domestic normative guidelines for

their application are lacking. In the Serbian context, recidivism risk assessments are often made in practice without a formalised probabilistic framework, frequently relying on implicit clinical judgement. In this respect, the present paper does not introduce a new form of reasoning through Bayes' theorem, but rather enables the formalisation and transparent presentation of conclusions that are already made under conditions of uncertainty in practice, albeit without a clear separation of assumptions, evidence, and levels of belief.

This study

The aim of this study is to demonstrate the analytical and practical value of the Bayesian inferential framework in assessing criminal recidivism risk within a forensic context. The specific contribution of the paper lies in the formalisation of individual risk assessment under conditions of limited forensic data. The research is based on a detailed analysis of a case study of a serial rapist, in which available empirical and qualitative data are used to formally update the probabilities of relevant hypotheses. Rather than pursuing statistical generalisation, the focus is placed on individualised risk assessment under conditions of limited and fragmentary information.

Such an approach enables an explicit linkage between evidence, theoretical assumptions, and derived conclusions, while clearly distinguishing the inferential process from normative decision-making. In this way, the study illustrates how Bayes' theorem can be applied as a coherent methodological tool in the analysis of complex criminal behaviour under real forensic conditions.

In line with the stated objective, the paper deliberately relies on a limited number of theoretically and methodologically fundamental sources. The rationale for this selection lies in the fact that the aim of the study is not to provide a review of the existing literature on sexual recidivism, but to demonstrate the formal Bayesian framework of reasoning in a specific forensic context. The selection of references was guided by their relevance to the normative and methodological issues of probabilistic reasoning and risk assessment, rather than by the quantity of cited sources.

Consistent with these theoretical and methodological premises, the objective of this paper is to demonstrate the application of Bayes' theorem in the analysis of criminal behaviour and in the assessment of the risk of reoffending for rape, through a case study of a serial rapist sentenced to a long-term term of imprisonment.

Method

Research design

The study is designed as a case study in which a Bayesian inferential framework is applied to assess criminal recidivism risk and to analyse criminal behaviour. The aim of the research is not statistical generalisation to a population, but rather an individualised probabilistic assessment of relevant outcomes for a specific offender under conditions of limited and fragmentary data.

The Bayesian approach enables the transparent updating of the probability of a hypothesis in light of new information and explicitly distinguishes between: (a) initial assumptions (prior), (b) the evidential strength of the available information, and (c) the final posterior estimate. In this paper, the case study is treated as a formal framework for probabilistic reasoning about future behaviour, with clearly acknowledged limitations regarding external validity, rather than as an illustrative narrative.

Data sources

The study draws upon combined data sources:

1. Case study of a serial rapist (Baić and Lajić, 2017), including:

- sociodemographic characteristics,
- criminal history and recidivism pattern,
- modus operandi,
- level of violence, impulsivity, and ritualistic behaviours,
- temporal distribution of the offences.

2. Empirical data from a quantitative study (Baić *et al.,* 2026, in press), used as a reference empirical framework for contextualising the findings and for estimating the prevalence of selected characteristics across relevant groups. The sample comprises 560 individuals convicted of rape, classified into three reference groups:

- CSO-NR – individuals convicted of rape without recidivism,
- CSO-RnR – individuals who reoffended, but not through repeated rape,
- CSO-RR – individuals who repeated the offence of rape.

In the referenced sample, the majority of offenders were non-recidivists, while 12.7% were rape-specific recidivists and an additional 26.3% were recidivists for other criminal offences (Baić *et al*., 2026, in press). These rates are used in the present study for empirical contextualisation and for the selection of variables, but not as the basis for the primary prior, as the aim of the analysis is not population-level estimation but an individually informed risk assessment in an extremely high-risk behavioural trajectory. The aforementioned data were not used to quantify likelihood ratios nor to construct a population prior, but solely to provide theoretical and empirical grounding for the selection of relevant variables within the case study framework.

Hypotheses and operationalisation

The Bayesian analysis is based on the following hypotheses:

- A2(T): The offender will commit rape again within period T following release (after 2029).
- A3: The offender's modus operandi will remain consistent in the event of a subsequent offence.

In the analytical part of the paper, hypothesis A2 is operationalised for a three-year period following release and denoted as A2(3) (2029–2032). The outcome A2(3) is treated as binary (yes/no): the reoccurrence of rape at any point during the specified period.

The primary focus of the study is on hypothesis A2(3), whereas hypothesis A3 is used as a supplementary analytical dimension in interpreting the stability of the criminal behavioural pattern, without being directly incorporated into the quantitative Bayesian updating.

Evidence (B)

The evidence used for Bayesian updating is based on the case study (Baić and Lajić, 2017) and operationalised as a set of indicators:

- B1 (historical recidivism pattern): repeated commission of rape following previous releases, with behavioural escalation;
- B2 (clinical risk): diagnosed antisocial personality disorder, accompanied by pronounced auto-aggressive/suicidal behaviour during imprisonment;
- B3 (behavioural pattern and violence): high level of physical aggression, use of a knife and threats, impulsivity, and a ritualistic component of behaviour.

In light of findings from the reference sample (Baić *et al.,* 2026, in press) indicating that sociodemographic characteristics (e.g., education, employment, marital status) generally do not clearly differentiate rape recidivists from other groups, the Bayesian analysis prioritised historical, clinical, and behavioural risk markers, under the assumption of their limited mutual independence, which is further considered in the model sensitivity discussion.

Bayesian analytical procedure

The analysis was conducted using Bayes' theorem:

$$P(A \mid B) = \frac{P(B \mid A) \cdot P(A)}{P(B)}$$

where:

- P(A) denotes the prior probability of the hypothesis (the initial degree of belief before considering evidence B),
- P(B | A) denotes the probability of the observed evidence given that the hypothesis is true,
- P(B) denotes the overall probability of the evidence,P(A | B) denotes the posterior probability of the hypothesis after taking the evidence into account.

In the practical calculation, the odds form of Bayes' theorem is also used:

$$O(A \mid B) = O(A) \times LR(B)4$$

where:

[4] In the literature, the likelihood ratio may also be denoted as Λ(B) or LA(B). In this paper, the standard notation LR(B) is used, defined as the ratio P(B|A)/P(B|¬A).

$$O(A) = P(A) / (1 - P(A))$$

$$LR(B) = P(B \mid A) / P(B \mid \neg A)$$

The analysis is based on explicitly stated model assumptions, including the choice of the prior and the estimation of likelihood ratios, the sensitivity of which is examined in the interpretative section of the paper.

Results

Defining the prior for hypothesis A2(3) (Individually informed prior)

Given that available domestic sources do not provide longitudinal rape recidivism rates for a clearly defined three-year post-release period, the prior probability of hypothesis A2(3) was derived from the offender's individual criminal history using beta-binomial Bayesian updating.

In the case study, a pattern of repeated rape following three successive prior releases (1999, 2004, 2009) was documented, that is, 3 recidivism events in 3 relevant opportunities. Starting from a weakly informative prior Beta(1,1), the following is obtained:

$$p \sim Beta(1 + 3, 1 + 0) = Beta(4, 1)$$

This posterior beta distribution, obtained relative to the initial weakly informative prior, represents an individually informed prior for the subsequent Bayesian analysis and is based exclusively on the historical evidence of prior releases and repeated offending. It should be noted that the estimate is based on a limited number of observations (n = 3), resulting in a relatively wide posterior variance and requiring methodological caution in interpretation.

For the sake of methodological clarity, it should be emphasised that this posterior beta distribution pertains to the parameter *p* (the probability of recidivism following release) and is derived from the historical record of prior releases and recidivism. It is subsequently used as an informed prior for hypothesis A2(3) in the next stage of Bayesian updating (B1–B3), in the spirit of an empirically informed (empirical Bayes) approach.

The mean of the beta distribution is:

$$E(p) = 4 / (4 + 1) = 0.80$$

The obtained value of 0.80 is interpreted in this study as the informed prior P(A2(3)) for the subsequent Bayesian analysis, rather than as the final posterior probability after incorporating evidence B1–B3.

Bayesian updating of the informed prior with evidence (B1–B3)

To illustrate the Bayesian updating, the odds form was used:

$$O(A2(3) \mid B) = O(A2(3)) \times LR(B)1^{2}$$

[1] In the literature, the likelihood ratio is sometimes denoted using alternative notations, such as Λ(B) or L_A(B), where the subscript A explicitly refers to the hypothesis to which the evidence

where:

$$O(A2(3)) = P(A2(3)) / (1 - P(A2(3)))$$

$$LR(B) = P(B \mid A2(3)) / P(B \mid \neg A2(3))$$

Starting from the informed prior P(A2(3))=0.80, the initial odds are:

$$O(A2(3)) = 0.80 / 0.20 = 4$$

Given that B1 represents a highly discriminative piece of evidence, while B2 and B3 further strengthen the clinical-behavioural risk profile, the value of LR(B) was estimated through sensitivity analysis in order to avoid reliance on a single arbitrary point estimate. In this study, evidence B1–B3 is treated as an aggregated evidential set whose overall probative strength is expressed through a single LR(B).

The LR(B) values were selected as a plausible range of evidential strength based on the combined forensic significance of markers B1–B3 and are presented through sensitivity analysis. These values are heuristic in nature and do not constitute direct empirical estimates derived from a single reference study, nor do they purport to represent a point empirical estimate.

Sensitivity Analysis (LR Range)

Three evidential strength scenarios were considered:

- **Conservative**: LR(B) = 8
- **Moderate**: LR(B) = 14
- **High**: LR(B) = 20

The posterior probability was calculated as:

$$P(A2(3) \mid B) = [O(A2(3)) \times LR(B)] / [1 + O(A2(3)) \times LR(B)]$$

(1) Conservative scenario (LR = 8)

$$O(A2(3) \mid B) = 4 \times 8 = 32;\ P(A2(3) \mid B) = 32/33 = 0.9697 \approx 0.97$$

(2) Moderate scenario (LR = 14)

$$O(A2(3) \mid B) = 4 \times 14 = 56;\ P(A2(3) \mid B) = 56/57 = 0.9825 \approx 0.98$$

(3) High scenario (LR = 20)

$$O(A2(3) \mid B) = 4 \times 20 = 80;\ P(A2(3) \mid B) = 80/81 = 0.9877 \approx 0.99$$

Main Finding

Across all three scenarios considered, the posterior probability of hypothesis A2(3) remains exceptionally high, ranging from approximately 0.97 to 0.99. This indicates that, after combining the individually informed prior (based on the historical evidence of re-

pertains. In the present study, the notation LR(B) is retained in accordance with standard forensic statistical practice.

cidivism) with the evidential set B1–B3, the posterior estimate of the probability of rape reoffending in the period 2029–2032 remains very high, within the assumptions of the applied Bayesian model and the examined range of evidential strength.

Discussion

Interpretation of the key finding

The results of the Bayesian analysis indicate that the posterior probability of hypothesis A2(3) that is, the reoccurrence of rape within a three-year period following release (2029–2032) remains exceptionally high and relatively stable, ranging from approximately 0.97 to 0.99, even under conservative assumptions regarding evidential strength, within the assumptions of the applied Bayesian model. This finding derives from the combination of an individually informed prior, based on the offender's criminal history, and strong evidence encompassing repeated commission of the same offence, escalation of violence, and stability of the criminal behavioural pattern, which is consistent with research emphasising the central role of a history of violent behaviour in the assessment of sexual recidivism risk (Hanson and Morton-Bourgon, 2005; Andrews and Bonta, 2010).

It is important to emphasise that the high posterior probability of recidivism obtained in this study does not represent a methodological anomaly, but rather a logical outcome of formal probabilistic reasoning in situations where the available evidence is highly discriminative. Donaldson and Wollert (2008) note that thresholds in the range of 95% to 99% may be justified in contexts where risk assessment carries serious legal and public safety implications, analogous to the standard of "beyond reasonable doubt". In this respect, the Bayesian framework enables a transparent, verifiable, and rational expression of the degree of belief, provided that model assumptions and sources of uncertainty are explicitly stated, in contrast to implicit or intuitive clinical judgements.

In this case, the Bayesian analysis formalises a conclusion that is often reached implicitly in clinical-criminological practice: when a consistent pattern of repeated rape following prior releases is documented in the offender's history, the probability of future recidivism remains high, even in the presence of potentially protective factors. These findings are consistent with a substantial body of literature highlighting the central role of criminal history, stable behavioural patterns, and early onset of violent offending in the assessment of sexual recidivism risk (Hanson and Morton-Bourgon, 2005; Mann, Hanson and Thornton, 2010; Andrews and Bonta, 2017).

The role of individual criminal history in prior formation

A particular strength of this study lies in the manner in which the prior probability of the recidivism hypothesis was defined. In the absence of domestic longitudinal rape recidivism rates for a clearly specified three-year post-release period, the prior was not drawn from the general population nor from aggregated rates of sexual offenders, but was instead derived from the individual criminal history of the specific offender using beta-binomi-

al Bayesian updating. This approach is consistent with the Bayesian principle that prior experiential evidence should be treated as a relevant source of information for the initial probability of a hypothesis (Jaynes, 2003; Gelman *et al*., 2014), while acknowledging the limitations of estimates based on a small number of historical observations.

Such an approach is methodologically justified within a case study framework and accords with the position that Bayesian reasoning is meaningful only when initial probabilities are grounded in relevant and contextually justified assumptions. Donaldson and Wollert (2008) explicitly warn that uncritical reliance on population base rates in forensic contexts may lead to erroneous and normatively problematic conclusions, particularly in the assessment of extreme and high-risk criminal trajectories.

In this respect, the use of population base rates to assess risk in individuals exhibiting stable patterns of severe violent behaviour may result in substantial underestimation of risk. By contrast, reliance on the offender's individual criminal history allows prior behaviour of the same individual to be treated as empirically relevant information about future risk, without uncritical dependence on population averages. This approach is consistent with the principles of structured professional judgement and with contemporary criminological models of criminal careers (Andrews and Bonta, 2010; Douglas *et al*., 2013).

Age, long-term imprisonment, and the limits of the "aging-out" effect

One of the key issues in post-release risk assessment following long-term imprisonment concerns the potential effect of offender ageing ("aging out of crime"). Although theoretical models and part of the empirical literature suggest that age at release and sentence length may function as protective factors with respect to criminal recidivism (Andrews and Bonta, 2010; Lussier, Corrado, and McCuish, 2016), the results of the present analysis indicate that even a conservative reduction of the prior does not lead to a substantial decrease in the posterior probability of recidivism within the examined model and the assumed range of evidential strength.

The reason lies in the strong evidential weight derived from the historical pattern of repeated recidivism, clinical characteristics, and stable behavioural patterns. This finding suggests that the ageing effect is not universal and that, in individuals with prolonged and severe recidivistic trajectories, its impact may be considerably limited, which is consistent with findings from developmental and life-course studies of sexual offending (Hanson and Morton-Bourgon, 2005; Lussier *et al*., 2012).

Demographic variables versus behavioural and dynamic risk factors

Empirical data from the reference domestic study on rape recidivism indicate that sociodemographic characteristics do not clearly differentiate non-recidivists from rape recidivists (Baić *et al*., 2026, in press). This finding is consistent with the results of the Bayesian analysis in the present study, in which the greatest inferential weight was attributed to historical, clinical, and behavioural risk factors rather than to static sociodemographic variables.

Such results further highlight the limitations of actuarial instruments based on group probabilities, particularly with regard to their calibration and applicability to individual cases, as already documented in the international literature on the assessment of violent and sexual recidivism risk (Hanson and Morton-Bourgon, 2009; Rossegger *et al.,* 2014). In forensic and criminal justice contexts, these limitations carry significant implications, as the application of group averages to individual cases may lead to systematic underestimation or overestimation of risk, especially in extreme or atypical criminal trajectories.

Methodological implications of the Bayesian approach

The application of Bayes' theorem in this study demonstrates that the probabilistic framework enables a clear separation between initial assumptions (priors), the available evidence, and their effect on the final risk estimate, thereby increasing the transparency and verifiability of the reasoning process (Jaynes, 2003; Gelman *et al*., 2014). The sensitivity analysis further shows that the principal conclusion remains stable even under conservative assumptions regarding evidential strength, which additionally supports the robustness of the findings and reduces the risk of arbitrary assessment.

The Bayesian approach does not offer the illusion of certain prediction of future behaviour; rather, it enables rational and transparent reasoning under uncertainty, with explicit specification of the degree of belief and the assumptions on which the conclusions rest. This understanding is consistent with contemporary views of forensic probabilistic reasoning, according to which Bayes' theorem constitutes a normative framework for the integration of evidence and risk assessment, rather than a mechanism of deterministic prediction (Donaldson and Wollert, 2008; Taroni *et al.,* 2014).

Limitations of the Study

This study has several important limitations that must be explicitly acknowledged. First, it is a single-case study, which precludes statistical generalisation of the findings to the broader population of sexual offenders. The aim of the research was not generalisation, but rather the demonstration of the methodological framework and inferential logic of Bayesian reasoning in a forensically complex and high-risk case.

Second, due to the lack of domestic longitudinal rape recidivism rates for a clearly defined post-release period, the prior probability was derived from the offender's individual criminal history. This represents a deliberate methodological choice appropriate to a case study design, but it requires caution when interpreting the findings beyond this context, particularly given the limited number of historical observations on which the estimate is based.

Third, the estimation of likelihood ratios (LR) is based on a combination of empirical findings and sensitivity analysis rather than on precise population-level estimates, which further emphasises that the results obtained represent a rational probabilistic assessment rather than empirical proof of future behaviour.

Conclusion

Despite the stated limitations, the results of this study indicate that Bayes' theorem constitutes a methodologically coherent and practically applicable framework for recidivism risk assessment in forensically complex and high-risk cases, within explicitly defined modelling assumptions, which is consistent with contemporary understandings of probabilistic reasoning in the forensic context (Jaynes, 2003; Taroni *et al.,* 2014).

In the present case of a serial rapist, the combination of an individually informed prior, derived from a stable pattern of prior recidivism, and strong evidence encompassing historical, clinical, and behavioural risk factors, indicates that the posterior estimate of the probability of rape reoffending in the period 2029–2032 remains exceptionally high (≈0.97–0.99), even under conservative assumptions regarding evidential strength, with the methodological caveat that the estimate pertains to the specific model and the available evidence. This finding is consistent with empirical research indicating that criminal history and stable patterns of violent behaviour are among the strongest predictors of sexual recidivism (Hanson and Morton-Bourgon, 2005; Andrews and Bonta, 2010; Mann, Hanson and Thornton, 2010).

The Bayesian framework does not replace normative legal decision-making, but it provides a transparent, verifiable, and rational basis for reasoning under uncertainty, with a clear distinction between probabilistic risk assessment and decisions that carry legal consequences, in line with the standards of contemporary forensic expertise (Donaldson and Wollert, 2008; Douglas *et al.,* 2013). In this way, the present study demonstrates that Bayes' theorem is not only mathematically sound, but also a methodologically and normatively grounded framework with significant implications for forensic and criminal justice practice, particularly in contexts where standardised actuarial instruments exhibit limited calibration or reduced applicability to individual cases (Wollert, 2006; Rossegger *et al.,* 2014).

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