Cost-Effectiveness Analysis of Prehospital Trauma Triage Strategies

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Introduction

Trauma care plays an important role in healthcare, especially in treating life-threatening injuries. Timely and proper interventions can significantly improve patient outcomes (Fuller et al., 2024). In the United Kingdom, the establishment of Major Trauma Centres (MTCs) has increased survival rates for severely injured patients, such as those with an Injury Severity Score (ISS) ≥ 16. However, ensuring the efficient use of resources within the trauma system remains a big challenge (Gianola et al., 2021; Fuller et al., 2021).

Prehospital triage tools are designed to guide paramedics in deciding whether to take trauma patients to an MTC or a local hospital. These decisions are informed by the sensitivity and specificity of the triage strategies, which directly affect patient outcomes and healthcare costs (van Rein et al., 2017). High sensitivity ensures that most severely injured patients (ISS ≥ 16) are sent to MTCs, but studies show that increasing sensitivity beyond a certain point led to only small improvements in health outcomes (Gianola et al., 2021). On the other hand, strategies with low specificity often cause overtriage, meaning non-severely injured patients are sent to MTCs, wasting resources and increasing overall costs (Fuller et al., 2021).

Recent studies have highlighted the trade-offs between sensitivity, specificity, and related costs in prehospital triage systems. Although sensitivity is crucial for patient safety, overly high sensitivity increases healthcare expenses without enough improvement in outcomes to justify the cost (Gianola et al., 2021; Fuller et al., 2021). For example, strategies with low specificity send too many non-severe cases to MTCs, which not only raises costs but also reduces the ability to care for truly critical patients (Fuller et al., 2021). This shows the importance of finding a balance between clinical effectiveness and cost-efficiency.

This study uses a decision-analytic framework to compare six hypothetical triage strategies designed for the UK healthcare system. Each strategy has different levels of sensitivity, specificity, and associated costs. By combining a decision tree for short-term outcomes and a Markov model for long-term health states, the analysis provides a complete understanding of both immediate and lifetime cost-effectiveness.

To address uncertainties in model parameters, the study uses deterministic sensitivity analysis (DSA) and probabilistic sensitivity analysis (PSA), which allow for a robust evaluation of cost-effectiveness across various scenarios. Additionally, the study calculates the Expected Value of Perfect Information (EVPI) to measure the potential benefits of reducing decision-making uncertainty and supporting targeted research investments. The evaluation follows the guidelines of the National Institute for Health and Care Excellence (NICE), using a willingness-to-pay threshold of £30,000 per quality-adjusted life year (QALY) gained and applying a discount rate of 3.5% for both costs and QALYs.

Method

This study developed a framework combining a decision tree and a subsequent Markov model to evaluate the cost-effectiveness of six trauma triage strategies within the UK healthcare system. The analysis tracks patients from their initial contact with paramedics through to long-term survival outcomes, incorporating both short-term and lifetime costs and benefits. The perspective of the study follows that of the National Health Service (NHS) and personal social services, ensuring that the economic evaluation aligns with UK healthcare policy standards.

Model Structure

The decision tree models the first year following traumatic injury and represents the initial triage decision: whether the patient is transported to a Major Trauma Centre (MTC) or a local hospital. Each strategy is defined by a specific combination of sensitivity and specificity, which determine the probability of correctly triaging severely injured patients (defined as those with an Injury Severity Score, ISS ≥ 16) to MTCs and the risk of overtriaging non-severely injured patients. Based on injury severity, patients are further categorized into three groups—ISS ≥ 16, 9 ≤ ISS < 16, and ISS < 9—with proportions derived using a Dirichlet distribution to reflect population heterogeneity. Due to the geographical density and existing trauma infrastructure in the UK, secondary transfers between hospitals were not incorporated into the model.

The decision tree estimates costs, survival, and quality-adjusted life years (QALYs) over the first post-injury year. Patients surviving the first year transition into a long-term Markov model, which begins at age 63 and continues until death. This model projects lifetime health outcomes and healthcare costs, applying age-specific mortality risks adjusted for trauma-related excess mortality using hazard ratios. Two separate Markov models were constructed to reflect differences in long-term survival between patients with ISS ≥ 16 and those with less severe injuries. Mortality transitions are informed by UK life tables and stratified by age and gender, ensuring alignment with population-based estimates. A half-cycle correction was applied to improve the accuracy of health state transitions, and both costs and QALYs were discounted at 3.5% annually in line with National Institute for Health and Care Excellence (NICE) guidelines. Final cost-effectiveness estimates were derived by combining the decision tree and Markov model outputs, weighted by the probability of surviving the first year.

All cost parameters were inflated to 2023 values using official NHS economic indices. Inflation adjustments applied the NHS Cost Inflation Index (NHSCII) for recent years and the Hospital and Community Health Services (HCHS) Index for historical data. Costs included ambulance transport, in-hospital care (stratified by facility type), post-discharge services, and long-term healthcare expenditures. To ensure comparability with the UK context, post-discharge costs originally sourced from the United States were converted using a 2008 purchasing power parity (PPP) exchange rate of 0.66 (USD to GBP) and subsequently inflated using NHSCII data. Cumulative inflation multipliers were used for components spanning multiple years, resulting in updated and consistent cost estimates for model inputs.

The evaluation focused on total lifetime healthcare costs and QALYs. Cost-effectiveness was assessed using incremental cost-effectiveness ratios (ICERs). In addition to base-case analysis, short-term mortality and cost outcomes were examined to support interpretation of near-term clinical impact.

Sensitivity Analysis

To account for parameter uncertainty, both deterministic sensitivity analysis (DSA) and probabilistic sensitivity analysis (PSA) were performed. PSA was conducted using 1,000 Monte Carlo simulations, drawing from prespecified distributions to estimate uncertainty in joint parameter effects. DSA involved one-way variation of key model parameters—such as utility values, mortality probabilities, post-discharge costs, and long-term care costs for ISS ≥ 16 patients—within a plausible ±10% range informed by literature and expert consultation. The impact of each parameter on the ICER between Rule 1 and Rule 2 was visually presented using a tornado diagram, which facilitated identification of parameters with the greatest influence on model outcomes. This analysis also helped to prioritize areas for future data collection where decision uncertainty was greatest.

Model parameters related to sensitivity and specificity were derived from published sources, particularly studies by Newgard and Pollard, and reflect the probability of appropriate hospital assignment by paramedics. Baseline mortality and survival probabilities were sourced from UK life tables and adjusted for trauma severity using hazard ratios based on ISS categories. A full list of model inputs, probability distributions, and ranges used in PSA are provided in Appendix 1.

Result

In the base-case analysis, all strategies were initially ranked by QALY to identify strictly dominated options. Rule6 and Rule5 were excluded as they had higher costs and lower effectiveness. Among the remaining, Rule3 was dominated and Rule4 was extendedly dominated by Rule2. Rule2 (£76,486.72; 10.1558 QALYs) was thus retained as the reference strategy. Rule1 provided the highest QALY (10.1825) with an incremental cost of £760.31, resulting in an ICER of £28,442/QALY. As this falls below the NICE threshold of £30,000/QALY, Rule1 is considered cost-effective if decision-makers are willing to pay for modest health improvements. In contrast, Rule4 and Rule3 did not offer sufficient QALY gains to justify their costs, and were excluded based on extended dominance criteria.

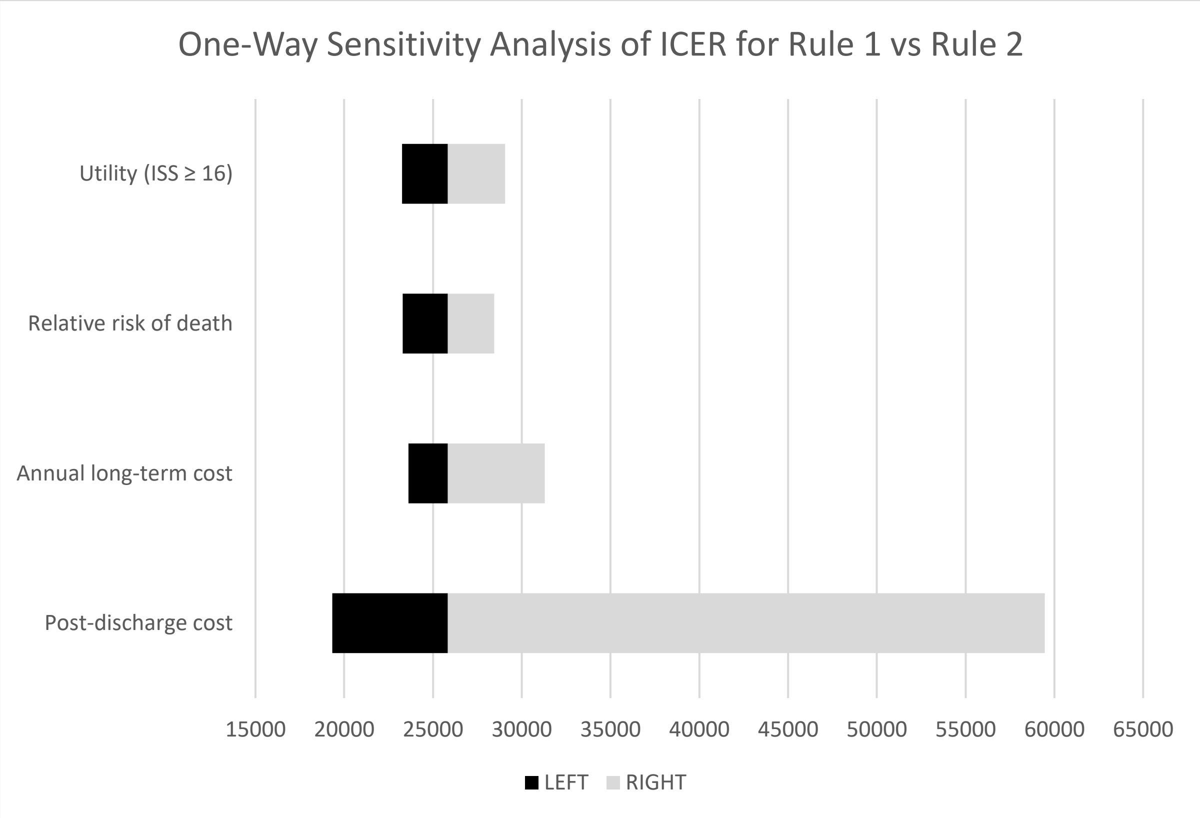
Table 1. ICER

Rule	Total Cost (£)	Total QALY	Incremental QALYs	ICER(£/QALY)
1	77,247.02	10.18	0.027	28,442
2	76,486.72	10.16	-	-
3	76,866.16	10.12	-	Dominated by R2
4	76,600.67	10.13	-	Dominated by R2
5	77,174.38	10.11	-	Dominated by R2
6	77,596.61	10.09	-	Dominated by R2

Deterministic Sensitivity Analysis (DSA)

A one-way DSA was conducted to assess the effect of varying key parameters by ±10%, including: utility (ISS ≥ 16), relative risk of death, post-discharge cost, and annual long-term cost. Each parameter was varied by ±10% to observe its impact on the ICER of Rule 1 versus Rule 2. The result tornado diagram (Figure 1) illustrates the impact of each parameter on the ICER of Rule 1 vs. Rule 2. Post-discharge cost was the most influential parameter, shifting the ICER between £19,328 and £59,455, indicating considerable sensitivity. In contrast, changes in utility, relative risk of death, and long-term costs showed moderate to limited effects.

Figure 1. Tornado Diagram — One-way sensitivity analysis on Rule 1 vs. Rule 2 ICER.



Probabilistic Sensitivity Analysis (PSA)

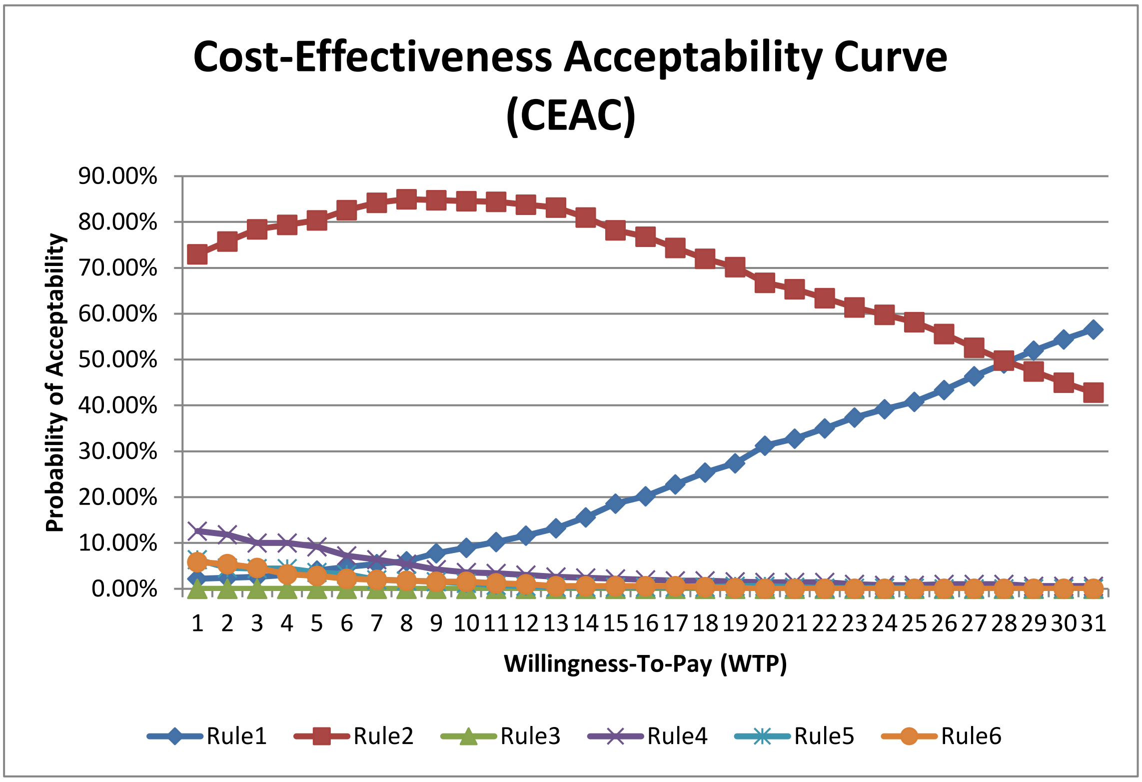
A probabilistic sensitivity analysis using 1,000 Monte Carlo simulations was performed to evaluate parameter uncertainty across joint distributions. As shown in Table 2, the mean probabilistic estimates were similar to the deterministic results, with Rule 1 consistently more effective and slightly more expensive than Rule 2.

Table 2. Deterministic vs. Probabilistic Cost-Effectiveness Estimates

Rule	DSA Cost (£)	DSA QALY	PSA Cost (£)	PSA QALY
1	77,247.02	10.18	77,313.46	10.17
2	76,486.72	10.16	76,521.59	10.14
3	76,866.16	10.12	76,887.86	10.10
4	76,600.67	10.13	76,797.89	10.10
5	77,174.38	10.11	77,151.93	10.08
6	77,596.61	10.09	77,540.44	10.05

To assess decision uncertainty, a Cost-Effectiveness Acceptability Curve (CEAC) was constructed (Figure 2). At lower WTP levels (<£20,000), Rule 2 had the highest probability of being cost-effective (>70%), Rule 1's probability gradually surpasses Rule 2, becoming the most acceptable strategy around £30,000/QALY.

Figure 2. CEAC — Probability of cost-effectiveness by WTP threshold.

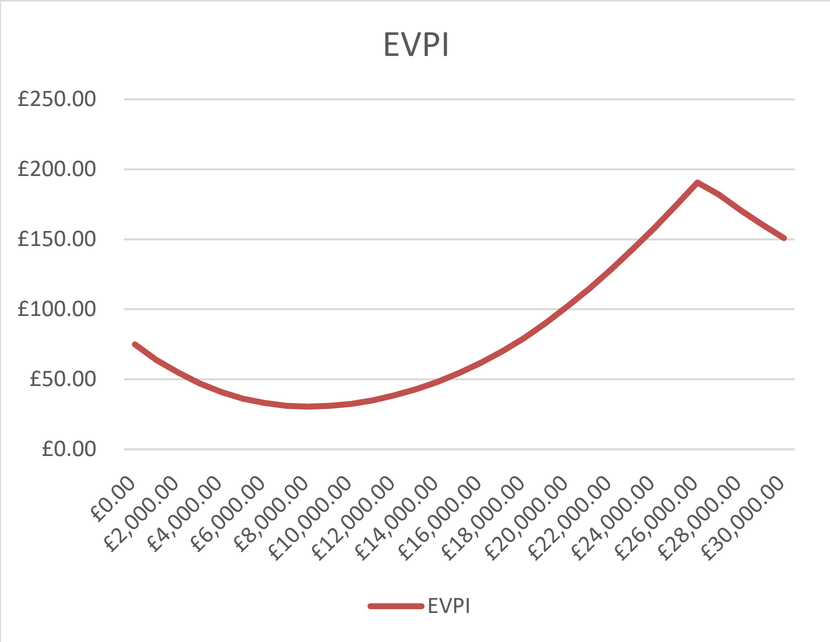


Expected Value of Perfect Information (EVPI)

To quantify the value of eliminating uncertainty, an EVPI analysis was performed. The individual EVPI peaked at £190.55 per person at a WTP of £26,000, indicating that further research at this threshold could deliver meaningful decision value.

As shown in Figure 3, EVPI is low when decisions are obvious (very low or very high WTP), and highest when cost-effectiveness rankings are most uncertain. The findings highlight the importance of reducing uncertainty in post-discharge costs and utility values, which could alter optimal strategy selection near the NICE threshold.

Figure 3. EVPI Curve — Peak uncertainty near £28,000 WTP



- At low WTP values (£0–£5,000/QALY), EVPI is relatively high (~£75), indicating that uncertainty in cost-effectiveness decisions is greatest when limited funds are available for healthcare interventions.
- As WTP increases, EVPI declines (~£30–£50 at £6,000–£15,000/QALY), suggesting that decision-makers are less uncertain about the optimal strategy at these thresholds.
- At WTP values near £20,000–£30,000/QALY, EVPI rises again (~£150–£190), peaking at £26,000/QALY (£190.55). This suggests that further research would be most valuable at these WTP thresholds, where uncertainty in selecting the optimal strategy remains significant.

Table 2. EVPI (£) at various WTP thresholds

WTP (£)	EVPI (£)
£0	£74.95
£5,000	£36.04
£10,000	£32.46
£15,000	£54.64
£20,000	£102.17
£25,000	£173.88
£26,000	£190.55
£30,000	£150.77

Discussion

The findings of this study illustrate the inherent tension between efficiency and equity in trauma triage decision-making. While Rule 2 was the most cost-effective strategy under a strict cost-minimization objective, Rule 1 offered improved health outcomes at an ICER of £28,442/QALY—well within NICE's accepted threshold. This demonstrates a key policy trade-off: when constrained by budget, Rule 2 preserves resources; when willing to invest in marginal gains, Rule 1 becomes a justifiable alternative.

These trade-offs are not only economic but also ethical. High-specificity strategies like Rule 2 reduce unnecessary MTC admissions, which is essential for preserving trauma center capacity (Pollard et al., 2022). However, they carry a greater risk of undertriage, potentially delaying access to definitive care and worsening outcomes (Newgard et al., 2016). In contrast, high-sensitivity strategies like Rule 1 reduce this risk but contribute to overtriage, stretching limited resources and increasing costs without proportional health gain (Morris et al., 2021). This echoes international findings suggesting that the optimal triage strategy must be responsive to local trauma system maturity, patient mix, and funding structure.

The Cost-Effectiveness Acceptability Curve (CEAC) supports this view, showing that Rule 1 becomes the most acceptable strategy as WTP exceeds £26,000/QALY. In well-resourced urban networks, where MTCs are geographically accessible and operational strain is lower, this shift is clinically and economically defensible. However, in rural or capacity-limited settings, overtriage may lead to excessive secondary transfers, increased delays, and unintended cost escalation—making Rule 2 a more pragmatic default strategy. These findings reinforce the need for regionally tailored triage protocols, rather than one-size-fits-all solutions.

The tornado diagram from the DSA reveals that post-discharge costs and utility estimates for ISS ≥ 16 are the most influential parameters. This underscores the need to improve real-world data collection on trauma recovery and long-term care utilization. For example, the utility value of 0.7–0.9 commonly used for survivors of severe injury may overestimate health-related quality of life, leading to biased QALY estimates and overstatement of strategy benefits.

The Expected Value of Perfect Information (EVPI) analysis further strengthens this point. The peak EVPI near £26,000 suggests that decision uncertainty is greatest at precisely the WTP level where the choice between Rule 1 and Rule 2 pivots. This justifies targeted data collection on high-impact parameters such as post-discharge costs for survivors of major trauma,Short-term mortality differences between MTCs and local hospitals, long-term HRQoL trajectories of ISS ≥ 16 patients and functional recovery, caregiver burden, and informal costs (which were excluded in this model)

Moreover, secondary transfers were not explicitly modelled, yet field triage studies have shown that delayed definitive care significantly affects both cost and outcome. Future models should incorporate inter-hospital transfer probabilities and delays, especially for rural or underserved regions.

Lastly, while this analysis reflects an NHS perspective, trauma has substantial societal impacts, including productivity loss and caregiver burden. Integrating a societal perspective could shift the cost-effectiveness balance, particularly for younger populations or those with long-term disability.

Conclusion

This study reinforces that Rule 2 is the most efficient strategy under constrained budgets, but Rule 1 becomes increasingly attractive when health outcome gains are prioritized. The optimal strategy is therefore context-dependent, influenced by regional MTC availability, triage accuracy, and system resilience. Future research should prioritize real-world transfer data, societal cost inclusion, regionalised CEAs, improved measurement of trauma recovery.

Only with better data can decision-makers confidently balance lives saved against costs incurred and design trauma systems that are both clinically sound and economically sustainable.

Appendix 1: Baseline parameters probabilities

Variable description	Deterministic mean	Distribution type	Alpha/N	Beta
Event probabilities				
Injury Severity (ISS)				
ISS ≥ 16	0.09068	Dirichlet	428	
9 ≤ ISS < 16	0.14915	Dirichlet	704	
ISS < 9	0.76017	Dirichlet	3588	
Triage Decision (Rule 1)				
Triage Positive (ISS ≥ 16)	0.95	Beta	38	2
Triage Negative (ISS ≥ 16)	0.05	Beta		
Triage Positive (ISS < 16)	0.8	Beta		
Triage Negative (ISS < 16)	0.2	Beta	200	800
Triage Decision (Rule 2)				
Triage Positive (ISS ≥ 16)	0.8	Beta	20	5
Triage Negative (ISS ≥ 16)	0.2	Beta		
Triage Positive (ISS < 16)	0.6	Beta		
Triage Negative (ISS < 16)	0.4	Beta	400	600
Triage Decision (Rule 3)				
Triage Positive (ISS ≥ 16)	0.75	Beta	30	10
Triage Negative (ISS ≥ 16)	0.25	Beta		
Triage Positive (ISS < 16)	0.45	Beta		
Triage Negative (ISS < 16)	0.55	Beta	550	450
Triage Decision (Rule 4)				
Triage Positive (ISS ≥ 16)	0.6	Beta	30	20
Triage Negative (ISS ≥ 16)	0.4	Beta		
Triage Positive (ISS < 16)	0.4	Beta		
Triage Negative (ISS < 16)	0.6	Beta	300	200
Triage Decision (Rule 5)				
Triage Positive (ISS ≥ 16)	0.5	Beta	10	10
Triage Negative (ISS ≥ 16)	0.5	Beta		
Triage Positive (ISS < 16)	0.25	Beta		
Triage Negative (ISS < 16)	0.75	Beta	375	125
Triage Decision (Rule 6)				
Triage Positive (ISS ≥ 16)	0.3	Beta	9	21
Triage Negative (ISS ≥ 16)	0.7	Beta		

Triage Positive (ISS < 16)	0.1	Beta		
Triage Negative (ISS < 16)	0.9	Beta	1800	200
Outcome Probabilities				
Death within 30 days (ISS ≥ 16, MTC)	0.1	Beta	477.78	4299.99
Death within 30 days (ISS < 16)	0.012	Beta	2186.2	179996.84
Relative risk for patients with an ISS ≥ 16 treated at a local hospital for death within 30 days	1.25	Lognormal	0.2163	
Death between 30 days and 1 year (ISS ≥ 16, MTC)	0.03	Beta	134.12	4336.5
Death between 30 days and 1 year (ISS < 16)	0.017	Beta	1091.33	63104.65
Relative risk for patients with an ISS ≥ 16 treated at a local hospital for deaths after 30 days and before 1 year	1.64	Lognormal	0.472	
State Transition Probabilities				
Hazard ratio for deaths for patients whose ISS ≥ 16 compared to the general population	5.19	Lognormal	1.648	
Hazard ratio for deaths for patients whose ISS < 16 compared to the general population	1.38	Lognormal	0.322	
HRQoL parameters				
Utility of people whose ISS ≥ 16	0.7	Beta	61.87	26.52
Utility of people whose ISS < 16	0.8	Beta	26.18	6.55

Variable description	Deterministic mean	Distribution type	Shape	Scale
Cost parameters				
Ambulance cost	£429.02	Gamma	323.31	1.33
In-hospital cost (ISS 1-8)	£10365.08	Gamma	164.7	62.93
In-hospital cost (ISS 9-15)	£9622.10	Gamma	465.91	20.65
In-hospital cost (ISS 16-24)	£15071.69	Gamma	180.13	83.67
In-hospital cost (ISS 25-34)	£19685.84	Gamma	88.79	221.70
In-hospital cost (ISS 35-75)	£26208.45	Gamma	27.59	913.51

In-hospital cost (ISS>16 ,weighted average cost)	£18052.89			
Post-discharge cost (ISS ≥ 16, MTC)	£36915.46	Gamma	370.54	99.63
Post-discharge cost (ISS ≥ 16, local)	£36243.05	Gamma	437.94	82.76
Post-discharge cost (ISS < 16, MTC)	£9786.32	Gamma	1276.67	544.34
Post-discharge cost (ISS < 16, local)	£10943.84	Gamma	515.77	21.22
Annual long-term cost (ISS ≥ 16)	£7,831.68	Gamma	19.58	391.58
Annual long-term cost (ISS < 16)	£3,464.13	Gamma	8.66	173.20

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