Injury Severity: Scales, Incidence, Hospitalization Rate, Mortality Risk, Economic Costs, Modeling Considerations, and Best Practices

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Abstract

Introduction: Injury assessment and modeling present several challenges. Methods are needed for assessing the severity of injuries, for quantifying impacts along those gradations (e.g., economic costs), and for comparing injuries to each other and to fatalities. While a variety of such methods exist, there is limited comprehensive, direct, and collated information available comparing them along various dimensions or to help assess their fitness for a particular purpose.

Method: Three common and widely applicable injury severity scales that are useful in injury and safety analyses are reviewed: hospitalized/non-hospitalized dichotomy; Abbreviated Injury Scale (AIS); and Injury Severity Score (ISS). Their advantages, limitations, caveats, and risks are discussed, and data for each are summarized (incidence, hospitalization rate, mortality risk, and economic costs). Operations research, machine learning, econometrics, and statistical classification methods are used to bound the range of AIS levels at each ISS value, to develop a probabilistic AIS-ISS map, and to transfer AIS-based economic costs onto the ISS scale (ordinal logistic regression, Gaussian naïve Bayes). A clustering algorithm (k-means) is also used to group ranges of AIS/ISS levels according to various data features.

Results: Bounding analysis reveals each ISS value links to one or a small number of AIS levels. The cluster assignments are reasonably stable across data features. And when viewed over the entire ISS range, the mapped AIS-based costs are remarkably linear, and reduced-form ISS cost models are presented.

Conclusions: The methodology can be applied to any quantity (not just costs). It therefore represents a fundamental development in the understanding of the relationship between the AIS and ISS.

Practical Applications: This greatly improves the comparability of the scales and facilitates the pooling of mixed AIS/ISS data in meta-analyses. In particular, it allows costs to be quantified for the ISS scale.

Keywords: Abbreviated Injury Scale (AIS); Injury Severity Score (ISS); machine learning; econometrics; statistical classification; ordinal logistic regression; naïve Bayes classifier; k-means clustering

I. Introduction

1.1. Injury modeling

Mortality and morbidity modeling is a significant aspect of injury, health, and safety analysis, as well as related economic and cost-effectiveness evaluations and risk management and policy decisions. Often, the focus is fatal injuries, and many analyses sidestep nonfatal injuries by examining only fatal injuries. Nevertheless, nonfatal injuries can be important, perhaps even more so than fatalities.

Injury modeling presents several challenges. Relative to deaths, nonfatal injuries are more prevalent, present along a spectrum of severity, and are quite multidimensional in their effects, particularly related to disability and impairment, pain and suffering, and reduced quality-of-life [1,2,3]. While death is not entirely unidimensional or monolithic, it is considerably less variable in its presentation and effects.[1] This necessitates methods for evaluating the severity of injury, for quantifying impacts along those gradations (e.g., economic costs), and for comparing nonfatal injuries to each other and to fatalities.

There exist a variety of such methods. Currently, this information is scattered, and there is limited comprehensive, direct, and collated information available to compare them (advantages, limitations, caveats, and risks) or to help assess their fitness for a particular purpose. This article fills these voids, by

[1] For example, the timing of death is variable (e.g., immediate, in hospital, reduced life expectancy).

summarizing and extending various injury data and models. In doing so, fundamental insights are derived relating to these scales and their relationship to one another. Throughout, relevant modeling considerations are discussed and best practice recommendations are presented.

1.2. Injury cost types

Tyree basic types of economic costs are used to describe injuries [4-11]

1. *Cost of injury*. Costs that are relatively easy to quantify in monetary terms (e.g., medical expenditures, lost work); can include both market and household productivity; excludes intangible costs (e.g., pain and suffering), and so generally regarded as a lower bound cost value.
2. *Quality-of-life.* Quality-related costs, as assessed using some quality measure; may also be translated into monetary terms, although the link between the quality measure and true economic value may be tenuous or uncertain.
3. *Willingness-to-pay*. Value society actually places on injury risk reductions, considering all of the trade-offs involved, as evidenced by behavior in economic markets (*revealed preference*).

Costs can also include losses of family members or caregivers. Different cost types can sometimes be added together (e.g., cost-of-injury and quality-related costs), to generate a more complete cost picture or facilitate comparisons (avoiding double counting). In this article, costs are per injury incident (not population level), in 2023 USD (using the Consumer Price Index), and given to three significant digits.

A common quality measure is the *quality-adjusted life year* (QALY),[2] which assesses the trade-offs between longevity and time spent in various health or injury states. One year of perfect health is one QALY; death confers zero QALY; and various disutility states exist between. While useful for making comparisons, many authors caution against assigning monetary values to QALYs, as linking it to economic value can be tenuous (because QALYs or similar goods are not traded in markets) [4,6,7,9,10,12].

1.3. Injury severity scales

Myriad injury severity scales have been developed and used [13-16]. A review by Mehmood *et al*. [17] identified 57 such scales. This article reviews and extends three of the most common and broadly applicable off-the-shelf severity scales. The focus is injury and safety analyses and related economic evaluations (not clinical settings), and only *anatomic* scales are included, or those for describing *physical* injuries (not disease/illness, psychological ailments, etc.). The scales are: hospitalized/non-hospitalized dichotomy (two-level); Abbreviated Injury Scale (six-level); and Injury Severity Score (44-level).

1.4. Hospitalized/non-hospitalized injuries

This bifurcation splits injuries into these mutually exclusive categories [5,18,19]

1. *Non-hospitalized*. Treated and released (e.g., at scene, hospital ED, outpatient, doctor's office). Can also include injuries sufficiently mild that the person did not seek formal treatment.
2. *Hospitalized*. Inpatient hospitalization, where the person survives at least until discharge.

[2] Similar measures include the *disability-adjusted life year* (DALY) and *health-adjusted life year* (HALY). However, these are not discussed, as they apply also (and perhaps mostly) to disease/illness rather than injuries.

Hospitalized injuries can be further stratified by their *length of stay* (LOS), which can be a reasonable surrogate for injury severity [20]. After the Boston Marathon bombing (2013), LOS was used to allocate victim compensation funds, with compensation for hospitalized persons increasing in their LOS [21]. Data on cost per hospital inpatient day by U.S. state are available from [22], and on average LOS and total cost per stay from [23]. And while useful, the hospitalized/non-hospitalized split can be somewhat of a blunt instrument, often unable to adequately differentiate the many gradations of injury.

1.5. Abbreviated Injury Scale

A more elaborate instrument is the *Abbreviated Injury Scale* (AIS), ranging from 1 to 6 (integer-valued). Based on expert deliberation and consensus, the AIS was developed by the Association for the Advancement of Automotive Medicine (AAAM), as a systematic and standardized way of characterizing injuries from motor vehicle accidents. It is useable across many different kinds of injuries and is often regarded as a good compromise between clinical detail and ease of application [1,14,15,25]. The methods of AIS scoring are periodically revised and expanded, most recently with the 2015 version [26].

In cases of multiple injuries, the *maximum AIS* (MAIS) is the most severe injury (highest AIS) anywhere in the body (for persons with only a single injury, AIS = MAIS). The different MAIS levels are perhaps best understood using the examples in Willis & LaTourrette [27] (Table 1). Injury researchers and investigators often consider the most severe level (MAIS 6) as equivalent to fatalities [2,11,27,28,29], although some MAIS 6 injuries are in fact survivable in some circumstances [1,15,28,30-35]. Nevertheless, theoretical justification exists for considering MAIS 6 overall as being indistinguishable from fatalities (Section 4.3).

The fundamental goal of the AIS is to divide the vast, diverse, complex, and multifaceted landscape of injuries into a handful of manageable levels – to facilitate categorization, analysis, research, communication, and discussion. In this way, the AIS is similar to many other scales, including the

- Enhanced Fujita scale (tornadoes)
- Saffir-Simpson scale (hurricanes)
- Modified Mercalli Intensity (earthquakes)
- Volcanic Explosivity Index (volcanic eruptions)
- International Nuclear and Radiological Event Scale (radiation disasters)
- Air Quality Index (air pollution hazards)
- Carnegie Classification (higher education institutions)
- Insurance Institute for Highway Safety crash ratings (vehicle safety)

The AIS has been used to characterize a wide array of injuries occurring in diverse settings, including: transportation accidents (its original purpose) [2,11,29,36], tornados [37], earthquakes [38], hurricanes [39], firearms [40], terrorist attacks [27,41,42], and war [43]. Rigorous AIS scoring requires specialized clinical knowledge and training. However, if injury descriptions are available, AIS scores can sometimes be estimated with sufficient accuracy (see also the injury clusters in Section 4.1). Semi-structured approaches are also available, such as [35].

The AIS was developed to describe injuries in motor vehicle accidents, which consist mainly of blunt trauma (push/pull/impact) types of injuries. Caution should be exercised when applying it to fundamentally different kinds of injuries, such as penetrating injuries (e.g., gunshot wounds) [13,16,40,44]. The MAIS also discards all injury information other than the most severe, and may not capture the full landscape of injury [3].

Table 1. Maximum Abbreviated Injury Scale (MAIS) Levels

Injury Severity		Example Injuries	General Prognosis
MAIS 1	Minor	Abrasion, laceration, strain, sprain, contusion	Treated and released (see also Section 1.4)
MAIS 2	Moderate	Simple broken bone, loss of consciousness, serious strain or sprain	Follow-up required, weeks to months to heal, but will heal
MAIS 3	Serious	Complicated fracture, serious joint injury, concussion, minor crush injury	Substantial follow-up needed, some minor disability likely
MAIS 4	Severe	Massive organ injury, heart laceration, loss of limb, crushed extremities	Hospitalization, substantial short-term and moderate long-term disability
MAIS 5	Critical	Spinal cord syndrome, crush syndrome with kidney failure	Extended hospitalization, significant long-term disability
MAIS 6	Maximum	Decapitation, massive destruction of head, spinal cord/column, brainstem, or torso, partial thickness burns to ≥90% of body area	Usually (though not invariably) fatal (see Table 3)

Sources: AAAM [26]; MAIS 1-5 from [27]; MAIS 6 examples from [31,34,35].

1.6. Injury Severity Score

A more information-rich alternative, especially useful in cases of multiple injuries, is the *Injury Severity Score* (ISS) [45].[3] Based on the AIS (Section 1.5), first, the most severe (highest AIS) injury in each of six defined body regions is noted (head/neck, face, chest, abdomen, extremities, and external). The ISS is then computed as the sum of squares of the three highest of these AIS values, each representing an injury in a different body region

$$ISS = (AIS_1)^2 + (AIS_2)^2 + (AIS_3)^2 \tag{1}$$

The ISS ranges from 1 (single AIS 1) to 75 (trio of AIS 5, or any number of AIS 6), taking on 44 possible integer values (with varying distance between adjacent ISS values). The developers of the ISS cite its linearity as one of its primary benefits relative to the MAIS (as it relates to mortality risk). The ISS is used mostly to control for injury severity or patient mix in injury and trauma studies, and to correlate it to various injury outcomes [14,16,31,32,44,49,50,51]. The ISS has proven enormously useful to researchers: *Google Scholar* reveals over 11,700 citations of the original ISS article (June 2025) (see also [50]).

The ISS is based on and is a cousin scale of the AIS (Section 1.5), and so inherits many of its limitations. Like the MAIS, the ISS discards much injury information. The ISS considers only the most severe injury in each body region (potentially biasing it in cases of many injuries in a single body region), and sometimes overlooks more severe injuries in favor of less severe ones in different body regions. It also considers only the three most severely injured body regions [52]. However, this might also be a benefit of the ISS, or taking a more "wholistic" approach, rather than "overfitting" to injuries in one body region. Kilgo *et al*. [50] find that when the body regions assumption is relaxed, and the three most severe injuries are used, regardless of where in the body they occur, the ISS value is unchanged in 56% of cases.

The ISS has three parameters (Equation 1), whereas the MAIS has one. Even if one or two of its component AIS values (Equation 1) are zero-valued, the ISS still has three parameters, as those zeroes

[3] Similar measures include the: *ICD-9 Injury Severity Score* (ICISS), *New Injury Severity Score* (NISS), and *Trauma and Injury Severity Score* (TRISS). However, these are not discussed in this article, as the NISS is not as ubiquitous as the ISS, and the ICISS and TRISS are most useful in clinical settings (not safety analyses).

nonetheless contain statistical information. From a statistical standpoint, justifying these additional parameters requires that the model fit improve. This idea is incorporated in statistics such as the *Akaike information criterion* (AIC) [53] and *Bayesian information criterion* (BIC) [54], which penalize models with more parameters (while also rewarding models with better fits). Whether or not sufficiently improved model fit is achieved (as assessed using these or other statistics) will depend on the nature and structure of the model and data, but should be considered in MAIS/ISS comparisons.

II. Methods

2.1. Literature searches

Data related to these scales (Sections 1.4-1.6) are collated, summarized, and compared (incidence, hospitalization rate, mortality risk, and economic costs). Mortality risk data can be used to remove deaths from mixed (fatal/nonfatal) data, or to adjust injury-only incidences to gauge total persons impacted. Additionally, mortality risk, while describing likelihood of *death*, may correlate with injury severity (or aspects of it), and so it is included. Unless otherwise noted, data are for nonfatal injuries.

Only the *severity of injury* is examined; all other factors are exogenous. Uncertainty and variability are discussed in Section 4.3. Literature reviews encompassed all works in English, that examine injuries overall (not narrow subsets), and in U.S. populations. Motor vehicle accident injuries are included, as these are very prevalent and well-studied. Only studies where data are articulated for each individual scale level are included (i.e., not in the form of ranges, distributions, or summary measures such as mean or median). When evaluating data quality across studies, both recency (coverage years) and abundancy (study size) were considered. All studies meeting the inclusion criteria are noted, but data from some older and smaller studies are not presented.

2.2. MAIS-ISS probabilistic map and ISS economic costs

Operations research, machine learning, econometrics, and statistical classification methods are used to bound the range of possible MAIS level at each ISS value, to develop a probabilistic MAIS-ISS map, and to generate ISS-based economic costs, by mapping AIS-based costs onto the ISS scale. All modeling and visualizations were performed using Python [55].

Bounding analysis is used to determine the feasibility region within the MAIS-ISS space, by exploiting the basic relationship between the AIS and ISS (Equation 1). At each MAIS level, the ISS is bounded between

$$ISS_{min} = (MAIS)^2 \tag{2}$$

$$ISS_{max} = 3 \cdot (MAIS)^2 \tag{3}$$

reflecting the AIS triplets (MAIS, 0, 0) and (MAIS, MAIS, MAIS), respectively (Equation 1), and where MAIS 6 is always ISS = 75 (Section 1.6). This feasibility region encapsulates all valid MAIS-ISS pairs.

Two statistical classification methods are used to allocate shares across MAIS levels at each ISS value

- *Ordinal logistic regression*.[4] Extension of linear regression that is used to model a multilevel categorical quantity (rather than a continuous linear relationship), and where there is a natural

[4] Python. *OrderedModel()* function, statsmodels library.

"order" (monotonicity) to the levels (e.g., MAIS levels). It uses the logistic function (s-curve) to assign probabilities across levels of the dependent variable (MAIS) at each value of the independent variable (ISS). Assumes the slopes are invariant across levels (MAIS), with the various categories differentiated only through their intercepts ("proportional odds").

- *Gaussian naïve Bayes*.[5] Grounded in Bayesian inference. Assumes the level probabilities are proportional to the probability density function of the normal distribution (hence, Gaussian), computed for each independent variable (ISS) and at each level of the dependent variable (MAIS), using sample means and sample standard deviations. The product of these distributions and the empirical class membership portions (MAIS) in the input data is taken, and the probabilities renormalized to sum to one. Assumes the predictors act independently (hence, "naïve"), and the modeling framework therefore cannot accommodate things like variable interaction terms, but this is less applicable in the case of only single predictor variable (ISS).

The *training data* (model input) are all valid MAIS-ISS combinations contained within the feasibility space (from the bounding analysis), which are left unweighted (so as to arrive at an "best" or central value). This modeling setup treats the ISS as a continuous quantity (even though it is technically only integer-valued). The maximum ISS = 75 can result either from the AIS triplet (5, 5, 5), which is MAIS 5, or from any number of MAIS 6 (Section 1.6). Collectively, the studies of [31,32,33] identified 1,460 survivors with ISS = 75 who had MAIS 6, versus only seven persons with ISS = 75 with MAIS 5. As such, ISS = 75 is essentially MAIS 6, and is modeled accordingly.

The two classifiers (above) differ somewhat in their predictions (for ISS values that link to multiple MAIS levels). Each classifier may capture important aspects of the data and modeling space, and so the midpoint was used. Both classifiers assign non-zero probabilities across all MAIS levels at each ISS value (because the logistic function and normal distribution both span the entire x-axis). To ensure the predictions remain in-range, the probabilities for all invalid MAIS-ISS combinations were recoded to zero, and the remaining probabilities renormalized to sum to one (at each ISS value).

The probabilistic map is demonstrated by using it to transfer AIS-based economic costs onto the ISS scale. Reduced-form ISS cost models are presented that can be readily applied by researchers and analysts. Although demonstrated using cost data, the method can be applied to any quantity (incidence, hospitalization rate, LOS, ICU admission, work days lost, disability, mortality, etc.). As such, this represents a fundamental development in the understanding of the relationship of the AIS and ISS, greatly improving the comparability of the scales and facilitating the pooling of mixed AIS/ISS data in meta-analyses.

2.3. Injury clusters and average costs

A clustering algorithm is used to group ranges of severity values (MAIS/ISS) according to various data features, including the newly-generated ISS costs (Section 2.2). These clusters can be especially useful in cases where specific MAIS/ISS values are unknown, but where severity *ranges* can reasonably be estimated. The clusters are fitted using *k-means clustering*,[6] which assigns observations to the cluster with the nearest centroid (hence, "means"), minimizing variance about the cluster centroids, maximizing within-cluster homogeneity. The lone model *hyperparameter*, k, is the number of clusters to fit. For MAIS, k = 2, and for ISS, k = (2, 3, 4) clusters are examined.

[5] Python. *GaussianNB()* function, scikit-learn library.
[6] Python. *KMeans()* function, scikit-learn library.

Finally, while the primary goal of this article is to stratify injuries by severity, it can also be useful and informative to have some injury cost values handy that are severity-neutral. These average injury costs, formed by combining the incidence and cost data various ways, are also presented and compared.

III. Results

3.1. Literature data

Hospitalized/non-hospitalized data are presented in Table 2. While the Finkelstein *et al*. [18] study size is larger, WISQARS [19] data are more recent. However, WISQARS may represent a more severely injured population (based on hospitalization rate). Regardless, the costs are similar.

MAIS data are summarized in Table 3. The studies differ in their data, methods, manner of AIS coding, etc., and exhibit some variability. For example, [1,28,30] consist of persons treated at hospital trauma centers (theoretical 100% hospitalization rate), and may represent more severely injured populations than [11,18]. The hospitalization rate blends the hospitalized/non-hospitalized distinction (Section 1.4) and the MAIS. Beginning at MAIS 4, all injuries require hospitalization (motor vehicle accidents). MAIS cost data are provided in Table 4. Note the non-monotonicity of the Graham *et al*. [29] costs (specifically, MAIS 4). The MAIS costs are also plotted in Figure 1, showing their generally exponential nature.

ISS data are presented in Table 5. Note that the study size in [50] is considerably larger and the data are more recent than in [44]. However, both study populations consist of persons treated at hospital trauma centers (potential 100% hospitalization rate), and may therefore be skewed towards more severe injuries (rather than being representative of injuries more broadly). Mortality risk is not always monotonic in the ISS. This is partly because different AIS triplets with the same ISS value (Equation 1) can have very different mortality rates [31,32,44,50], and also because injury incidence varies enormously across ISS values, potentially contributing to variability at the less-populated ISS values. The majority of injured persons exist at only three ISS values (1, 4, 9).

Table 2. Hospitalized/Non-Hospitalized Injuries Incidence and Economic Costs

Injury Severity	**Injury Incidence**		**Cost (2023$)**	
	Finkelstein *et al*. [18]	WISQARS [19]	Finkelstein *et al*. [18] + QoL [19]	WISQARS [19]
Non-hospitalized	96.3%	84.5%	$85,300	$88,000
Hospitalized	3.7%	15.5%	$247,000	$235,000

QoL = quality-of-life. Incidence of nonfatal injuries. Mortality rate zero for both groups. Cost per injury incident. Additional data available in [5], but are more dated (1985).
WISQARS [19] - 26,480,000 injuries (2023), medical/work costs and monetized QALYs (Section 1.2), using the methods of [10,24].
Finkelstein *et al*. [18] - 49,978,023 injuries (2000), medical/work costs, supplemented using QoL costs of WISQARS [19] (for better comparisons).

Table 3. Maximum Abbreviated Injury Scale (MAIS) Incidence, Hospitalization, and Mortality

Injury Severity	Injury Incidence			Hospitalization Rate	Mortality Risk		
	Copes *et al*. [30]	Finkelstein *et al*. [18]	Blincoe *et al*. [11]	Blincoe *et al*. [11]	Copes *et al*. [30]	Gennarelli *et al*. [28]	Gennarelli & Wodzin [1]
MAIS 1	12.4%	76.6%	86.0%	0.007	0.002	0.007	0.007
MAIS 2	34.9%	20.7%	9.5%	0.233	0.002	0.017	0.008
MAIS 3	35.6%	1.9%	3.1%	0.815	0.053	0.054	0.035
MAIS 4	13.0%	0.3%	0.4%	1	0.224	0.202	0.146
MAIS 5	3.9%	0.1%	0.2%	1	0.459	0.453	0.396
MAIS 6	0.1%	0.3%	0.8%	1	0.893	0.873	0.790

Incidence and hospitalization for nonfatal injuries. Mortality risk uses pooled fatal/nonfatal data.
Schellenberg *et al*. [34] additionally find a MAIS 6 mortality risk of 0.746 (19,247 fatal/nonfatal, 2007-2017).
Additional data available in [45] (motor vehicle accidents), but the study size is smaller (1,840 injuries/247 deaths), the data are more dated (1968-1969), and MAIS 6 was not used, and also in [46], but the study size is smaller (5,333 injuries/201 deaths) and all persons had only a single injury.
Blincoe *et al*. [11] - 4,470,023 injuries/36,500 deaths (2019); motor vehicle accidents (reported and estimated non-reported); includes various victim types (e.g., vehicle occupants, motorcyclists, bicyclists, pedestrians); MAIS 6 fatal.
Finkelstein *et al*. [18] - approx. 43,100,000 injuries (2000); excludes unknown MAIS (approx. 6,950,000).
Copes *et al*. [30] - 85,820 injuries/8,381 deaths (1982-1988).
Gennarelli & Wodzin [1] - 181,707 fatal/nonfatal ("past several years"); all persons had only a single injury.
Gennarelli *et al*. [28] - 174,160 fatal/nonfatal (1982-1989).

Table 4. Maximum Abbreviated Injury Scale (MAIS) Economic Costs

Injury Severity	ISS Bounds (Figure 2)		Cost (2023$)			
	Min.	Max.	Graham *et al*. [29,47]	Finkelstein *et al*. [18] + QoL [11]	DOT [2,47]	Blincoe *et al*. [11]
MAIS 1	1	3	$0	$52,700	$39,600	$59,000
MAIS 2	4	12	$1,450,000	$490,000	$620,000	$551,000
MAIS 3	9	27	$2,110,000	$2,130,000	$1,390,000	$2,410,000
MAIS 4	16	48	$924,000	$3,590,000	$3,510,000	$4,270,000
MAIS 5	25	75	$10,700,000	$6,130,000	$7,830,000	$7,170,000
MAIS 6	75	75	$13,200,000	$11,200,000	$13,200,000	$11,800,000

CoI = cost of injury. DOT = U.S. Department of Transportation. ISS = Injury Severity Score. QoL = quality-of-life.
VSL = value of statistical life. WTP = willingness-to-pay. Cost per injury incident.
Blincoe *et al*. [11] - CoI/QoL measure; motor vehicle accidents (2019); medical, EMS, productivity, workplace, insurance, and legal costs and monetized QALYs (Section 1.2); MAIS 6 estimated as weighted average of MAIS 5 (25%) and deaths (75%), on the basis that MAIS 6 resemble fatalities 75% of the time [34].
Finkelstein *et al*. [18] - CoI/QoL measure; medical/work lost costs, supplemented using QoL costs of Blincoe *et al*. [11] (for better comparisons); excludes unknown MAIS (approx. 6,950,000).
DOT VSL [47] – WTP measure; $13.2 million (2023$); wage-risk studies (analyzing wages paid to workers to perform riskier employment); applied to DOT [2] and Graham *et al*. [29] injury fractions.
DOT [2] - QoL/WTP measure; quality-adjusted portion of remaining life lost (0.003, 0.047, 0.105, 0.266, 0.593, 1), MAIS 6 fatal. Similar to QALY (Section 1.2), *years of potential life lost* (YPLL), and *value of statistical life year* (VSLY).
Graham *et al*. [29] - QoL/WTP measure; disutility fractions (0, 0.11, 0.16, 0.07, 0.81, 1), based on the *Functional Capacity Index* (FCI) [48]; MAIS 1 excluded (because they are relatively minor); MAIS 6 fatal.

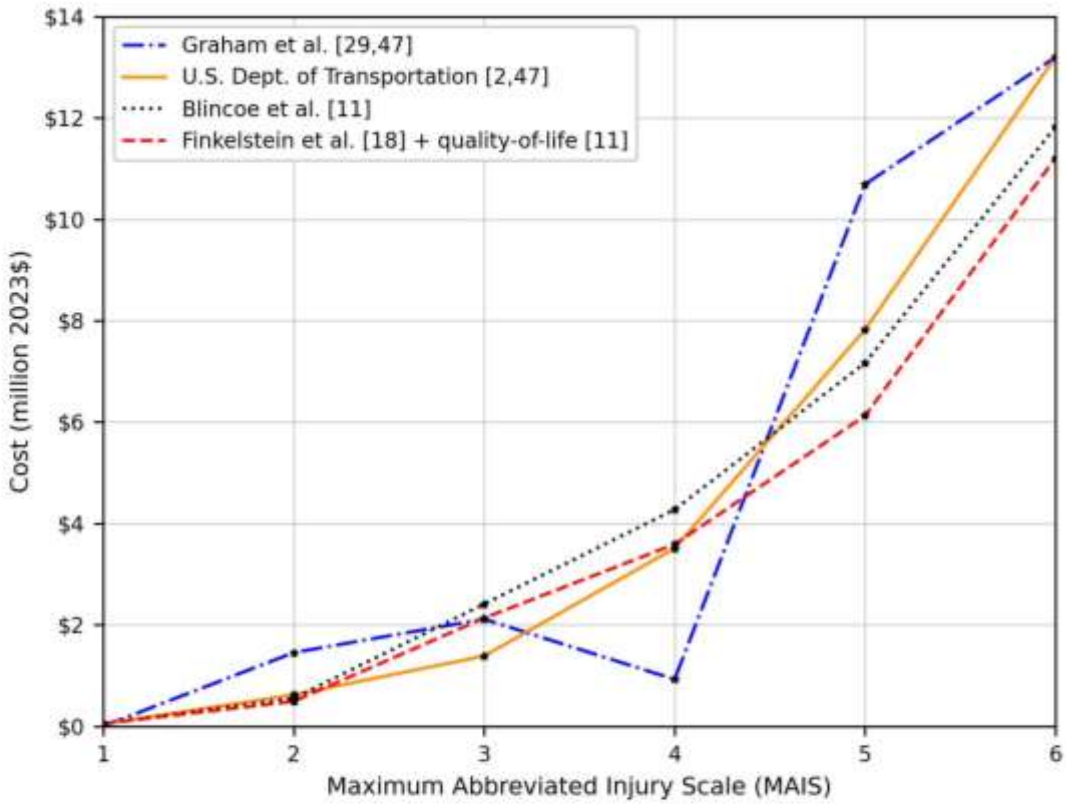

Figure 1. Maximum Abbreviated Injury Scale (MAIS) Economic Costs

Table 5. Injury Severity Score (ISS) Incidence and Mortality

ISS	Injury Incidence		Mortality Risk		ISS (cont.)	Injury Incidence (cont.)		Mortality Risk (cont.)	
	Copes *et al.* [44]	Kilgo *et al.* [50]	Copes *et al.* [44]	Kilgo *et al.* [50]		Copes *et al.* [44]	Kilgo *et al.* [50]	Copes *et al.* [44]	Kilgo *et al.* [50]
1	13.28%	14.69%	0.003	0.007	**26**	0.83%	0.78%	0.237	0.276
2	1.49%	3.09%	0.000	0.003	**27**	0.39%	0.50%	0.191	0.144
3	0.11%	0.40%	0.000	0.006	**29**	1.18%	1.11%	0.226	0.175
4	18.79%	19.64%	0.003	0.006	**30**	0.14%	0.20%	0.208	0.318
5	8.85%	8.25%	0.005	0.004	**32**	0.16%	0.06%	0.290	0.288
6	0.83%	1.26%	0.000	0.004	**33**	0.17%	0.18%	0.324	0.292
8	3.57%	2.17%	0.008	0.008	**34**	0.85%	0.66%	0.331	0.300
9	19.80%	20.84%	0.025	0.023	**35**	0.11%	0.15%	0.407	0.387
10	6.60%	5.62%	0.020	0.020	**36**	0.10%	0.13%	0.440	0.192
11	0.37%	0.75%	0.000	0.012	**38**	0.21%	0.30%	0.356	0.376
12	0.80%	0.71%	0.000	0.009	**41**	0.27%	0.20%	0.449	0.393
13	3.65%	2.89%	0.029	0.025	**42**	0.02%	0.04%	0.727	0.498
14	2.33%	2.66%	0.024	0.020	**43**	0.11%	0.19%	0.385	0.413
16	3.91%	2.41%	0.146	0.128	**45**	0.07%	0.09%	0.583	0.478
17	3.03%	3.01%	0.104	0.047	**48**	0%	0.02%	1.000	0.462
18	1.11%	1.11%	0.088	0.074	**50**	0.12%	0.15%	0.564	0.546
19	0.64%	0.79%	0.063	0.052	**51**	0.01%	0.01%	0.667	0.694
20	1.14%	0.68%	0.141	0.087	**54**	0.01%	0.02%	0.800	0.611
21	0.72%	0.68%	0.123	0.063	**57**	0%	0.03%	1.000	0.602
22	1.13%	1.42%	0.087	0.055	**59**	0.01%	0.02%	0.667	0.694
24	0.59%	0.51%	0.099	0.074	**66**	0%	0.01%	1.000	0.773
25	2.46%	1.48%	0.382	0.438	**75**	0.03%	0.08%	0.926	0.812

Incidence of nonfatal injuries. Mortality risk uses pooled fatal/nonfatal data. Copes *et al*. [44] - 13,925 injuries/951 deaths (1982-1985). Kilgo *et al*. [50] - 342,319 injuries/19,057 deaths (1994-2002).

3.2. MAIS-ISS probabilistic map

The ISS is based on the AIS (Equation 1), and this special relationship allows the MAIS to be linked (mapped) to the ISS, either perfectly or within a small range of MAIS values. This "feasibility region" within the MAIS-ISS space (Figure 2) exhibits a cantilever-like structure, with multiple MAIS "shelfs" overlapping vertically. These bounds align with the information in [44], but are more extensive, enumerating the full range of MAIS levels that are possible at each ISS value (rather than heuristics).

The feasibility region contains 76 total MAIS-ISS combinations (not to be confused with the maximum ISS = 75). Around a third (15/44, 34%) of ISS values link to a single MAIS level; the majority (26/44, 59%) link to two MAIS levels; and three midrange ISS (25, 26, 27) exhibit the most variability, linking to three MAIS levels (3, 4, 5). Overall, about two thirds of ISS values (29/44, 66%) link to multiple MAIS levels.

Machine learning and statistical classification methods are used to generate a MAIS-ISS probabilistic map and allocate shares (probabilities) across MAIS levels at each ISS value (for those ISS that link to more than one possible MAIS levels). In doing so, all invalid MAIS-ISS combinations are assigned zero probability. The resulting shares (Table 6) provide a direct link between the MAIS and ISS, allowing any quantity that was developed for one scale to be transferred (mapped) onto the other.

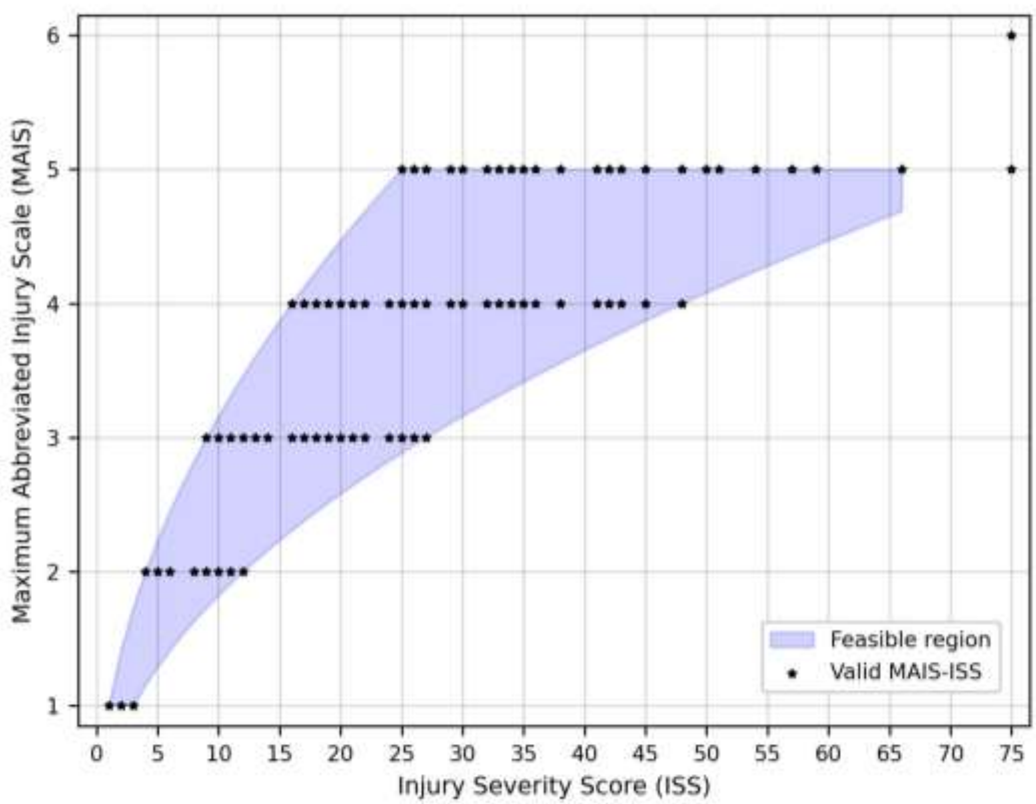

Figure 2. MAIS-ISS Feasibility Region and Valid MAIS-ISS Pairs

Table 6. Injury Severity Score (ISS) - Maximum Abbreviated Injury Scale (MAIS) Shares

ISS	MAIS		Shares					
	Bounds	Avg.	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	MAIS 6
1	(1)	1.00	100%	-	-	-	-	-
2	(1)	1.00	100%	-	-	-	-	-
3	(1)	1.00	100%	-	-	-	-	-
4	(2)	2.00	-	100%	-	-	-	-
5	(2)	2.00	-	100%	-	-	-	-
6	(2)	2.00	-	100%	-	-	-	-
8	(2)	2.00	-	100%	-	-	-	-
9	(2, 3)	2.37	-	62.8%	37.2%	-	-	-
10	(2, 3)	2.44	-	56.0%	44.0%	-	-	-
11	(2, 3)	2.53	-	47.2%	52.8%	-	-	-
12	(2, 3)	2.63	-	36.9%	63.1%	-	-	-
13	(3)	3.00	-	-	100%	-	-	-
14	(3)	3.00	-	-	100%	-	-	-
16	(3, 4)	3.25	-	-	75.0%	25.0%	-	-
17	(3, 4)	3.28	-	-	72.2%	27.8%	-	-
18	(3, 4)	3.31	-	-	68.9%	31.1%	-	-
19	(3, 4)	3.35	-	-	65.2%	34.8%	-	-
20	(3, 4)	3.39	-	-	61.0%	39.0%	-	-
21	(3, 4)	3.44	-	-	56.4%	43.6%	-	-
22	(3, 4)	3.49	-	-	51.4%	48.6%	-	-
24	(3, 4)	3.59	-	-	40.7%	59.3%	-	-
25	(3, 4, 5)	3.82	-	-	30.6%	56.7%	12.7%	-
26	(3, 4, 5)	3.89	-	-	25.4%	59.8%	14.8%	-
27	(3, 4, 5)	3.97	-	-	20.6%	62.2%	17.2%	-
29	(4, 5)	4.26	-	-	-	74.2%	25.8%	-
30	(4, 5)	4.28	-	-	-	71.7%	28.3%	-
32	(4, 5)	4.34	-	-	-	65.8%	34.2%	-
33	(4, 5)	4.38	-	-	-	62.5%	37.5%	-
34	(4, 5)	4.41	-	-	-	58.9%	41.1%	-
35	(4, 5)	4.45	-	-	-	55.2%	44.8%	-
36	(4, 5)	4.49	-	-	-	51.3%	48.7%	-
38	(4, 5)	4.57	-	-	-	43.4%	56.6%	-
41	(4, 5)	4.68	-	-	-	32.3%	67.7%	-
42	(4, 5)	4.71	-	-	-	28.9%	71.1%	-
43	(4, 5)	4.74	-	-	-	25.7%	74.3%	-
45	(4, 5)	4.80	-	-	-	20.1%	79.9%	-
48	(4, 5)	4.87	-	-	-	13.5%	86.5%	-
50	(5)	5.00	-	-	-	-	100%	-
51	(5)	5.00	-	-	-	-	100%	-
54	(5)	5.00	-	-	-	-	100%	-
57	(5)	5.00	-	-	-	-	100%	-
59	(5)	5.00	-	-	-	-	100%	-
66	(5)	5.00	-	-	-	-	100%	-
75	(5, 6)	6.00	-	-	-	-	-	100%

MAIS bounds from Figure 2. Average MAIS value determined using MAIS shares. Dashes represent zeroes. Shares for ISS = 75 discussed in Section 2.2.

3.3. ISS economic costs

Literature searches did not reveal any cost values that are specific to the ISS scale, at least nothing nearly as extensive and comprehensive as exists for the MAIS (Table 4).[7] However, an econometrics-based approach can be used to specify ISS costs, using the probabilistic map (Section 3.2) to transfer MAIS-based costs onto the ISS scale. This is done by fusing the MAIS costs (Table 4) and MAIS shares (Table 6).

The ISS cost curves (Figure 3) inherit the "shelfs" in the MAIS-ISS feasibility region (Figure 2), most notably, ISS = 50-66. The ISS costs are always non-decreasing, except for a segment of the Graham *et al*. [29] curve (ISS = 16-24), stemming from the non-monotonicity of those underlying cost values (Figure 1). Beginning midrange (ISS ≥ 36), the Graham *et al*. costs are strictly greater than or equal to the others.

When viewed over the entire ISS range, the costs are remarkably linear. This is because the MAIS costs increase faster-than-linearly (Figure 1), the feasibility region increases slower-than-linearly (Figure 2), and these factors are offsetting. Recall also that the developers of the ISS cite its linearity as a primary benefit (Section 1.6). Accordingly, a simple yet reasonable reduced-form ISS cost model is a linear function going through these two points: 1) MAIS 1 cost at ISS = 1 (or zero cost at ISS = 0); and 2) MAIS 6 cost at ISS = 75.

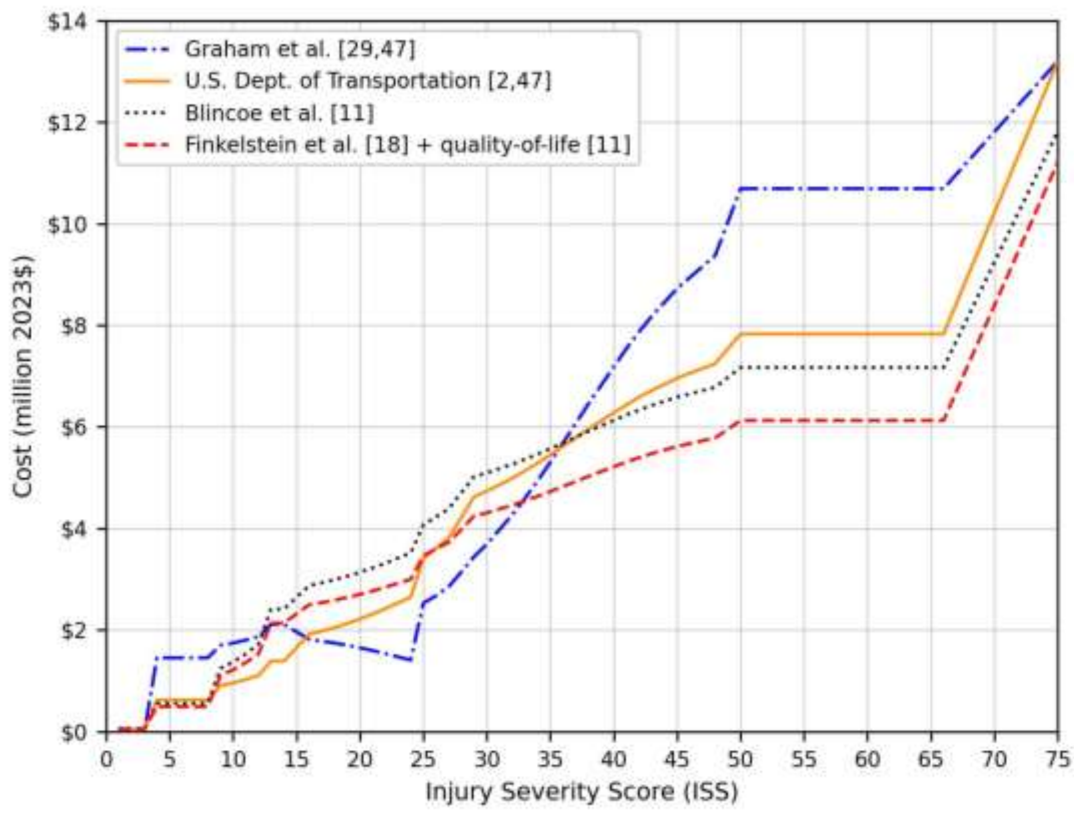

Figure 3. Maximum Abbreviated Injury Scale (MAIS) Economic Costs Mapped to the ISS

7 For example, Kuo *et al*. [51] correlate the ISS to medical costs (and demonstrate generally linear relationships – see also Section 1.6).

IV. Discussion

4.1. Injury clusters

In addition to stratifying injury values by severity, it can also be useful to go in the other direction, "condensing" ranges of severity values (MAIS/ISS), by grouping them according to various data features. This can be especially useful in cases where only limited information on severity of injuries is available, but where *ranges* of severity values (buckets) may be much less uncertain.

The cluster assignments (Table 7) are reasonably stable across data features (within each severity scale). For the MAIS clusters (k = 2), MAIS 1 is never left in isolation, and the first cluster extends up to MAIS (2, 3, 4), depending on the particular data feature used to generate them. For the ISS, with two clusters (k = 2), the results are invariant across data features (threshold: ISS = 31). With three ISS clusters (k = 3), depending on the particular data feature, the first two clusters cease at: ISS = 18-22 / ISS = 38-45. Finally, with four ISS clusters (k = 4), the first three clusters cease at: ISS = 13-16 / ISS = 27-33 / ISS = 45-51.

A threshold of ISS = 15 is often used to classify major trauma or serious injury [56]. This is where MAIS 4 emerges (Figure 2), and also where mortality risk departs from being flush with the ISS-axis (Table 5). The four-level ISS clustering routines all selected essentially this same threshold for the first cluster (note that ISS = 15 cannot occur).

The National Trauma Data Bank (NTDB) [57] uses a fourfold ISS categorization: 1-8 (minor), 9-15 (moderate), 16-24 (severe), and 25-75 (very severe). However, none of the four-level ISS cluster categorizations align particularly well with these divisions. Of course, the threshold that is most useful in clinical settings may be quite different from that selected by a clustering algorithm.

4.2. Average injury costs

In addition to stratifying injury costs by severity (the primary aim of this article), it can also be useful and informative to have some injury costs handy that are severity-neutral ("snapshot" cost values). Additionally, this improves the comparability of the various data sources that are used, which vary in the average severity levels that they represent.

The average costs (Table 8) are formed by combining the incidence and cost data (Tables 2-5) in various permutations. The hospitalized/non-hospitalized values are considerably below the MAIS/ISS values. Among the MAIS/ISS costs, the study populations in [30,44,50] consist of persons treated at hospital trauma centers (possible 100% hospitalization rate), and may represent generally more severely injured populations than [11,18]. Among the ISS studies, the average severity values (ISS = 9.0-9.5) correspond to about MAIS = 2.4 (Table 6), which is much better aligned with the average value in [30] (MAIS = 2.6) rather than [11,18] (MAIS = 1.2-1.3).

When valuing injuries that are of generally unknown severity, Chatterjee & Abkowitz [42] suggest averaging the cost values across all MAIS levels. However, given the generally exponentially nature of the MAIS costs (Figure 1), a better choice may be the *geometric mean* (non-zero values only), so as to put greater emphasis on *lower* values (rather than more catastrophic injuries).

Table 7. Maximum Abbreviated Injury Scale (MAIS) and Injury Severity Score (ISS) Clusters

Clustering Input			Cluster Assignments (MAIS/ISS ranges)			
Injury Severity Scale	**Feature Type**	**Data Source**	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**
MAIS (*k* = 2)	Injury incidence	Copes *et al*. [30]	1-4	5-6	-	-
		Finkelstein *et al*. [18]	1-4	5-6	-	-
		Blincoe *et al*. [11]	1-3	4-6	-	-
	Hospitalization rate	Blincoe *et al*. [11]	1-3	4-6	-	-
	Mortality risk	Copes *et al*. [30]	1-3	4-6	-	-
		Gennarelli *et al*. [28]	1-3	4-6	-	-
		Gennarelli & Wodzin [1]	1-4	5-6	-	-
	Economic costs	Graham *et al*. [29,47]	1-3	4-6	-	-
		Finkelstein *et al*. [18] + QoL [11]	1-2	3-6	-	-
		DOT [2,47]	1-4	5-6	-	-
		Blincoe *et al*. [11]	1-3	4-6	-	-
ISS (*k* = 2)	Injury incidence	Copes *et al.* [44]	1-30	32-75	-	-
		Kilgo *et al*. [50]	1-30	32-75	-	-
	Mortality risk	Copes *et al.* [44]	1-30	32-75	-	-
		Kilgo *et al*. [50]	1-30	32-75	-	-
	Economic costs	Graham *et al*. [29,47]	1-30	32-75	-	-
		Finkelstein *et al*. [18] + QoL [11]	1-30	32-75	-	-
		DOT [2,47]	1-30	32-75	-	-
		Blincoe *et al*. [11]	1-30	32-75	-	-
ISS (*k* = 3)	Injury incidence	Copes *et al.* [44]	1-18	19-38	41-75	-
		Kilgo *et al*. [50]	1-18	19-38	41-75	-
	Mortality risk	Copes *et al.* [44]	1-22	24-45	48-75	-
		Kilgo *et al*. [50]	1-18	19-38	41-75	-
	Economic costs	Graham *et al*. [29,47]	1-18	19-38	41-75	-
		Finkelstein *et al*. [18] + QoL [11]	1-21	22-43	45-75	-
		DOT [2,47]	1-18	19-38	41-75	-
		Blincoe *et al*. [11]	1-18	19-38	41-75	-
ISS (*k* = 4)	Injury incidence	Copes *et al.* [44]	1-14	16-30	32-50	51-75
		Kilgo *et al*. [50]	1-14	16-30	32-48	50-75
	Mortality risk	Copes *et al.* [44]	1-16	17-33	34-51	54-75
		Kilgo *et al*. [50]	1-14	16-30	32-45	48-75
	Economic costs	Graham *et al*. [29,47]	1-14	16-30	32-51	54-75
		Finkelstein *et al*. [18] + QoL [11]	1-14	16-27	29-45	48-75
		DOT [2,47]	1-14	16-30	32-50	51-75
		Blincoe *et al*. [11]	1-13	14-27	29-45	48-75

QoL = quality-of-life. K-means clusters (*k* total). Severity ranges are inclusive. Dashes represent not applicable.

Table 8. Average Injury Costs (Product of Incidence and Costs)

Injury Severity			Cost (2023$)				
Scale	Injury Incidence Data	Avg.	Graham *et al.* [29,47]	Finkelstein *et al.* [18] + QoL [11,19]	DOT [2,47]	Blincoe *et al.* [11]	WISQARS [19]
HOS/ NH	Finkelstein *et al.* [18]	3.7%	-	$91,400	-	-	$93,500
	WISQARS [19]	15.5%	-	$110,000	-	-	$111,000
MAIS	Copes *et al.* [30]	2.6	$1,810,000	$1,650,000	$1,490,000	$1,900,000	-
	Finkelstein *et al.* [18]	1.3	$402,000	$240,000	$252,000	$268,000	-
	Blincoe *et al.* [11]	1.2	$332,000	$275,000	$271,000	$304,000	-
ISS	Copes *et al.* [44]	9.5*	$1,560,000	$1,230,000	$1,120,000	$1,410,000	-
	Kilgo *et al.* [50]	9.0*	$1,510,000	$1,160,000	$1,070,000	$1,320,000	-

*Corresponds to about MAIS = 2.6 (Table 6). HOS/NH = hospitalized/non-hospitalized. ISS = Injury Severity Score. MAIS = maximum Abbreviated Injury Scale. QoL = quality-of-life. Incidence of nonfatal injuries. Cost per injury incident. HOS/NH average severity is the percent hospitalized. Dashes represent not applicable. Copes *et al.* [44] data aggregated over age groups and injury types. Finkelstein *et al.* [18] medical/work costs supplemented using QoL costs from either WISQARS [19] (HOS/NH) or Blincoe *et al.* [11] (MAIS/ISS) (for better comparisons).

4.3. Uncertainty, variability, and bounding

The injury data presented represent average or expected values, and do not capture the considerable variation that exists about these central values. Dimensions along which injury values can vary include [5,15,18,19]: injury characteristics (e.g., mechanism/cause, body region, poly-injury), individual impacted (e.g., age, co-morbidities), and treatment characteristics (e.g., promptness, quality, availability/cost). Uncertainty analysis is therefore an important aspect of injury and safety analysis [2,6,10,58].

The MAIS-ISS feasible region (Figure 2) bounds the range of MAIS levels that are possible at each ISS value. However, residual variation will nevertheless remain *within* MAIS levels. Based on literature reviews, DOT [2] recommends parametric variation of 40% about the central or base injury values. If left unbounded, at times, this may cause the value of injury to exceed that of fatalities (base value), as is the case with the Graham *et al*. [29] MAIS 5 cost. This is counterintuitive, but not necessarily nonsensical.

Miller *et al*. [5] note that while death is the cessation of physical functioning and loss of all future life years, it also squelches pain and suffering and the costs of treatment. They suggest three categories of injuries – quadriplegia, severe head trauma, and catastrophic burns – cause comparable or greater losses than death. The worst fate possible, they posit, is severe burns, with a loss almost 40% greater than death (1982 treatment capabilities). This also provides a rationale for considering MAIS 6 overall as being indistinguishable from fatalities (Section 1.5), because while some MAIS 6 injuries are in fact survivable, others may entail costs exceeding those of fatalities.

Conversely, and paradoxically, at the other extreme, there may be justification for considering some injuries as having zero or even *negative* cost (i.e., benefits). In a study of severe burn survivors, Pindus *et al*. [59] found that some rated their quality-of-life as *improved*. Some of the positive impacts cited included increased family closeness, being more goal-oriented, improved health behaviors, enhanced sensitivity to disabled persons, and greater appreciation of life.

4.4. Limitations

The methods presented could be refined for use in any particular application, by using data that are more specific to the particular injuries or subpopulations of interest. Rich application-specific data could also allow for rigorous handling of uncertainty and the quantifying of probability distributions for various injury outcomes. The MAIS shares (Table 6) too could potentially be improved, using data on the true prevalence of different MAIS levels across ISS values, rather than statistical classification methods.

V. Practical applications

This article brings together, reviews, and extends three of the most common and broadly applicable injury severity scales that are useful in injury and safety analyses. It collates, summarizes, and compares data along these gradations of injury, clusters ranges of severity values according to various data features, and develops reduced-form ISS cost models. Throughout, relevant modeling considerations are discussed and best practice recommendations are offered.

The data and models can be readily applied by injury and safety researchers, investigators, and analysts. The methodology to transfer AIS-based costs onto the ISS scale can be applied to any quantity, not just costs (incidence, hospitalization rate, LOS, ICU admission, work days lost, disability, mortality, etc.). It therefore represents a fundamental development in the understanding of the relationship between the AIS and ISS. This greatly improves the comparability of the scales and facilitates the pooling of mixed AIS/ISS data in meta-analyses. Previously, such comparisons had to be made informally (e.g., using heuristics), or data for the two scales analyzed separately, or data for one scale discarded. The AIS and ISS can now be compared reasonably directly (using the information in Table 6), and reduced-form ISS cost models are now available.

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