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

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Sept. 2025

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Abstract

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

Method: Three common and widely applicable injury severity scales 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, mortality, and economic costs). Operations research and econometrics methods are used to enumerate the theoretical range of AIS levels at each ISS value, subset these to AIS-ISS pairs that can actually occur, develop a probabilistic AIS-ISS map, transfer AIS-based cost data onto the ISS scale, and cluster ranges of severity levels according to various data features.

Results: Each ISS value links to at most two valid AIS levels. The cluster assignments are remarkably consistent, and invariant across data features (for a given number of clusters fit). When viewed over the entire ISS range, both the average AIS (power function) and mapped ISS costs are reasonably linear, and reduced-form ISS cost and AIS-ISS linkage models are presented.

Conclusions: The methodology can be applied to any injury quantity (not just costs), and represents a new development in the understanding of the AIS-ISS relationship.

Practical Applications: This improves the comparability of the scales, allows seeming disparate AIS/ISS values to be better and more directly compared, facilitates the pooling of mixed AIS/ISS data in meta-analyses, and allows costs for the ISS scale to be quantified.

Keywords: Abbreviated Injury Scale (AIS); Injury Severity Score (ISS); econometrics; logistic regression; k-means clustering

I. Introduction

1.1. Injury modeling challenges

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

Injury modeling presents several challenges. Nonfatal injuries are more prevalent that deaths, present along a spectrum of severity, and are multidimensional in their effects, particularly as it relates to disability and impairment, pain and suffering, and quality-of-life [1,2,3]. For sure, death is not entirely unidimensional or monolithic. For example, the *timing* of death is variable (relative to the event that precipitated it) and presents along a spectrum (e.g., immediate, in hospital, reduced life expectancy). However, death is far less variable in its presentation and effects than injuries.

This necessitates methods for evaluating injury severity, for quantifying impacts along those gradations (e.g., economic costs), and for systematically comparing nonfatal injuries to each other and to fatalities. A variety of such methods exist. Currently, this information is scattered, with limited comprehensive, direct, and collated information available to compare them (advantages, limitations, caveats, and risks), assess their fitness for a particular purpose (across diverse injury datasets), or provide best practices for applying them in safety analyses.

This article fills these voids, by summarizing and extending various injury data and scales. In doing so, new insights are derived relating to the scales and their relationship to one another. This improves the comparability of the scales, allows seeming disparate severity values expressed on different scales to be better and more directly compared, facilitates the pooling of mixed data in meta-analyses, and allows any quantity (e.g., economic costs) for one scale to be mapped (transferred or imputed) onto the other scale. Interesting sources of variation and counterintuitive results are identified and discussed. Throughout, relevant modeling considerations and best practice recommendations are offered.

1.2. Injury cost types

Three 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 productivity (formal employment) and household productivity (family and household responsibilities); generally regarded as a lower bound cost value.
2. *Quality-of-life.* Quality-related costs, or the more intangible and difficult-to-monetize costs of injuries, such as pain and suffering and disability and impairment (aside from their impacts on productivity); assessed using some quality measure or instrument; may also be translated into monetary terms, although the link between the quality metric and true economic value may be tenuous or uncertain.
3. *Willingness-to-pay*. Value that society actually places on injury risk reductions, considering all of the trade-offs involved, as evidenced by behavior of persons and firms in economic markets (*revealed preference*); often based on wage-risk studies.

The various cost types are illustrated using the example of an individual injured in a motor vehicle accident. The person (or their insurer) may incur costs for medical treatment and recovery (e.g., hospital, rehabilitation, outpatient, pharmacy, caretakers). The individual, their household, and their employer may all experience losses stemming from the person's absence from or reduced participation in normal activities. These *costs of injury* do not include more *quality-related costs*, such as pain and psychological anguish experienced that the person may also experience. These costs, alone or in aggregate, also may or may not align with *willingness-to-pay* estimates.

Willingness-to-pay studies are often based on wage-risk studies, analyzing wages that workers accept to perform riskier employment. These studies typically assume efficient economic markets, where workers (and employers) have accurate and complete information of job risks and workers have multiple employment options available to them. Neither of these may be the case in actuality. Wage rates that are mutually acceptable to employees and employers ("micro") also may not be a good proxy for the societal value of injury risk reductions ("macro"). Many wage-risk studies also do not stratify results by injury severity, disproportionally represent injuries occurring in workplace and occupational settings, and use injury metrics germane to those particular settings (e.g., overall injury rate, injuries resulting in a lost workday, total workdays lost) [65].

A common quality-related measure is the *quality-adjusted life year* (QALY),[1] which assesses the trade-offs between longevity and time spent in various health or injury states. One year of perfect health equals one QALY; death confers zero QALY; and myriad disutility states between these extrema. QALY values might be based on survey data, structured interviews or expert elicitations, time-to-recovery and functional limitation data, etc. And while useful for making comparisons, many authors caution against assigning monetary values to QALYs, as linking QALYs (or any quality measure) to economic value can be tenuous (because QALYs or similar goods are not traded in economic markets, and so their value in the economic sense is not directly observable) [4,6,7,9,10,12].

Costs can also include losses and disutility incurred by family members or caregivers. Different cost components can sometimes be summed (e.g., cost-of-injury and quality costs), to generate a more complete cost picture or facilitate comparisons (being careful to avoid double counting). In this article, all costs are per injury incident (not population level), given in 2023 U.S. dollars (using the Consumer Price Index-CPI for inflation adjustments), and given to three significant digits.

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 injury severity scales. The focus is scales for use in injury and safety analyses and related economic evaluations (not clinical settings). Only *anatomic* severity scales are included, or those describing *physical* injuries (not disease, illness, sickness, psychological ailments, etc.). In order increasing complexity, these scales are

- Hospitalized/non-hospitalized dichotomy (two-level)
- Abbreviated Injury Scale (AIS) (six-level)
- Injury Severity Score (ISS) (44-level)

1.4. Hospitalized and non-hospitalized injuries

This simple characterization splits injuries into two mutually exclusive categories [5,18,19]

1. *Non-hospitalized*. Treated and released (e.g., at scene, hospital ED, outpatient, doctor's office).
2. *Hospitalized*. Inpatient hospitalization, where the person survives at least until discharge.

Non-hospitalized injuries can also include injuries that were sufficiently mild that the person did not seek formal treatment. Hospitalized injuries are 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 payments for hospitalized persons increasing in their LOS value [21]. Cost per hospital inpatient day data by U.S. state are available from [22], and on average LOS and total cost per stay from [23]. However, not all in-patient days may be equivalent (from a cost or other standpoint). And while often useful, the hospitalized/non-hospitalized bifurcation can be a somewhat blunt instrument, often unable to differentiate the many gradations of injury.

[1] 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 or illness rather than injuries.

1.5. Abbreviated Injury Scale (AIS)

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

For multiple injuries, the *maximum AIS* (MAIS) is the most severe injury (highest AIS). This discards all injury information other than the most severe, potentially limiting its ability to capture the full landscape of injury [3] (Section 1.1). In this article, the AIS and MAIS are used interchangeably. 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 are survivable [1,15,28,30-35]. Nevertheless, theoretical justification exists for considering MAIS 6 overall as being indistinguishable from fatalities (Section 4.3).

The basic goal of the AIS is to divide the vast, diverse, complex, and multifaceted landscape of injuries (Section 1.1) 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, such as 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)

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 clustered injury values in Section 4.1). Semi-structured approaches are also available, such as [35]. If injury diagnosis codes are at-hand, in the form of International Classification of Diseases (ICD) codes, AIS (and ISS) values can also be estimated using the R software's 'ICDPICR' package [60]. While the severity scores it outputs are estimates, the results have shown good alignment with other methods [61].

The AIS was developed to describe injuries in motor vehicle accidents, which consist mainly of blunt trauma types of injuries (push/pull/impact). 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]. Nevertheless, 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].

Table 1. Maximum Abbreviated Injury Scale - 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 also Table 3)

MAIS = maximum Abbreviated Injury Scale. Sources: AAAM [26]; MAIS 1-5 from [27]; MAIS 6 from [31,34,35].

1.6. Injury Severity Score (ISS)

A more information-rich alternative, one that can be especially useful in cases of multiple injuries, is the *Injury Severity Score* (ISS) [45],[2] which is based on the AIS. First, the most severe (highest AIS) injury in each of six pre-defined body regions is noted (head/neck, face, chest, abdomen, extremities, and external). The ISS is then the sum of squares of the three highest of these AIS values

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

each representing an injury in a different body region. The ISS ranges from 1 (for a single AIS 1) to 75 (for a trio of AIS 5 or any number of AIS 6), taking on 44 possible integer values (with varying distance between adjacent ISS values). The ISS developers cite its linearity (as it relates to mortality risk) as a primary benefit relative to the MAIS (previous subsection). 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 [14,16,31,32,44,49,50,51,62]. The ISS has proven enormously useful to researchers: *Google Scholar* reveals >11,900 citations of the original ISS article (Sept. 2025) (see also the discussion in [50]).

The ISS is based on the AIS (Section 1.5), and so inherits many of its limitations. Like the MAIS, the ISS effectively discards much injury information. It considers only the most severe injury in each body region, potentially biasing it for multiple injuries in a single body region. It also means that the ISS sometimes overlooks more severe injuries in favor of less severe ones occurring in a different body region. It also includes only the three most severely injured body regions [52]. However, this could also be a benefit of the ISS, or taking a more "holistic" approach rather than "overfitting" to injuries in a single 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 the majority (56%) of cases.

[2] 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).

1.7. Statistical perspective

The ISS has three parameters whereas the MAIS has only one. Even if one or two of its component AIS values are zero-valued (Equation 1), the ISS still has three parameters, as the zeros nonetheless contain statistical information. Specifically, it conveys the information that the parameter does *not* take on any of the values one through six, and also that the ISS body region associated with it was not injured.

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 that have more parameters (while rewarding models with better fits). Whether or not sufficiently improved predictive power 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 when making MAIS/ISS comparisons.

II. Methods

2.1. Literature searches

Data related to these three scales are collated, summarized, and compared (incidence, hospitalization, mortality, and economic costs). Mortality risk data can be used to remove deaths from mixed (fatal/nonfatal) data, or to adjust injury-only incidence estimates to gauge the total number of persons impacted. Unless otherwise noted, all data are for nonfatal injuries only.

Only the *severity of injury* dimension is varied. Uncertainty and variability are discussed in Section 4.3. Literature reviews included all works in English, examining 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 level of the scale are included (not in the form of ranges, distributions, or summary statistics). When comparing data quality across studies, both recency (years covered) and abundancy (study size) were considered. All studies meeting the inclusion criteria are noted, although data from some older and smaller studies are not presented.

2.2. MAIS-ISS map

Operations research and econometrics methods are used to enumerate the theoretical range of MAIS levels at each ISS value, subset to MAIS-ISS pairs that can actually occur, develop a probabilistic AIS-ISS map, and transfer AIS-based cost data onto the ISS scale. All modeling and visualizations were performed using Python [55].

First, bounding analysis is used to assess the extremities of the theoretical MAIS-ISS space. By design (Equation 1), at each MAIS level, the ISS value necessarily falls 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. MAIS 6 is automatically assigned ISS 75 (Section 1.6). As such, the region encompasses ISS 1-66 and MAIS 1-5 (along with ISS 75).

However, this does not consider that some theoretical MAIS-ISS pairs may not actually occur, nor the relative likelihood of those pairs that remain. The conditional MAIS distribution (shares) is specified using data on the empirical prevalence of different AIS triplets at each ISS value. This forms the basis of the probabilistic MAIS-ISS map, which is used to link and transfer costs between the scales (see next subsection). This assumes that the empirical injury incidence is the only relevant factor when allocating MAIS shares (see also Section 4.4). The average MAIS curve (computed using these shares) is well-modeled by power function best fits (OLS regression, log-log). This provides a simple link between the scales, allowing more direct comparisons of even seemingly disparate MAIS and ISS values.

Restricting to valid MAIS-ISS pairs eliminates a sizeable portion of the theoretical space. These impacts are investigated formally using *logistic regression*, which is an extension of linear regression that is used to model a categorical quantity (rather than a linear relationship). It uses the logistic function (s-curve) to estimate probabilities across levels of the dependent variable. If the categories have a natural "order" or monotonicity (e.g., MAIS), *ordinal logistic regression*[3] is available, which assumes the slopes are invariant across levels ("proportional odds"), with the categories (MAIS) being differentiated only through their intercepts. Otherwise, *multinomial logistic regression*[4] relaxes this assumption, allowing the regression to select differential slopes across levels.

Logistic regression is used because relative to many other statistical classification methods (e.g., random forest, Bayes classifier), its functional form is easier to comprehend and its parameter values easier to interpret. It therefore represents a more "controlled" modeling environment, making the impacts of changes more apparent. The *training data* are MAIS-ISS pairs. Although technically integer-valued, the ISS is modeled as a continuous quantity (as it is often treated in analyses). The regression data excludes ISS 1-3, because they are associated with MAIS 1 only (and conversely, MAIS 1 with ISS 1-3 only), and also ISS 75, which is essentially MAIS 6 only (Table 6).

2.3. ISS economic costs

The probabilistic map (previous subsection) is demonstrated by using it to transfer AIS-based economic costs onto the ISS scale. The underlying AIS costs are assumed invariant, both within and across ISS values. Data is lacking on how the costs might vary along these dimensions. Even if the maximum potential bounds of variation are known or could be specified (Section 4.3), the functional form is also important, yet difficult to specify (i.e., may be non-uniform).

Although the methodology is used to transfer cost data from one scale to the other, it can be applied to any injury quantity (incidence, hospitalization, LOS, ICU admission, mortality, work lost, disability, etc.). As such, it represents a new development in the understanding of the AIS-ISS relationship, improving the comparability of the scales and facilitating the pooling of mixed AIS/ISS data in meta-analyses.

Reduced-form models are presented, fitting linear (OLS)[5] regression models to the average MAIS (see preceding subsection) and mapped ISS costs. Both unrestricted and constrained model forms are examined. *Unrestricted models* have no restrictions on their parameter values, and are statistically fit. *Constrained models* have parameter values that are selected so as to hit certain specified benchmarks (or to align with known boundary conditions), and are algebraically fit (simultaneous equation solving).

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[3] Python, OrderedModel() function, statsmodels library.
[4] Python, MNLogit() function, statsmodels library.
[5] Python, OLS() function, statsmodels library.

A *reduced-form model* is a streamlined version of a more complex model, system, or process. Their potential benefits are primarily threefold [63,64]

- *Transparency*. Equations using a minimum of predictors and without complicated inputs.
- *Flexibility*. Applicable to many different circumstances and useable by non-experts.
- *Rapidity*. Capable of generating results quickly with rapid turnarounds.

These benefits are typically achieved by sacrificing some level of accuracy or granularity (levels that could potentially be achieved using more convoluted models and techniques). Navigating these trade-offs represents the fundamental art and science of reduced-form modeling: creating models that are sufficiently accurate, yet also simple and broadly applicable.

2.4. Clustered injury values

A clustering algorithm is used to group ranges of MAIS/ISS values according to various data features, including the newly-generated ISS costs (previous subsection). Mortality risk, while describing likelihood of *death*, may nonetheless correlate with injury severity (or aspects of it), and so is included. These clusters can be especially useful for practitioners facing course severity information, or where specific MAIS/ISS values are unknown but severity *ranges* can be specified. *K-means clustering*[6] is used, an iterative routine that assigns observations to the cluster with the nearest centroid (hence, "means"), minimizing the variance about the cluster centroids and maximizing within-cluster homogeneity.

The lone model *hyperparameter*, *k*, is the number of clusters to fit. For MAIS, two and three clusters are examined. Any more than this would cause the expected MAIS levels per cluster to fall below two, which is deemed to be too thin a partitioning. Studies use a variety of ISS total number of cohorts and specific partitions, complicating the ability to systematically compare. Based on literature reviews, and using a classification and regression tree (CART) based algorithm (focused on mortality), Rozenfeld *et al*. [62] suggest using four ISS groups for most samples, and at most six groups. The ISS is also grounded in the AIS, which has six levels (one of which, MAIS 6, occurs only at ISS 75), and so more than five or six ISS groups may be unwise, given this underlying structure of the scale. Additionally, given the relative empirical scarcity of some ISS values (Table 5), further augmenting the number of clusters increases the risk that some cohorts will contain small populations and complicate meaningful statistical analyses. Given all of this, a maximum of six ISS clusters are fitted.

2.5. Average injury costs

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 can be applied by injury researchers seeking some off-the-shelf injury values that they can apply, without having to devote significant resources to injury modeling. These average injury costs, formed by combining the incidence and cost data in various ways, are also presented and compared.

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

III. Results

3.1. Literature data

Data for hospitalized and non-hospitalized injuries 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 somewhat more severely injured population (hospitalization rate). Regardless, the costs are similar between the two sources.

MAIS injury data are summarized in Table 3. These studies differ in their data, methods, manner of AIS coding, etc., and exhibit some variability (see also Section 4.2). For example, [1,28,30] consist of persons treated at hospital trauma centers (theoretical 100% hospitalization rate), potentially representing more severely injured populations than [11,18]. 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).

Cost data by MAIS level are summarized in Table 4. The DOT [2] values are based on the concept of *quality-adjusted portion of remaining life lost*, which is similar to the QALY (Section 1.2).[7] DOT uses this approach for injury valuation because it could not locate willingness-to-pay studies and estimates (Section 1.2) across a sufficient range of injury severities. The Graham *et al*. [29] costs exhibit non-monotonicity (MAIS 4), and all of the MAIS cost have a generally exponential nature (Figure 1).

Table 5 presents the ISS injury data. Note that the study size in [50] is much larger and the data more recent than in [44]. However, both study populations consist of persons treated at hospital trauma centers (potential 100% hospitalization rate), and may be skewed towards more severe injuries (rather than being representative of injuries more generally). Mortality risk is not always monotonic in the ISS. This is partly because different AIS triplets with the same ISS value (Table 6) can have very different mortality rates [31,32,44,50]. Injury incidence also varies enormously across ISS values, potentially contributing to variability at the less-populated ISS values, and the majority of injured persons exist at only three ISS values: 1, 4, or 9.

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

Injury Severity	**Incidence** (distribution)		**Cost per Injury Incident** (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. Additional data available in [5], but are more dated (1985).
WISQARS [19] - 26,480,000 injuries (2023), medical and work costs and monetized QALYs (Section 1.2), using methods of [10,24].
Finkelstein *et al*. [18] - 49,978,023 injuries (2000), medical and work costs, supplemented using QoL costs of [19] (for better comparisons).

[7] Similar measures include *years of potential life lost* (YPLL) and *value of a statistical life year* (VSLY).

Table 3. Maximum Abbreviated Injury Scale - Incidence, Hospitalization, and Mortality

Injury Severity	**Incidence** (distribution)			**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

MAIS = maximum Abbreviated Injury Scale. Nonfatal injury incidence and hospitalization. Mortality risk uses pooled fatal/nonfatal data.
Blincoe *et al*. [11] - 4,470,023 injuries/36,500 deaths (2019); motor vehicle accidents (reported and estimated non-reported); aggregated over victim types (e.g., vehicle occupants, 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).
Schellenberg *et al*. [34] additionally find a MAIS 6 mortality risk of 0.746 (19,247 fatal/nonfatal, 2007-2017).
Additional data (motor vehicle accidents) available in [45], but the study is smaller (1,840 injuries/247 deaths), more dated (1968-1969), and MAIS 6 was not used, and also in [46], but is smaller (5,333 injuries/201 deaths) and all persons had only a single injury.

Table 4. Maximum Abbreviated Injury Scale - Economic Costs

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

CoI = cost of injury. DOT = U.S. Department of Transportation. MAIS = maximum Abbreviated Injury Scale. QoL = quality-of-life. VSL = value of a statistical life. WTP = willingness-to-pay.
DOT VSL [47] - WTP measure; $13.2 million; from wage-risk studies (Section 1.2); applied to [2] and [29].
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 [48]; MAIS 1 excluded (relatively minor); MAIS 6 fatal; applied to DOT VSL [47].
Finkelstein *et al*. [18] - CoI/QoL measure; medical and work lost costs, supplemented using QoL costs of [11] (for better comparisons); excludes unknown MAIS (approx. 6,950,000).
DOT [2,47] - QoL/WTP measure; quality-adjusted portions of remaining life lost (0.003, 0.047, 0.105, 0.266, 0.593, 1); MAIS 6 fatal; applied to DOT VSL [47].
Blincoe *et al*. [11] - CoI/QoL measure; motor vehicle accidents (2019); includes medical, EMS, productivity, workplace, insurance, 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].

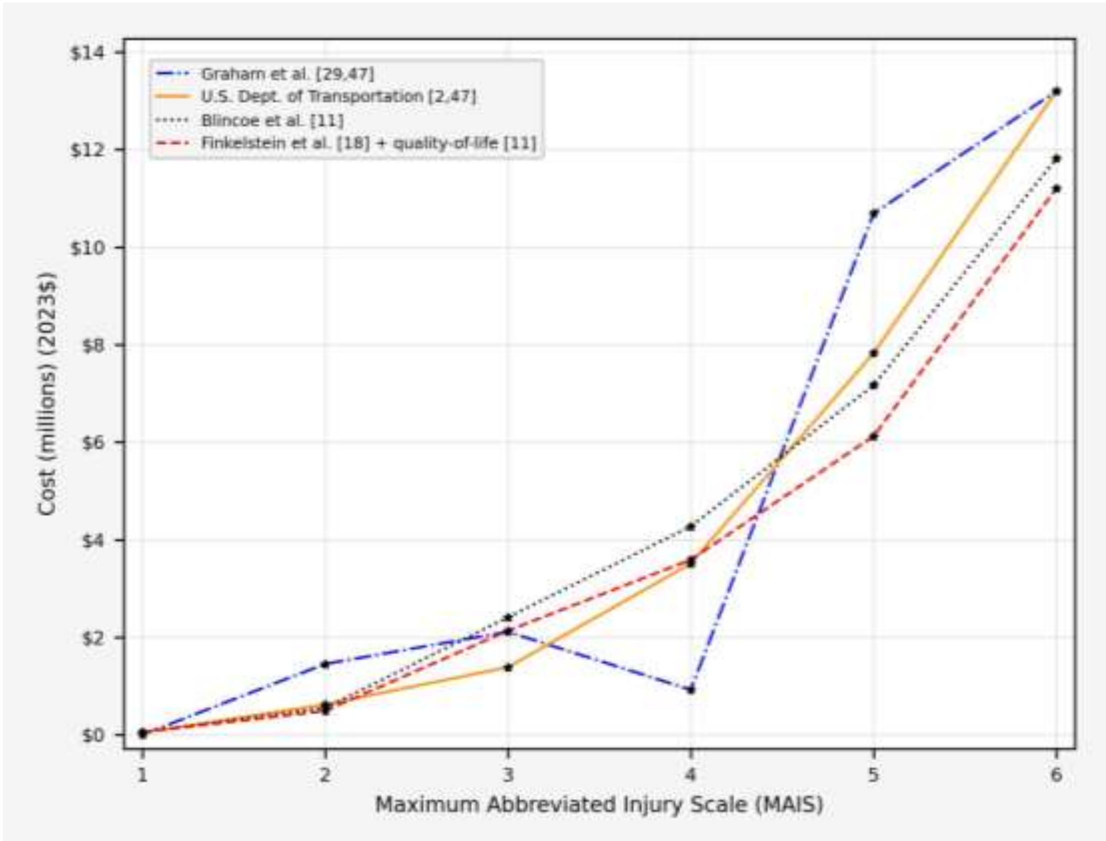

Figure 1. Maximum Abbreviated Injury Scale - Economic Costs

Table 5. Injury Severity Score - Incidence and Mortality

ISS	Incidence (distribution)		Mortality Risk		ISS (cont.)	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	0.003	**27**	0.39%	0.50%	0.191	0.144
3	0.11%	0.40%	0	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	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	0.012	**38**	0.21%	0.30%	0.356	0.376
12	0.80%	0.71%	0	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	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	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	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); aggregated over age groups and injury types.
Kilgo *et al*. [50] - 342,319 injuries/19,057 deaths (1994-2002).

3.2. MAIS-ISS map

The special AIS-ISS relationship (Equation 1) allows the MAIS to be linked (mapped) to the ISS – either perfectly or within a small range of MAIS values. Theoretically, the total number of MAIS-ISS pairs is 76 (not to be confused with the maximum ISS scale value of 75). However, many of these MAIS-ISS pairs cannot actually occur. Subsetting to valid MAIS-ISS pairs eliminates over a quarter of these, leaving 55 pairs (Table 6). Each ISS value links to at most two valid MAIS-ISS pairs. Among valid pairs, 12 link to more than one AIS triplet, although only 11 of these link to more than one MAIS level (ISS 50 has two triplets, but is MAIS 5 only). ISS 27 links to MAIS 3 and 5, but not MAIS 4, and ISS 9 can occur with one or three body regions impacted, but not two body regions.

The impacts of subsetting to valid MAIS-ISS pairs are investigated formally using logistic regression, by examining the changes in the coefficient values (Table 7). Likelihood ratio tests are used to test the proportional odds assumption (Section 2.2), indicating that the more flexible multinomial logistic regression model offers a significant increase in model fit (at the $\alpha = 0.05$ level), and is deemed worthwhile relative to the simpler ordinal logistic regression model. Regardless, the coefficient values do not vary drastically between the two MAIS-ISS scenarios (theoretical, valid only). The logistic regression models in Table 7 are presented to show the impacts of including different sets of MAIS-ISS pairs, but are not otherwise used in the modeling. If used to predict probabilities across MAIS levels, the outputs for all non-sensical MAIS-ISS pairs should be recoded to zero, and the remaining probabilities renormalized to sum to one (by ISS).[8]

The plot of the MAIS-ISS theoretical region (Figure 2) exhibits a cantilever-like structure, increasing slower-than-linearly in the ISS. At each ISS value, the average MAIS value is computed using the AIS triplets that can occur at that ISS value, based on their empirical prevalence (Table 6). The average MAIS value is quite non-monotonic in the ISS – "pinballing" around the theoretical region, often vacillating from one extremity to the other and then reversing (quasi-cyclically), with multiple instances of changes of one entire MAIS level between adjacent ISS values. The extent to which the average MAIS curve "paints" the entire theoretical region so thoroughly is notable, and could have implications for sensitivity analyses (see also Section 4.3). Figure 2 also shows the results of power function equation best fits to the average MAIS, which are further elaborated in Table 8.

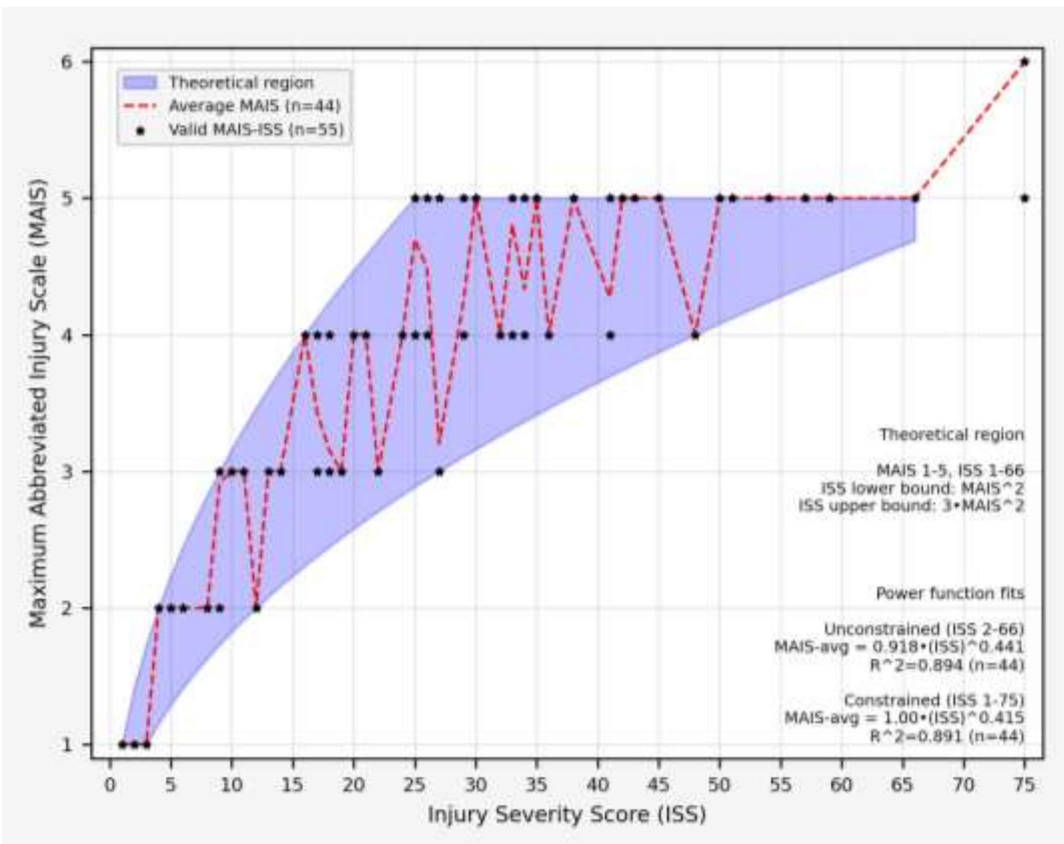

Figure 2. MAIS-ISS Theoretical Region and Empirical Map

[8] Logistic regression, unmodified, always predicts non-zero probabilities across all levels of the dependent variable for any arbitrary input value (because the logistic function's domain spans the entire x-axis).

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

ISS	MAIS		AIS Triplet		Shares		Total	Body Regions	Avg. MAIS
	Theory	Valid	#1	#2	#1	#2			
1	[1]	[1]	(1, 0, 0)	-	100%	-	-	[1]	1.00
2	[1]	[1]	(1, 1, 0)	-	100%	-	-	[2]	1.00
3	[1]	[1]	(1, 1, 1)	-	100%	-	-	[3]	1.00
4	[2]	[2]	(2, 0, 0)	-	100%	-	-	[1]	2.00
5	[2]	[2]	(2, 1, 0)	-	100%	-	-	[2]	2.00
6	[2]	[2]	(2, 1, 1)	-	100%	-	-	[3]	2.00
8	[2]	[2]	(2, 2, 0)	-	100%	-	-	[2]	2.00
9	[2, 3]	[2, 3]	(2, 2, 1)	(3, 0, 0)	8.03%	91.97%	101,267	[1, 3]	2.92
10	[2, 3]	[3]	(3, 1, 0)	-	100%	-	-	[2]	3.00
11	[2, 3]	[3]	(3, 1, 1)	-	100%	-	-	[3]	3.00
12	[2, 3]	[2]	(2, 2, 2)	-	100%	-	-	[3]	2.00
13	[3]	[3]	(3, 2, 0)	-	100%	-	-	[2]	3.00
14	[3]	[3]	(3, 2, 1)	-	100%	-	-	[3]	3.00
16	[3, 4]	[4]	(4, 0, 0)	-	100%	-	-	[1]	4.00
17	[3, 4]	[3, 4]	(3, 2, 2)	(4, 1, 0)	57.06%	42.94%	11,590	[2, 3]	3.43
18	[3, 4]	[3, 4]	(3, 3, 0)	(4, 1, 1)	84.68%	15.32%	4,550	[2, 3]	3.15
19	[3, 4]	[3]	(3, 1, 1)	-	100%	-	-	[3]	3.00
20	[3, 4]	[4]	(4, 2, 0)	-	100%	-	-	[2]	4.00
21	[3, 4]	[4]	(4, 2, 1)	-	100%	-	-	[3]	4.00
22	[3, 4]	[3]	(3, 3, 2)	-	100%	-	-	[3]	3.00
24	[3, 4]	[4]	(4, 2, 2)	-	100%	-	-	[3]	4.00
25	[3, 4, 5]	[4, 5]	(4, 3, 0)	(5, 0, 0)	30.08%	69.92%	6,751	[1, 2]	4.70
26	[3, 4, 5]	[4, 5]	(4, 3, 1)	(5, 1, 0)	50.94%	49.06%	3,031	[2, 3]	4.49
27	[3, 4, 5]	[3, 5]	(3, 3, 3)	(5, 1, 1)	89.80%	10.20%	1,942	[3]	3.20
29	[4, 5]	[4, 5]	(4, 3, 2)*	(5, 2, 0)	75.48%	24.52%	4,588	[2, 3]	4.25
30	[4, 5]	[5]	(5, 2, 1)	-	100%	-	-	[3]	5.00
32	[4, 5]	[4]	(4, 4, 0)	-	100%	-	-	[2]	4.00
33	[4, 5]	[4, 5]	(4, 4, 1)	(5, 2, 2)*	19.05%	80.95%	735	[3]	4.81
34	[4, 5]	[4, 5]	(4, 3, 3)	(5, 3, 0)	66.46%	33.54%	2,701	[2, 3]	4.34
35	[4, 5]	[5]	(5, 3, 1)	-	100%	-	-	[3]	5.00
36	[4, 5]	[4]	(4, 4, 2)	-	100%	-	-	[3]	4.00
38	[4, 5]	[5]	(5, 3, 2)	-	100%	-	-	[3]	5.00
41	[4, 5]	[4, 5]	(4, 4, 3)*	(5, 4, 0)	72.73%	27.27%	880	[2, 3]	4.27
42	[4, 5]	[5]	(5, 4, 1)	-	100%	-	-	[3]	5.00
43	[4, 5]	[5]	(5, 3, 3)	-	100%	-	-	[3]	5.00
45	[4, 5]	[5]	(5, 4, 2)	-	100%	-	-	[3]	5.00
48	[4, 5]	[4]	(4, 4, 4)	-	100%	-	-	[3]	4.00
50	[5]	[5]	(5, 4, 3)	(5, 5, 0)	87.84%	12.16%	633	[2, 3]	5.00
51	[5]	[5]	(5, 5, 1)	-	100%	-	-	[3]	5.00
54	[5]	[5]	(5, 5, 2)	-	100%	-	-	[3]	5.00
57	[5]	[5]	(5, 4, 4)	-	100%	-	-	[3]	5.00
59	[5]	[5]	(5, 5, 3)	-	100%	-	-	[3]	5.00
66	[5]	[5]	(5, 5, 4)	-	100%	-	-	[3]	5.00
75	[5, 6]	[5, 6]	(5, 5, 5)	(6, 0, 0)	0.48%	99.52%	1,467	[1, 3]	6.00

AIS triplets from [31,32,33,50], and the total count is the sum of their study sizes. Asterisks indicate triplets that are not listed in the table in [49]. “Theory” is all theoretical MAIS-ISS pairs. “Valid” is only MAIS-ISS pairs that can actually occur. Shares are empirical prevalence by AIS triplet (used to compute the average MAIS). Body regions impacted is the total non-zero elements in the AIS triplet. Dashes indicate not applicable or not specified.

Table 7. Logistic Regression Models Predicting MAIS Level from ISS

Model Type	MAIS-ISS	Y	X	Coefficients	
				Constant	Slope
Multinomial Logistic Regression	Theoretical (*n*=71)	MAIS 3	*ISS*	-7.46 (p=0.044)	0.705 (p=0.040)
		MAIS 4		-12.5 (p=0.002)	0.940 (p=0.008)
		MAIS 5		-16.2 (p<0.001)	1.04 (p=0.003)
	Valid only (*n*=50)	MAIS 3	*ISS*	-6.78 (p=0.075)	0.687 (p=0.069)
		MAIS 4		-12.0 (p=0.006)	0.956 (p=0.016)
		MAIS 5		-15.9 (p=0.001)	1.08 (p=0.007)
Likelihood Ratio Test	**MAIS-ISS**	**Y**	**X**	**Statistics**	
				Log-Likelihood	**Chi-Squared**
	Theoretical (*n*=71)	*MAIS*	*ISS*	LL-full = -52.5 LL-simpler = -59.5	$\chi 2$ = 14.0 (p=0.001, dof=2)
	Valid only (*n*=50)	*MAIS*	*ISS*	LL-full = -33.6 LL-simpler = -38.2	$\chi 2$ = 9.08 (p=0.011, dof=2)

ISS = Injury Severity Score. MAIS = maximum Abbreviated Injury Scale. "Theoretical" is all MAIS-ISS pairs that could occur in theory. "Valid" is only MAIS-ISS pairs that can actually occur. MAIS 2 is the reference level for the multinomial regressions. ISS 1-3 and ISS 75 (five valid MAIS-ISS pairs) excluded from the training data (Section 3.2). Caveats regarding using these equations and probability recoding procedures are described in Section 3.2. Ordinal logistic regression results (not shown) are the basis of comparison for the likelihood ratio tests. Chi-squared statistic is equal to twice the difference between the log-likelihood (LL) of the "full" model (multinomial) and that of the simpler model (ordinal). Degrees of freedom (dof) is the number of additional parameters in the "full" model versus that in the simpler model.

3.3. ISS economic costs

Literature searches did not reveal any cost data for the ISS scale that are anyway near as comprehensive as exists for the MAIS.[9] Nevertheless, the probabilistic map (Section 3.2) can be used to transfer MAIS-based costs onto the ISS scale, by fusing MAIS costs (Table 4) and ISS-MAIS shares (Table 6).

The mapped ISS costs (Figure 3) exhibit considerable variation, especially in the midrange values (ISS 25-50). This is a consequence of the variability and non-monotonicity in the average MAIS value (Figure 2). The Graham *et al*. [29] costs are particularly erratic, repeatedly swinging over an order-of-magnitude between adjacent ISS values ($1 million to $10 million), reducing the model fit (R^2). Despite this variation, when viewed over the entire ISS range, the mapped ISS costs are reasonably linear. This result is the confluence of the MAIS costs increasing faster-than-linearly (Figure 1), and the MAIS-ISS theoretical region (and average MAIS) increasing slower-than-linearly (Figure 2). Recall also that the developers of the ISS cite its linearity as a primary benefit (Section 1.6).

Additional support for these linearities is given in Table 8, which presents a series of reduced-form ISS cost and MAIS-ISS linkage models. This encompasses both constrained models, which are designed to align with specific boundary conditions, and unrestricted models, with no parameter restrictions. Formal regression diagnostics and robustness checks are also included. Note that these models predict cost in *millions* of dollars. The unrestricted version of the Graham *et al*. [29] cost model predicts negative cost values at ISS 1 and 2. The constrained model forms resolve this, by intersecting either zero dollars at the

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

(non-existent) ISS 0, or MAIS 1 cost at ISS 1 (and MAIS 6 cost at ISS 75 in both cases). However, this comes at the expense of some model fit (R^2). The reduced-form ISS cost models are not otherwise used in the modeling or analysis.

Table 8 also presents power functions modeling the average MAIS as a function of the ISS (both variables log-transformed). The predictions of the unrestricted power function extend slightly below MAIS 1 at ISS 1 and slightly above MAIS 6 at ISS 75. The constrained version of the model resolves this, with parameter values set so as to hit these boundary points exactly, and with minimal accompanying reduction in model fit (R^2). Analysis of residuals data (Table 8) and residual plots (not shown) indicate the regressions do not have any significant heteroscedasticity, and residuals that are reasonably normally distributed.

The power functions provide a method for converting severity values coded on one scale into their analogues on the other scale. The relationship is simple, direct, consistent, smooth, and monotonic, and improves comparisons of seeming disparate MAIS/ISS values (e.g., MAIS 2 versus ISS 25). While variation about the power function best-fit lines exist, they can nonetheless be used to control for injury severity in analyses and the pooling of mixed MAIS/ISS data in meta-analyses. This is what is currently done using the ISS (Section 1.6), even though many injury quantities are non-monotonic in the ISS (Tables 5 and 6).

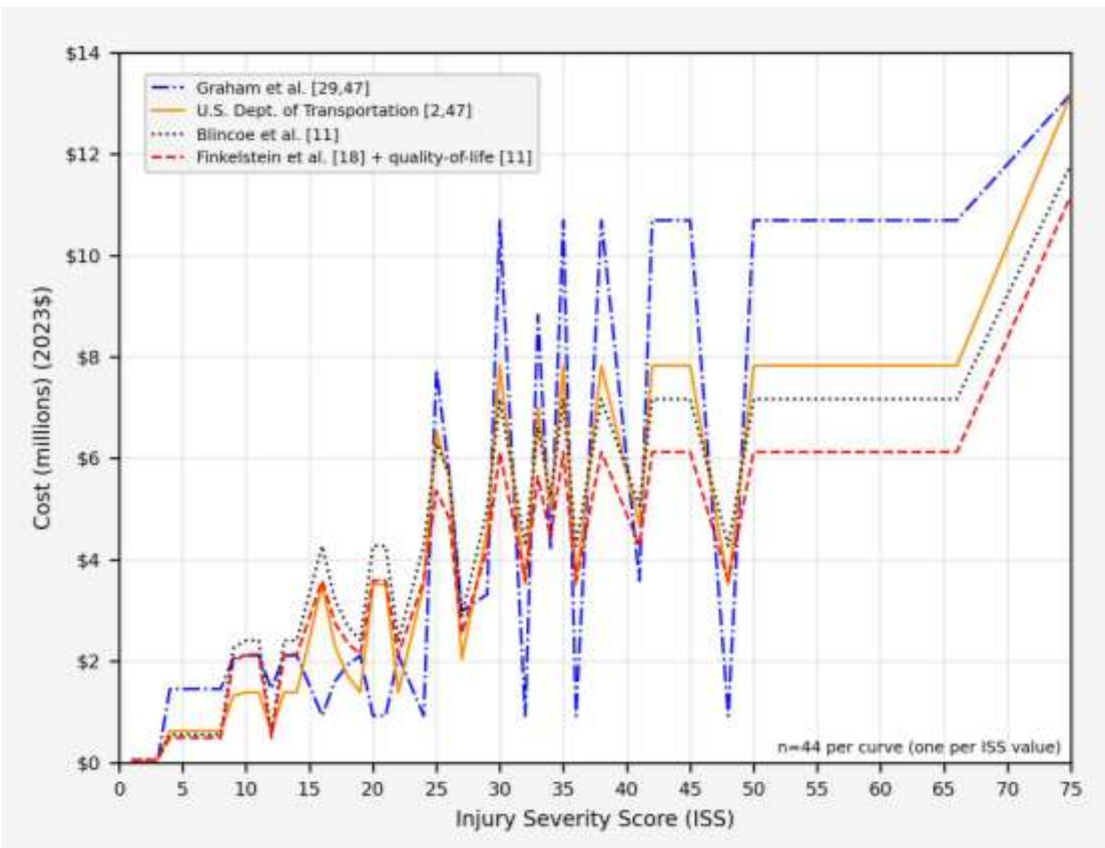

Figure 3. Maximum Abbreviated Injury Scale (MAIS) Economic Costs Mapped to the ISS

Table 8. Reduced-Form Injury Severity Score Linear Regression Models

Dependent (Y)	X	Form	Coefficients		R^2	Resid. Norm.
			Constant	Slope		
ln(*MAIS-avg*)	ln(*ISS*)	U	-0.0854 (p=0.254)	0.441 (p<0.001)	0.894	0.995
		C1	0	0.415	0.891	-
Graham *et al*. [29,47]	*ISS*	U	-0.474 (p=0.515)	0.187 (p<0.001)	0.643	0.993
Finkelstein *et al*. [18] + QoL [11]			0.483 (p=0.105)	0.116 (p<0.001)	0.808	0.993
DOT [2,47]			-0.125 (p=0.755)	0.154 (p<0.001)	0.800	0.986
Blincoe *et al*. [11]			0.622 (p=0.067)	0.132 (p<0.001)	0.810	0.993
Graham *et al*. [29,47]	*ISS*	C2	0	0.176	0.640	-
Finkelstein *et al*. [18] + QoL [11]			0	0.149	0.701	-
DOT [2,47]			0	0.176	0.729	-
Blincoe *et al*. [11]			0	0.158	0.779	-
Graham *et al*. [29,47]	*ISS*	C3	-0.178	0.178	0.642	-
Finkelstein *et al*. [18] + QoL [11]			-0.0980	0.151	0.705	-
DOT [2,47]			-0.138	0.178	0.739	-
Blincoe *et al*. [11]			-0.0999	0.159	0.777	-

DOT = U.S. Department of Transportation. ISS = Injury Severity Score. MAIS = maximum Abbreviated Injury Scale.
QoL = quality-of-life. Cost predictions in million 2023$ (*n*=44). Dashes indicate not applicable or not specified.
U - Unrestricted (no parameter restrictions).
C1 - Constrained to intersect: MAIS 1 at ISS 1 / MAIS 6 at ISS 75.
C2 - Constrained to intersect: $0 at (non-existent) ISS 0 / MAIS 6 cost at ISS 75.
C3 - Constrained to intersect: MAIS 1 cost at ISS 1 / MAIS 6 cost at ISS 75.
Average MAIS is incidence-weighted by ISS value (Table 6) and modeled using a power function (log-log linear).
Some predictions of the unrestricted models (U) are out-of-range (Section 3.3).
p-values and residuals analysis not presented for the constrained models (because they are algebraically rather than statistically fit). R^2 values are presented, to facilitate comparisons with the other models.
Residuals normality (far right column) is the correlation between the residuals: (1) empirical cumulative distribution function; and (2) fitted cumulative normal distribution. Greater values are sought.

IV. Discussion

4.1. Clustered injury values

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), grouping them according to various data features. This can be especially useful in cases where only limited or course severity information is available. These cluster assignments, which are summarized in Table 9 (MAIS) and Table 10 (ISS), are invariant across data features (for a given *k*-value). Additionally, the MAIS clusters always split that scale evenly, with (6/*k*) MAIS levels in each cluster. The consistency of these clustering results underscores the usefulness of the MAIS/ISS scales for managing the vast and diverse landscape of injuries (Section 1.1).

ISS 15 is frequently used to classify major trauma or serious injury [56]. This is where MAIS 4 emerges (Table 6), and where mortality risk departs from the ISS-axis (Table 5). The four-level ISS clusters all selected this as the first cluster (note that ISS 15 itself cannot occur). The National Trauma Data Bank (NTDB) [57] ISS categorization is fourfold: 1-8 / 9-15 / 16-24 / 25-75. These are the same cohorts recommended by Rozenfeld *et al*. [62] for use with most injury data samples (Section 2.4). However, the four-level ISS clusters do not align particularly well with these divisions. Of course, the thresholds most useful in clinical settings may be quite different from those selected by a clustering algorithm.

Table 9. Maximum Abbreviated Injury Scale - Clusters

Total Clusters Fit	Feature Type	Data Source	Cluster Assignments (MAIS ranges)		
			C1	C2	C3
k = 2	Incidence	Copes *et al*. [30] Finkelstein *et al*. [18] Blincoe *et al*. [11]	1-3	4-6	-
	Hospitalization	Blincoe *et al*. [11]			
	Mortality	Copes *et al*. [30] Gennarelli *et al*. [28] Gennarelli & Wodzin [1]			
	Costs	Graham *et al*. [29,47] Finkelstein *et al*. [18] + QoL [11] DOT [2,47] Blincoe *et al*. [11]			
k = 3	Incidence	Copes *et al*. [30] Finkelstein *et al*. [18] Blincoe *et al*. [11]	1-2	3-4	5-6
	Hospitalization	Blincoe *et al*. [11]			
	Mortality	Copes *et al*. [30] Gennarelli *et al*. [28] Gennarelli & Wodzin [1]			
	Costs	Graham *et al*. [29,47] Finkelstein *et al*. [18] + QoL [11] DOT [2,47] Blincoe *et al*. [11]			

MAIS = maximum Abbreviated Injury Scale. QoL = quality-of-life. K-means clustering (*k* in total). Cluster assignments do not vary across data features (for a given value of *k*). Ranges are inclusive. Incidence of nonfatal injuries. Mortality risk uses pooled fatal/nonfatal data. Dashes indicate not applicable.

Table 10. Injury Severity Score - Clusters

Total Clusters Fit	Feature Type	Data Source	Cluster Assignments (ISS ranges)					
			C1	**C2**	**C3**	**C4**	**C5**	**C6**
k = 2	Incidence	Copes *et al.* [44] Kilgo *et al*. [50]	1-30	32-75	-	-	-	-
	Mortality	Copes *et al.* [44] Kilgo *et al*. [50]						
	Costs	Graham *et al*. [29,47] Finkelstein *et al*. [18] + QoL [11] DOT [2,47] Blincoe *et al*. [11]						
k = 3	Incidence	Copes *et al.* [44] Kilgo *et al*. [50]	1-22	24-45	48-75	-	-	-
	Mortality	Copes *et al.* [44] Kilgo *et al*. [50]						
	Costs	Graham *et al*. [29,47] Finkelstein *et al*. [18] + QoL [11] DOT [2,47] Blincoe *et al*. [11]						
k = 4	Incidence	Copes *et al.* [44] Kilgo *et al*. [50]	1-14	16-30	32-48	50-75	-	-
	Mortality	Copes *et al.* [44] Kilgo *et al*. [50]						
	Costs	Graham *et al*. [29,47] Finkelstein *et al*. [18] + QoL [11] DOT [2,47] Blincoe *et al*. [11]						
k = 5	Incidence	Copes *et al.* [44] Kilgo *et al*. [50]	1-13	14-26	27-38	41-54	57-75	-
	Mortality	Copes *et al.* [44] Kilgo *et al*. [50]						
	Costs	Graham *et al*. [29,47] Finkelstein *et al*. [18] + QoL [11] DOT [2,47] Blincoe *et al*. [11]						
k = 6	Incidence	Copes *et al.* [44] Kilgo *et al*. [50]	1-11	12-22	24-34	35-45	48-59	66-75
	Mortality	Copes *et al.* [44] Kilgo *et al*. [50]						
	Costs	Graham *et al*. [29,47] Finkelstein *et al*. [18] + QoL [11] DOT [2,47] Blincoe *et al*. [11]						

ISS = Injury Severity Score. QoL = quality-of-life. K-means clustering (*k* in total). Cluster assignments do not vary across data features (for a given value of *k*). Ranges are inclusive. Incidence of nonfatal injuries. Mortality risk uses pooled fatal/nonfatal data. Dashes indicate not applicable.

4.2. Average injury costs

In addition to stratifying injury costs by severity, it can also be useful and informative to generate severity-neutral injury cost values ("snapshot" costs). These can be applied in analyses where the focus may not be injuries, but there is still a desire to incorporate some injury cost information (without doing any detailed modeling). Additionally, this improves the comparability of the injury data sources used, which vary considerably in the average severity levels they represent.

Average severities across studies and severity scales are summarized in Table 11, and average costs in Table 12. Among the MAIS/ISS results, 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 in [11,18]. For the MAIS/ISS, Table 12 also presents the corresponding severity values on the other scale, computed using the power functions (Table 8). Among the ISS studies, the average severities (ISS 9 to 9.5) correspond to about MAIS 2.4 or 2.5, which is much more closely aligned with the average value in [30] (MAIS 2.6) than those in [11,18] (MAIS 1.2 to 1.3).

Average costs (Table 12) are formed by meshing incidence (Tables 3 and 5) and costs (Table 4, Figure 3) together in various permutations. The hospitalized/non-hospitalized costs are considerably below the MAIS/ISS costs, possibly because of differential severity levels involved. Additional research is needed to better compare hospitalized/non-hospitalized injuries to those coded on the MAIS/ISS scales. Among the MAIS/ISS costs, those for [11,18] are considerably below those of the other sources, in line with the fact that their study populations were, on balance, less severely injured (Table 11).

When specifying cost values for injuries that are of generally unknown severity, Chatterjee & Abkowitz [42] suggest averaging costs 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), putting greater emphasis on *lower* values (rather than more catastrophic injuries).

Table 11. Average Injury Severity - Variation Across Studies and Severity Scales

Severity Scale	Data Source	Avg. Severity	MAIS Analogue		ISS Analogue	
			Unrestricted	Constrained	Unrestricted	Constrained
HOSP	Finkelstein *et al*. [18]	3.7%	-	-	-	-
	WISQARS [19]	15.5%	-	-	-	-
MAIS	Copes *et al*. [30]	2.61	-	-	10.7	10.1
	Finkelstein *et al*. [18]	1.28	-	-	2.11	1.80
	Blincoe *et al*. [11]	1.22	-	-	1.90	1.61
ISS	Copes *et al*. [44]	9.48	2.47	2.54	-	-
	Kilgo *et al*. [50]	9.01	2.42	2.49	-	-

HOSP = hospitalized/non-hospitalized. ISS = Injury Severity Score. MAIS = maximum Abbreviated Injury Scale. Analogue values computed using average MAIS power functions (Table 8). "Unrestricted" models do not have any parameter restrictions, and "constrained" models are fit so as to intersect two points: MAIS 1 at ISS 1 / MAIS 6 at ISS 75. Average severity value for HOSP is percent hospitalized. Dashes indicate not applicable or not specified.

Table 12. Average Injury Costs - Variation Across Studies and Severity Scales

Severity Scale	Data Source	Cost per Injury Incident (2023$)				
		Graham *et al.* [29,47]	Finkelstein *et al.* [18] + QoL [11,19]	DOT [2,47]	Blincoe *et al.* [11]	WISQARS [19]
HOSP	Finkelstein *et al.* [18]	-	$91,400	-	-	$93,500
	WISQARS [19]	-	$110,000	-	-	$111,000
MAIS	Copes *et al.* [30]	$1,810,000	$1,650,000	$1,490,000	$1,900,000	-
	Finkelstein *et al.* [18]	$402,000	$240,000	$252,000	$268,000	-
	Blincoe *et al.* [11]	$332,000	$275,000	$271,000	$304,000	-
ISS	Copes *et al.* [44]	$1,770,000	$1,570,000	$1,400,000	$1,810,000	-
	Kilgo *et al.* [50]	$1,710,000	$1,460,000	$1,290,000	$1,680,000	-

HOSP = hospitalized/non-hospitalized. ISS = Injury Severity Score. MAIS = maximum Abbreviated Injury Scale. QoL = quality-of-life. Finkelstein *et al*. [18] costs supplemented using QoL costs from either [19] (HOSP) or [11] (MAIS/ISS) (for better comparisons). Dashes indicate not applicable or not specified.

4.3. Uncertainty and variability

All of the injury data presented are average or expected values. This neglects the considerable variation that exists about these central values (see also Section 1.1). 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 and related risk management activities and policy-making [2,6,10,58].

Significant variation may exist *within* MAIS levels (see also the discussion in next subsection). Based on literature reviews, DOT [2] recommends parametric variation of 40% about the central or base injury values. If left unbounded, this can cause the value of injury to exceed that of fatalities (base value), as is the case with the Graham *et al*. [29] cost values (MAIS 5). The implication of this in cost-effectiveness analyses is that preventing some injuries may be deemed more cost-efficient than preventing fatalities (all else equivalent). This result is counterintuitive, but not necessarily nonsensical.

Miller *et al*. [5] note that while death entails the cessation of physical functioning and loss of all future life years, it also squelches pain and suffering and the costs of medical treatment. They suggest three general injury categories – 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 total 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 are 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 study participants rated their quality-of-life as *improved*. Some of the positive impacts cited included greater appreciation of life, increased family closeness, being more goal-oriented, improved health behaviors, and enhanced sensitivity to disabled persons.

4.4. Limitations and generalizability

Two assumptions are central to the analysis. The first is that MAIS prevalence (incidence) is a good way of combining disparate MAIS levels at each ISS value. In actuality, some MAIS levels may be more/less influential than their empirical prevalence would suggest. The second assumption is that the MAIS cost values (Table 4) are invariant, both across and within ISS values. However, these costs may vary, just as many other injury elements are variable at this level (Table 6).

The AIS-ISS mapping inherits artifacts of these assumptions, and additional research is needed to assess their veracity and usefulness. The ideal data structure would consist of *both* AIS and ISS scores (and all of their component information), coded on the same population (with scores applied in a consistent and repeatable manner), and representing a broad cross-section of persons, injuries, and settings (and also including data elements that would allow for these factors to be controlled for in analyses).

Only U.S. injury data are used. The inclusion of non-U.S. datasets and cross-country comparisons is problematic, for two main reasons: (1) different relative frequencies of injuries, treatment characteristics, and injury outcomes across countries; and (2) the U.S. medical system, and its corollary systems of health insurance and medical financing, is qualitatively very different from the structures that exist in many other countries. One of the most extensive non-U.S. data sources may be Israel, and its national trauma registry, which has been used by many injury researchers (e.g., [62]).

The analysis is also somewhat centric to motor vehicle accident injuries. This represents much of the input data, and the AIS/ISS were originally developed to describe injuries from motor vehicle accidents. It is unknown how well the results might generalize to other types of injuries, especially those that are very different from the kinds sustained in motor vehicle accidents. The MAIS/ISS analyses are also necessarily limited to cases where AIS/ISS values have been assigned (or estimated), and it is unknown how representative this subset may be of injuries overall.

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 for these scales, clusters ranges of severity values according to various data features, and develops reduced-form ISS cost models and MAIS-ISS linkage functions. Interesting boundary cases and sources of variation are identified. Throughout, relevant modeling considerations are discussed and best practice recommendations offered.

The data and models presented can be readily used in injury analyses. The methodology used to transfer AIS-based costs onto the ISS scale can be applied to any injury quantity, not just costs (incidence, hospitalization, LOS, ICU admission, mortality, work days lost, disability, etc.). It therefore represents a new development in the understanding of the AIS-ISS relationship, improves the comparability of the scales, allows seeming disparate AIS/ISS values to be better and more directly compared, facilitates the pooling of mixed AIS/ISS data in meta-analyses, and allows cost values for the ISS scale to be quantified. Previously, such comparisons either had to be made informally (e.g., using heuristics), or data for the scales analyzed separately, or data for one scale discarded. AIS-ISS comparisons can now more be made more directly, and reduced-form ISS cost models are available.

Acknowledgements

This research was supported by the United States Department of Homeland Security through the National Center for Risk and Economic Analysis of Terrorism Events (CREATE) under Cooperative Agreement No. 2010-ST-061-RE0001. However, any opinions, findings, and conclusions or recommendations in this document are those of the author and do not necessarily reflect views of the United States Department of Homeland Security or the University of Southern California. The methods were further refined and extended by the author as an independent consultant. The author thanks Howard Kunreuther, Wilhelmine Miller, Lisa Robinson, Adam Rose, Henry Willis, and three anonymous reviewers for their assistance with various aspects of the study, data, and analysis. However, any opinions, findings, conclusions, or recommendations are those solely of the author.

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