Indexes of Severity: Conceptual Development

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A discussion of severity index development is presented in relation to conceptual issues in index definition, analytic issues in index formulation and validation issues in index application. The CHOP index is discussed along with six severity indexes described in an earlier paper dealing with underlying concepts to illustrate the material presented. Replies are provided to specific questions raised in an accompanying paper discussing the Injury Severity Score.

This conceptual material is presented to provide a foundation for severity index development, to suggest criteria to be used in their formulation and testing, and to identify analyses that can lead to the successful selection and application of an index for a defined purpose.

THE literature on scaling severity shares a common goal of describing injuries and illnesses through the use of quantitative measures. Such scales are developed to facilitate the analysis of injury and illness for purposes that include simple descriptive statistics, comparative studies, or as indicators for intervention. For example, the Cumulative Illness Rating Scale (CIRS) [1] is designed to predict mortality while the Injury Severity Score (ISS) [2] is suggested as a method for evaluating emergency care. Finally, the Trauma Index (TI) [3] has been developed for the initial routing of triage of trauma patients. In addition to the apparent diversity of intended purposes for which the various indexes in the literature are proposed, they are also presented as being developed from different analytic approaches as well. For example, the Multiattribute Severity Score (MSS) [4] is derived from clinical assessments while the estimated survival probability index [5] follows from retrospective statistical calculations and the Trauma Index, the SIMBOL rating and evaluation system [6], and the Injury Severity Score, among others, are based on ad hoc formulations.

These comments are not made to detract from any of the cited indexes but rather are directed at identifying similarities and differences among them that can lead to an evaluation of alternative indexing approaches. My primary objective will be to expand on the ideas introduced in my 1976 paper on underlying concepts in order to promote the conceptual development of severity indexes. Consequently, this paper is organized according to conceptual issues in index definition, analytic issues in index formulation and validation issues in index application. I will also attempt to respond to the points raised in the O'Neill, Zador, Baker paper published in this issue.

Conceptual Issues In Index Definition

A careful review of the severity index literature would identify not only those analytic similarities identified earlier [7], but also a number of definitional differences. These differences include the types of attributes used in defining an index, the point in time

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relative to the injury or illness at which the index is to be calculated (also, the skill level of the individual needed to make the assessment of severity) and the focus of the severity assessment.

Attribute Definition

Attributes that describe an injury or illness can be chosen to reflect the individual, the injury or illness, or the response of the individual to that injury/illness. Table 1 illustrates attributes from several severity indexes according to these categories. It is interesting to note that, while none of the indexes surveyed include attributes from all three categories, the one that includes an attribute descriptive of the individual does not include attributes that describe the individual's condition relative to the injury. One index is based entirely on injury/illness descriptors while another uses only those attributes that describe the individual's condition. The remaining indexes include attributes that define both the injury/illness and their effect on the individual. Sometimes this is done with separate attributes such as in the Trauma Index (e.g., the type of injury and the effect on the sensorium) or by gradations in severity of a single attribute such as in the Cumulative Illness Rating Scale (e.g., a renal illness that ranges from no interference with normal activity to being disabling). Only the indexes that contain attributes which describe an individual's response to an injury or illness can be modified dynamically to reflect a patient's changing condition.

Selection of attributes from each of these categories might be defended on the basis of the availability of certain types of data within the constraints of the intended application of the index.

Table 1: Attribute Types for Selected Attributes and Severity Indexes*

Individual	Injury/Illness	Individual Response to Injury/Illness
MSS: Number of past medical problems	MSS: % of body covered by partial-thickness burn	———
———	ESP: ICDA trauma code	———
———	ISS: Rib fracture	ISS: Respiratory embarrassment
———	TI: Blunt trauma	TI: Motor or sensory loss
———	CIRS: Renal disease	CIRS: Disabling renal disease
———	———	SIMBOL: Awake, coherent

* In all cases, the examples cited are partial attribute definitions selected for illustration.

However, there seems to be no compelling reason to omit such characteristics as an individual's age, sex or prior medical history since these are known to effect severity. In contradiction to the O'Neill, Zador, Baker paper, attributes affecting outcome should be included in index formulations.

Index Application

As the severity indexes described in the literature differ in the attributes they contain, they also differ in their intended locus of application. For example, the estimated survival probability index (ESP) is to be calculated from retrospective chart review, while the TI is intended to be applied by nonphysicians as a means for the initial assessment of trauma. The MSS, ISS and CIRS reflect assessments by skilled personnel, for the most part, physicians.

Another concept in severity index definition and application concerns uncertainty in severity assessments. In the prehospital setting this may be due to the absence of a physician, the inability to recognize certain diagnostic signs or the lack of necessary equipment. On admission, for example, it may be practically impossible to distinguish between deep second degree burns and third degree burns, and some factors contributing to death are known only at autopsy. In the best of circumstances the extent of the injury or illness or the individual's condition may be uncertain.

This raises the question as to whether, and how, uncertainty should be included in index formulations. Techniques for incorporating uncertainty in index scaling follow from utility theory,[1] more specifically, multiattribute utility theory which has been applied in a variety of health care settings. Utility theory explicitly deals with the range of possible values that an attribute might conceivably attain in a particular instance and incorporates it into an appropriate severity appraisal.

Index Focus

A review of severity indexes reveals the need for a sharper definition of the term severity. Are severity values, for example, to be predictive of outcomes if the condition goes untreated? If there is optimal care (a tertiary level care facility, perhaps)? Or average care, given the range of medical care quality that one is likely to receive? Certainly an injury that occurs an hour or more away from medical care may be judged more severe than the identical injury with access to medical care within a few minutes. If severity values are intended to correlate with outcomes, then whenever they are directly assessed, some model of medical care must be included in the assessments. For example, the threat of life of a 40 percent body surface area burn may very well depend on whether space in a burn unit is available. Therefore, the expert who assigns a severity value to that size burn must be doing so within the context of some definition of a health care delivery system.

These concepts require further explication in order to construct meaningful tests of index validity. For example, if an index scales threat to life in the absence of care, then comparisons with empirical data generated from a wide variety of health care systems encounters will produce a shift in the opposite direction from a comparison made with a scale that predicts mortality under optimal care conditions. Such comparisons do not permit a proper test of either type of severity index.

Analytic Issues In Index Formulation

In their most general sense, the severity indexes that concern us are formulated in two parts. First, numerical values are associated with a specific descriptive attribute (e.g., flail chest or 60 percent body surface area of partial thickness burn) and then, when either multiple injuries are involved or other attributes need to be included, a formula is used to aggregate the individual values.

Variation in analytic approach to index formulation is reflected in the literature in both the assignment of numerical values to specific attributes and the aggregation of the individual attributes. The Multiattribute Severity Score and the CHOP index (a general nonacute physiological index of severity) [9] use interval scaling techniques for value determinations while others use rank order approaches (that is, categorical assignments of severity values). The Injury Severity Score squares the categorical values defined by the Abbreviated Injury Scale [10]. The majority of indexes reviewed take a simple summation approach to aggregating individual attribute values. For this reason, they are considered within the framework of additive value functions.[2] The one exception is the clustering approach taken by Sacco et al. in the formulation of the CHOP index [9].

Additive Value Functions

As noted, the majority of indexes take a summation approach to aggregating individual attribute values. Only the MSS attempts to weight the attributes differentially to express their relative contribution to overall severity. The remainder take an equal weighting approach. Not surprisingly, the choice of technique establishes a number of mathematical properties (or provides for certain implications) which either must be assumed or verified if the methods are to be acceptable. In the case of additive value functions, the property that is assumed is called preferential independence [11] or, in the context of this paper, severity independence.

> Definition: The pair of attributes X and Y is severity independent of attribute Z if the conditional severity in (x,y) space, given z at some level z', does not depend on z'.

Note also that if the pair of attributes X,Y are severity independent of Z, then the substitution rate between X and Y at the point (x,y) does not depend on z' for all x,y, and z'. Using the MSS as an example may help to illustrate this property somewhat more clearly.[3] Consider the injury profiles described in Table 2. Holding attributes X_3, X_4 and X_5 fixed at the levels indicated, the MSS would have the same value if the percent of body covered by full-thickness burn was decreased to 35 and the patient's age increased to approximately 45. Severity independence implies that the equivalence of these MSS profiles will hold for any level of X_3, X_4 and X_5.

Two questions can be posed from this example: (1) Did the physicians or other experts who established the severity contribution of individual attributes intend for this property to hold? and (2) Can the property be shown to hold with observed data (e.g., mortality rates) as opposed to the severity index score?

The first question cannot be answered from the material currently available in the literature on severity indexes. Insight regarding the second question is provided from data by Baker et al. [2] on the ISS.[4]

Consider the two injury profiles in which the values of the three highest AIS scores are as follows (5, 3, 0–2) and (5, 4, 0–2). The observed mortality percentages, as reported by Baker, are 59 and 62, respectively. If we were to assume that these figures are approximately equal, then the mortality percentages should also be approximately equal when the third attribute

Table 2: Example of a Burn-Injury Profile and the Calculation of Severity Using the Multiattribute Severity Score*

	x_i	$V(x_i)$	λ_i
x_1: percent of body covered by full-thickness burn	40	50	.371
x_2: age of patient	38	15	.292
x_3: number of past medical problems	1	55	.218
x_4: percent of body covered by partial-thickness burn	20	4	.071
x_5: burn site	Chest, Abdomen, Perineum, Neck, Legs, Buttocks	45	.048
	$\Sigma\lambda_i V(x_i) = 37.36$		

*Reprinted from Gustafson, G. and D.C. Holloway, A decision-theory approach to measuring severity in illness, *Health Services Research*, Spring 1975.

is fixed at a value of 3. From Figure 3 of the Baker paper, we see that the mortality associated with the profiles (5, 3, 3) and (5, 4, 3) are 86 and 92 which are indeed almost the same. This provides supportive evidence in establishing severity independence. Suppose, however, the first attribute is held fixed at a value of 3. If the profiles (5, 3, 3) and (5, 4, 3) imply approximately equal mortality, then so should the profiles (3, 3, 3) and (3, 4, 3). Extrapolating from the data of Figure 3 of the Baker paper, the mortality of the first injury profile should be somewhat less than 18 while that of the second is 43. This suggests that severity independence may not hold at the lower ISS values.

Another difficulty noted in the calculations of ISS scores based on the Baker paper is that the profiles (3, 3, 5) and (0–2, 4, 5) have markedly different mortality rates (86 and 62, respectively), even though the ISS scores are very close.[5] A problem in basing calculations on this data may be the effect of the inclusion of DOAs in the mortality figures, since we note a dramatic shift in mortality when they are excluded.

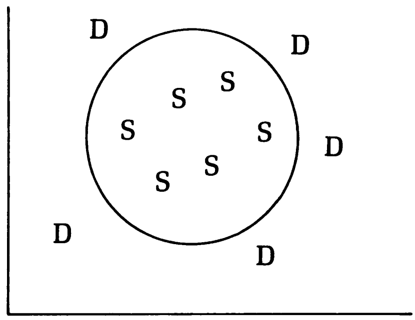
These examples illustrate the property of severity independence which is implied by additive value functions.

Certainly in the case of additive value functions, the property of severity independence must be considered as a criterion that requires validation. As we have seen, the ISS goes farther than any other index in establishing severity independence since it can be shown to hold in certain circumstances based on empirical data. In all fairness to the authors of that index, such evidence is often accepted in practice and the additive value function considered to be a reasonable approximation.

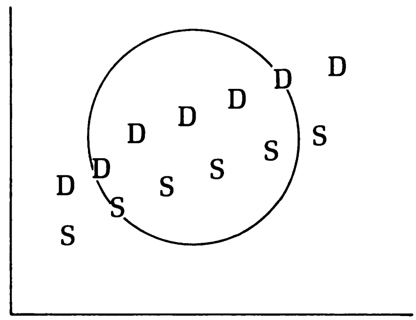
Euclidean Distance Functions (Clustering Approaches)

A somewhat different approach to the formulation of severity indexes has been taken by Champion and Sacco [9, 13] based on the application of con-

Figures 1 & 2



(1)



(2)

cepts drawn from pattern recognition theory. An example of one of the indexes proposed by Champion and Sacco is the CHOP (a general nonacute physiological index) formulated as a measure of Euclidean distance from some desired (average) value of each of the five parameters from which it is constructed.[6] Each parameter is normalized by using estimates of the mean and standard deviation of the distribution of each of the parameters taken from a retrospective review of patients. The CHOP differs markedly from the other indexes considered in that it uses precise physiological measurements available primarily (except for blood pressure) from laboratory findings. More importantly, the difference between the CHOP index and the others is in its analytic formulation. First, we note that the index measures distance from a mean value represented as a 4-tuple (mean value of four variables). The variables are normalized so that each is given exactly the same weight in calculating the index. Further, the contribution of each to the calculated distance measure is independent of the others. As a result, the CHOP index defines a sphere in 4-space. To illustrate the implications of such a formulation, consider the index with only two variables (the CHOP index defines a circle in 2-space).

In the above illustrations, survivors are denoted with an S and deaths with a D. We see from Figure 1 that the CHOP index (in 2-space) would correctly differentiate between survivors and deaths when survivors are charted in a circular arrangement. However, if another arrangement is hypothesized such as in Figure 2 above, the CHOP index will still try to delineate a circle of survivors which would include some deaths. The two groups in Figure 2 are separable, yet the Euclidean distance measure cannot distinguish between them. This problem, well known in pattern recognition theory, stems from the Euclidean distance assumption of independence among attributes and is not often found in practice.

Validation Issues In Index Application

The severity indexes considered in this paper are developed either from subjective judgments of attribute severity levels and assumptions regarding attribute aggregations or from statistical estimation procedures. In the former case, validity is tested by comparing assessed index scores with observed measures obtained through the analysis of large data sets. In the latter case (the ESP index fits into this category), index values are calculated from observed measures in large data sets and compared with the same measures in other data sets. For example, the ESP is calculated from data describing mortality from three large regions of the United States for a one year period and compared to observed mortality from another large geographic region. The MSS and ISS, in contrast, develop severity scores from the subjective estimates of expert assessors and then make comparisons to existing data sets.

The acceptability of such analyses as arguments by which to establish index validity must be tempered somewhat by considering several issues that remain unanswered in these types of comparisons. These issues arise primarily from conceptual problems related to the intended severity index application and also the types and sources of data with which the comparisons are made. One primary issue follows from the relationships between severity appraisals: quality of care and outcome. Another results from considerations of the quality of data sets available for analysis and the level of precision needed for an index to be successfully applied.

Quality of Care Issues

The first of these issues has been touched upon earlier in noting that the subjective assignment of severity values to individual attributes presupposes some model of health care delivery. That is, the nature of the health care system response to an injury or illness of a given type must be considered in making severity assessments. Usually, this model of health care is implicit and, in applying an index, it is not clear how the model may bias comparisons with observed results. Certainly it may be possible to test the magnitude of such biases by explicitly defining urban, rural, tertiary-level or primary care-level models and determining the extent to which severity judgments vary.

It should be noted that this need not be a problem when two health care delivery systems are to be compared using a severity index to control for case mix since they are both measured on the same scale. No results of such attempted analyses have been reported in the literature however. The issue looms larger when existing data sets are used for comparisons with index scores to extablish validity since differences in the implicit model and the empirical one may do more to affect analytic results than the index itself.

A similar issue arises in validation studies when there may be differences in the perception of severity between expert assessors and medical staffs providing care. It is possible that expert assessors working from limited information may define increased severity due to possible complications which must be ruled out (they may not be reflected in the set of attributes which are chosen to describe an injury or illness). An opposite effect may be the result of complicating factors which are present but are unknown to expert severity index assessors. Both types of shifts in severity appraisals will alter comparisons between index scores and empirical data. Consequently, when such data sets are used for validation studies, the hypothesis being tested includes not only the index, but also factors associated with differences in severity perceptions which will affect both index scores and the variables being measured. An appropriate test of validity would insure that the severity index assessors and health system practitioners are working under a common set of assumptions so that analyses properly reflect the strengths and weaknesses of the index itself.

One additional point to be made regarding comparisons with existing data sets is the effect of inherent variations in quality of care that the data set represents. Consider the ESP index for example. It is calculated from data collected from large geographic regions of the country, and wide variations in health care would be represented in that data. If the ESP is shown to be highly related to observed mortality outcomes in that data set, then it must be very insensitive to variations in health care quality. Such an index would have little practical utility as a means for evaluating health care delivery.

Data Analysis Issues

There are two types of issues which warrant discussion. One concerns the nature of the data analyses reported in the literature, and the other deals with the intended application of an index and the resultant requirements for index precision.

The first observation which I would like to make is that the authors of severity indexes describe their formulation in the context of a specific problem area for a single purpose. For example, the ISS has been developed to correlate with mortality[7] for purposes of evaluating emergency and subsequent care. Why then should an index derived from expert judgments of potential mortality be the subject of analyses comparing it to time of death (survival time), length of hospital stay, disability, percentage of major surgery, plasms cortisol concentrations and airway patency in fatal accidents [14–17]? Is it their implication that ISS measures a generic severity or is it that several variables are known to correlate with mortality and consequently will also correlate with anything else related to mortality?

To apply the same index to scale a variety of measures seems rather ambitious and in a completely opposite direction from that of the developers of the AIS who formulated the Comprehensive Injury Scale (CIS) to separately identify severity in relation to impairment, treatment period, threat to life, energy dissipation and incidence.

Calculated relationships between index values and observed variables have little meaning if they are not tied to the intended application of an index. If an index such as the MSS, ISS or ESP is to serve as a predictor of mortality for quality of care evaluations, then the severity classifications introduced would be accompanied by estimates of their precision. For example, given any particular data set, if a category of injury or illness is inversely weighted by the severity associated with that category then predicted mortality should be constant. Similarly for each category of illness and/or injury, validation studies should establish confidence intervals with respect to expected and observed outcomes to permit the application of an index in the evaluation of care. To date, published studies have not provided estimates of the errors associated with scaling severity from which it would be possible to determine the significance of observed differences in comparisons of outcomes.

Both Bull [16] and Krischer [7] note that in some instances individuals with lower ISS scores may have higher likelihoods of death than some individuals with higher scores. Gustafson and Holloway [4] note the same phenomenon with analyses of more than 6,000 burn patients using the MSS. These reversals pose questions for all severity indexes in that, while isolated exceptions are bound to occur, there should be some guidelines as to the minimum number of cases needed in any severity category to adequately draw inferences from index rankings.

Summary

The above discussion has been focused on conceptual issues in severity index development with the hope that it will identify concerns which should be addressed prior to the application of any of the indexes currently found in the literature. Relative to the other indexes, more experience seems to have been accumulated with the ISS and therefore it should be better able to address these concerns. However, even though the extensive work published regarding the development and application of the ISS has permitted a more detailed discussion of it, the issues raised here are common to all the indexes cited. It would seem that additional insight into these issues might be gained by comparisons of indexes when applied to common data sets.

An issue which has not been addressed before, but must surely be of concern to any who wish to use severity indexes, is the quality of data available for index application. For example, the ESP uses ICDA categories (the ISS can also be modified to use ICDA categories) while the MSS makes use of estimates, for example, of the percent of body surface area burned. Other indexes make use of location of injury or even more subjective estimates of the extent to which an illness interferes with normal activities. The reliability of these types of data is known to vary considerably [19,20] which suggests that either there should be criteria which establish the adequacy of a data base for purposes of index application or there should be a means by which the precision of an index can be calibrated on any given data set. Estimates of precision might be based on minimum numbers of cases in appropriated categories of severity as well as the quality of the data. Clearly there needs to be a better understanding of the trade-offs between index simplicity, index precision and data quality in deciding which attributes are to be included in index definitions.

It is hoped that the material presented in this paper helps further the establishment of criteria for severity index development and identifies a conceptual base for further work on indexes of severity.

END NOTES

[1] O'Neill et al. introduce the concept of utility so as to criticize the use of the term additive value functions. They choose not to pursue a utility theory framework in their paper, so it would seem their criticism is at best irrelevant. But in raising the issue, they introduce still other problems with severity indexes. First, utility functions are interval-scaled measures and therefore are not applicable to any of the severity indexes under discussion except possibly the MSS or the CHOP index. Second, the analytic assumptions needed to justify the additive form of a multiattribute utility function are more stringent than those needed to establish additive value functions [11,12]. Lastly, it should be noted that the application of utility theory in a decision analysis context specifically deals with the scaling of

preference which takes into account the uncertainty in any particular decision. That is, utilities are special types of values such that if the appropriate utility is assigned to each possible consequence, then decisions with higher expected utilities (i.e., the sum of the products of the probabilities and their utilities) are consistent with preferences of the decision maker. None of the indexes discussed or proposed in the literature to date include the concept of uncertainty, making it inappropriate to consider these indexes within such a framework.

2 See note 1 above.

3 The MSS is comprised of five attributes and for our purposes, let the complement of attributes X_1 and X_2 be called Z (see Table 2). Since the MSS is an additive value function, X_1 and X_2 are severity independent of Z from which follows

$$\text{if} \quad MSS(x'_1, x'_2, z') \geq MSS(x''_1, x''_2, z')$$
$$\text{then} \quad MSS(x'_1, x'_2, z) \geq MSS(x''_1, x''_2, z)$$

for all values of Z.

4 There appears to be a difference in interpretation with respect to the ISS as an additive value function. If the ISS is formulated as ISS $= X^2 + Y^2 + Z^2$ where x, y, z are the three highest AIS ratings from six body regions, then O'Neill et al. [8] are willing to accept the additive value function framework (by definition) and the independence assumptions necessary to justify this particular formulation. However, they also appear to insist that severity values from all six body regions must be included in the formulation, despite the fact that the three lowest AIS ratings are never used in the computations, and, in that regard, they maintain that the ISS is not an additive value function. This difference in definition extends to the number of possible values that can be generated by the ISS. The Injury Severity Score can take on only 44 different values in the range 0 to 75. Furthermore, 11 of these 44 values can be achieved in either of two, and only two, ways. Stoner et al. [14] make the specious argument that there are additional possible ways of arriving at an ISS score. For example, according to them, there are three ways to arrive at an ISS score of 1: (1, 0, 0), (0, 1, 0) and (0, 0, 1). However, to imply that these profiles are in any way different is nonsensical since there is not particular significance imparted to the ordering of the attributes in the profile. Further, an argument based on attributes not included in the calculations is less than convincing. Hence, since the ISS is calculated from three attributes (as the sum of the squared values) we will continue to consider it as an additive value function.

5 If one scores the 0–2 grade of the third most severe injury as 2, then the profile with the smaller ISS score (3, 3, 5) has the larger mortality associated with it. No matter how this attribute is scored, the ISS values of the profiles differ by two only.

6 $$\text{CHOP INDEX} = \sqrt{\left(\frac{C-1.0}{15}\right)^2 + \left(\frac{H-37.0}{6}\right)^2 + \left(\frac{O-292.0}{15.0}\right)^2 + \left(\frac{P-127.0}{21.0}\right)^2}$$

where: C = serum creatinine
H = hematocrit
O = serum osmolality
P = systolic blood pressure

[7] Most recently O'Neill, Zador and Baker state that the ISS "is not (and was never claimed to be) linearly related to mortality." They go on to clearly show the nonlinear relationship between the ISS and observed mortality rates by means of a graph. This statement is in contradiction to their own detailing of the development of the ISS in which they report improved correlation by proposing the ISS as it is now currently defined. Simply stated, correlation is a measure of linear association. To deny linearity, O'Neill, Zador and Baker cast doubt on their own results and those reported by Semmlow and Cone [17] as well. Further, since the ISS is an ordinal scale one presumes that reported correlations were Spearman or Kendall or other appropriate nonparametric technique, although no inkling of technique is provided in published analyses. Contrary to O'Neill, Zador and Baker, I do not consider logistic or probit transformations of index values as a suitable means for obtaining an interval scale from an ordinal scale.

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