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Sustainable goals in combating human trafficking: Analysis by mathematics of uncertainty

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Abstract

We use mathematics of uncertainty to analyze the relationship between the sustainable development goals and human trafficking. This comes about naturally due to the use of multiplication in the determination of metrics in scoring categories by the Stakeholder Forum. We develop a method for ranking the members of the Organization for Economic Cooperation and Development in their achievement of the sustainable development goals that are pertinent to trafficking in humans. This method includes linear equations involving ten of the SDGs. SGD 5 (Gender Equality), 8 (Decent Work and Economic Growth), and 16 (Peace, Justice, and Strong Institutions) carry the most weight in determining these rankings. We found that Denmark, Finland, Iceland, and Sweden rank the highest in achieving the sustainable development goals pertinent to human trafficking. We discuss how our methods can be placed in a setting of fuzzy hyperstructures.

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1 Introduction

The issues of sustainability, climate change, human trafficking, and modern slavery are of the most important issues facing the world. They are related. The purpose of this paper is to use mathematics of uncertainty to analyze the relationship between sustainability and human trafficking. We also would like to discuss the possible study of these issues using fuzzy hyperstructures, in particular fuzzy hypergraphs. We first present our results on sustainabilty and human trafficking so that the reader can better understand our suggestions. We next comment on climate change and modern slavery. We close the paper with a discussion of how our results are related to fuzzy hypergraphs.

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The members of all UN's Member States agreed to the 2030 Agenda for Sustainable Development. The 17 Sustainable Developmental Goals (SDGs) address five broad areas of critical importance: People, Planet, Prosperity, Peace, and Partnership, [17]. It is stated in [17, 18], that as an over arching principle, the Goals posit that States have a collective interest and responsibility to ensure that the most vulnerable people and populations - including migrants and refugees - are not left behind by economic, social, and environmental progress.

Out of the 17 SDGs, trafficking in persons is specifically mentioned in three targets under three goals: 5 (Gender Equality), 8 (Decent Work and Economic Growth), and 16 (Peace, Justice, and Strong Institutions). However many other SDG targets and goals are relevant to addressing trafficking in persons. This issue is rooted in development issues at-large including poverty, education, child labor, abuse, and exploitation, gender equality and discrimination, migration and the effects of climate change, [17]. Other SDGs mentioned in [17] that contribute to combatting trafficking in persons are $10, 4, 17$. The specific targets of the SDGs that contribute to combatting trafficking in persons are $5.2, 8.7, 16.2, 5.3, 10.7, 4.1, 4.3, 4.4, 17.18$ and 17.19[17]. It is mentioned by Professor Rochelle Dalla, Editor in-Chief of the Journal of Human Trafficking, that SDG 12 is also important in combatting trafficking persons since it is directly related to the promotion of Fair Trade production, advocacy, and market practices, an addition to consumer knowledge and choice [19].

In this paper, we introduce a new approach to analyze the impact of the SDGs on trafficking in persons. Our goal is to introduce to the study of sustainability concepts from mathematics of uncertainty. This includes the important area of Dempster-Shafer theory. Fuzzy graph theory has been applied to the study of human trafficking, immigration, and modern slavery, [4]. We consider countries that are members of the Organization for Economic Cooperation and Development (OECD). The OECD is a forum where the government of 36 democracies with market economies work with each other, as well as with more than 70 non-member economies to promote economic growth, prosperity, and sustainable development.

One of the main outcomes from the UN Conference on Sustainable Development (Rio+20) in 2012 was international agreement to negotiate a new set of global Sustainable Development Goals (SDGs) to guide the path of sustainable development after 2015, [9]. It is stated in [9] that all of the SDGs are relevant and apply in general terms to all countries including developed countries. However, the nature and balance of the challenges they represent will be different in different national contexts. The report in [9] proposes a methodology for identifying which of the different goals and targets represent the biggest transformational challenges in any given implementation context.

The 17 SDGs are G_1 : No Poverty, G_2 : Zero Hunger, G_3 : Good Health and Well Being, G_4 : Quality education, G_5 : Gender Equality, G_6 : Clean Water and Sanitation, G_7 : Affordable and Clean Energy, G_8 : Decent Work and Economic Growth, G_9 : Industry, Innovation, and Infrastructure, G_{10} : Reduced Inequalities, G_{11} : Sustainable Cities and Communities, G_{12} : Responsible Construction and Production, G_{13} : Climate Action, G_{14} : Life Below Water, G_{15} : Life on Land, G_{16} : Peace, Justice, and Strong Institutions, G_{17} : Partnerships and Goals, [21, 10]. These SDGs are discussed in more detail in [21, 10].

In [9], Stakeholder Forum created a methodology or analytical tool to enable relative scores to be assigned to each of the different targets and goals according to their difference significance in different contexts. The method uses a number of assessors to assign their own independent scores of the significance of each of the proposed targets in the implementation context in question, according to three separate criteria. The three criteria proposed are applicability, implementability, and the transformational impact (both in the country concerned and for the world as a whole), [9, Proposition 10]. The assessors' scores are then aggregated and averaged to give an overall score for each target, and then combined to give an average score for each goal. The methodology is described in more detail in Section 2.

The general effect is to give the highest scores to those targets and goals which are both clearly applicable and implementable in the country in question and which represent the biggest transformational challenge. Conversely, lower scores are given to targets and goals which are less applicable or implementable in a particular country for reasons given in [9].

We use the analytic hierarchy process [11, 12], the Guiasu method [1], and the Yen method [13, 14] to determine which countries are, in the opinion of the experts, the best in achieving sustainability. This is accomplished by constructing linear equations involving the SDGs as independent variables and a measure of success as the dependent variable. These methods are described in Section 3. We find that Denmark, Finland, and Sweden rank the highest in achieving the sustainable development goals pertinent to human trafficking.

Our paper relies heavily on the concept of a t-norm, [2], for reasons given in Section 2. A t-norm is the extension of intersection in set theory to intersection in fuzzy set theory. We provide the definition of a t-norm. First, we explain some notation. We let $[0,1]$ denote the set of all real numbers between and including 0 and1. Then $[0,1] \times [0,1]$ denotes the set of all ordered pairs of elements from $[0,1]$. We let $i : [0,1] \times [0,1] \to [0,1]$ denote a function from $i : [0,1] \times [0,1]$ into $[0,1]$.

Definition 1.1. *Let $i : [0,1] \times [0,1] \to [0,1]$. Then i is called a t-norm if the following conditions hold:* $\forall a, b, c \in [0,1]$,

(1) $i(a,1) = 1$ *(boundary condition),*
(2) $b \leq c$ *implies* $i(a,b) \leq i(a,c)$ *(monotonicity),*
(3) $i(a,b) = i(b,a)$ *(commutativity),*
(4) $i(a, i(b,c)) = i(i(a,b), c)$ *(associativity).*

Example 1.2. (1) *Standard intersection:* $i(a,b) = a \wedge b$, *where* $\wedge$ *denotes minimum;*
(2) *Algebraic product:* $i(a,b) = ab$;
(3) *Bounded difference:* $i(a,b) = 0 \vee (a + b - 1)$, *where* $\vee$ *denotes maximum.*

We use these t-norms to illustrate our approach for the following reasons: Algebraic product (multiplication) is in keeping with the approach in [9], where the t-norm multiplication was used to emphasize that for a goal or target to score highly, it must meet all criteria. Standard intersection is the largest t-norm and thus is the least punitive t-norm. Bounded difference is more punitive than algebraic product since $0 \vee (a + b - 1) \leq ab$ for all $a, b \in [0,1]$.

2 Scoring assessment

The following table is determined by the table in [9, Annex 2, p.12], Results of the Scoring Assessment. In [9], the table present the individual category scores and the overall scores for each goal and target. These were obtained by averaging the collective scores from the assessors. The scores given were out of a maximum of 2 for individual category scores and a maximum of 8 for overall scores. An overall score was then obtained for each target by multiplying the scores given to each of the three categories. Multiplication was used to emphasize that for a goal or target to score highly, it must meet all three criteria. Goals that are not immediately relevant to human trafficking are excluded from the analysis. We divided the individual category scores by 2 so that the resulting scores were out of a maximum of 1. The overall scores were divided by 8 so the resulting scores were out of a maximum of 1. In this way, we have placed the scoring in a fuzzy logic setting, [15]. For example, multiplication is a particular t-norm in mathematics of uncertainty.

Goal/Target	Applicable	Implementable	Transformative	Overall bounded difference	Overall algebraic product	Overall standard intersection
G_1	0.53	0.94	0.33	0.1	0.22	0.33
G_4	0.5	0.9	0.3333	0.12	0.20	0.33
4.1	0.15	0.85	0.15	0.0	0.019	0.15
4.3	0.5	0.85	0.35	0.0	0.149	0.35
4.4	0.85	1.0	0.5	0.35	0.425	0.5
G_5	0.75	0.75	0.75	0.25	0.43	0.75
5.2	1.0	0.65	1.0	0.65	0.65	0.65
5.3	0.5	0.85	0.5	0.0	0.212	0.5
G_6	0.5	0.85	0.5	0.0	0.21	0.5
6.2	0.5	0.85	0.5	0.0	0.212	0.5
G_8	0.83	0.95	0.72	0.5	0.60	0.72
8.5	0.85	0.85	0.65	0.35	0.470	0.65
8.7	1.0	1.0	1.0	1.0	1.0	1.0
8.8	0.65	1.0	0.5	0.15	0.325	0.5
G_{10}	0.5	0.5	0.5	0.0	0.12	0.5
10.7	0.5	0.5	0.5	0.0	0.125	0.5
G_{11}	0.5	0.85	0.65	0.0	0.28	0.5
11.7	0.5	0.85	0.65	0.0	0.28	0.5
G_{12}	0.5	0.5	0.5	0.0	0.12	0.5
G_{16}	1.0	0.85	1.0	0.85	0.85	0.85
16.2	1.0	0.85	1.0	0.85	0.85	0.85
G_{17}	0.5	0.5	0.5	0.0	0.12	0.5
17.18	0.5	0.5	0.5	0.0	0.125	0.5
17.19	0.5	0.5	0.5	0.0	0.125	0.5

Table 2.1 Scoring Assessment

3 Analytic Hierarchy, Guiasu, and Yen Methods

Guiasu Method

The Guiasu method describes the process of reaching a verdict by probabilistic weighting the available evidence. The Guiasu method is a generalization of Dempster-Shafer theory [1, 2] and makes use of fuzzy set theory [15].

A body of information induces a probability (credibility) distribution m on $P(X)$, the set of all subsets of X. That is, m is a function of $P(X)$ into the closed interval $[0,1]$, written $m : P(X) \to [0,1]$, such that $m(A) \geq 0 \forall A \in P(X)$ and $\sum_{A \in P(X)} m(A) = 1$. The class of focal subsets of X corresponding to m is denoted by $\mathcal{F}(X;m) = \{A | A \subseteq X, m(A) > 0\}$. A pair of dependent bodies of information, say i and j, induce a joint probability (credibility) distribution, namely $m_{ij} : P(X) \times P(X) \to [0,1]$ such that $m_{ij}(A,B) \geq 0$ and $\sum_{A \subseteq X} m_{ij}(A,B) = 1$. If the bodies of information are independent, then $m_{ij} = m_i m_j$. The corresponding class of focal pairs of subsets is $F(X,X;m_{ij}) = \{(A,B)|A,B \subseteq X, m_{ij}(A,B) > 0\}$. The weights corresponding to the body of information for which m is the probability (credibility) distribution is on $P(X)$ are $w(\cdot|\cdot) : P(X) \times \mathcal{F}(X;m) \to [0,\infty)$. The weighted body of information provides the new probability (credibility) distribution on $P(X)$ given by $\mu(C) = \sum_{A \in F(X;m)} w(C|A)m(A)$. We can generalize this procedure to formulate the weights $w_{ij}(\cdot|\cdot,\cdot)$ are assigned to a mixed body of information inducing a joint probability (credibility) distribution induced on $P(X)$ by the weighted (i,j)-th body of information, i.e.,

$$\mu_{ij}(C) = \sum_{(A,B) \in F(X,Xm_{ij})} w_{ij}(C|A,B)m_{ij}(A,B), C \in P(X),$$

where $w_{ij}(C|A,B)$ is the weight of the subset C given $(A,B) \in \mathcal{F}(X,X;m_{ij})$.

If the probability (credibility) distribution m on X is such that $\sum_{A \in F(X;m)} m(A) = 1$ and $\forall A \in F(X;m), |A| = 1$, then it is called probabilistic. Given k goals ($k = 10$ SDGs in this application) and n experts ($n = 3$ t-norms in this application). Assume the experts assign numbers to each SDG as th their importance with respect to the overarching goal (sustainability) to form a $k \times n$ matrix $W = [w_{ij}]$. When the columns of the matrix are normalized, we can consider that each column of the of the resulting matrix N to be a probability (credibility) distribution for each expert (t-norm in this application). These probability (credibility) distributions are probabilistic with the focal elements being singleton sets consisting of an SDG. The row averages provide the Guiasu weights, one for each SDG.

Theorem 3.1. [8] *The row averages of N give the Guiasu weights $w_i, i = 1, ..., k$..*

Analytic Hierarchy Process

Each expert E_j(t-norm), assigned a number, w_{ij}, to each SDG,$G_i, i = 1, ..., n$, as its importance with respect to the overarching goal (sustainability). The row average, w_i of each row of the matrix $W = [w_{ij}]$ is determined to form an $m \times m$-matrix R whose ij-th element is w_i/w_j. The columns of R are then normalized in order to form the $m \times m$-matrix N whose ij-th element is $(w_i/w_j)/\sum_{i=1}^{m} w_i/w_j = w_i/\sum_{i=1}^{m} w_i, i = 1, ..., m$. This row vector yields the weights for the SDGs for the linear equation of the overarching goal, the dependent variable, in terms of the SDGs, the independent variables.

If the matrix W already has its columns normalized, then $w_i = \sum_{j=1}^{n} w_{ij}/n, i = 1, ..., m$. Since $\sum_{i=1}^{m} w_{ij} = 1.j = 1, ..., n$, it follows that $\sum_{i=1}^{m} w_i = 1$. Hence $w_i/\sum_{i=1}^{m} w_i = w_i$,i.e., w_i is the weight for the i-th SDG in the linear equation, $i = 1, ..., m$. It thus follows that if the columns of W are already normal, then the Guiasu method (with probabilistic assignments) and the analytic hierarchy process yield the same weights. However, in general, the Guiasu weights and the analytic hierarchy process can have quite different weights [8].

Yen Method

Yen's method addresses the issue of managing imprecise and vague information in evidential reasoning by combining the Dempster-Shafer theory with fuzzy set theory. Several researchers have extended the Dempster-Shafer theory to deal with vague information, but their extensions did not preserve an important principle that the belief and plausibility measures are lower and upper probabilities. Yen's method preserves this principle. Nevertheless, we use various measures of subsethood to determine belief functions. We do this to compare the results of the beliefs with Yen's method.

Yen's method is developed under the assumption that the focal elements are normal. If the fuzzy focal elements are not normal, he normalizes them.

4 Main results

We use the analytic hierarchy process [11, 12] and the Guiasu method [1]. These methods allow us not only to determine which countries are, in the opinion of the experts, the best in achieving sustainability, but also to construct a linear equation involving the goals as independent variables and a measure of success as the dependent variable. The entries in the following table are from Table 2.1.

AHP	Bounded Difference	Algebraic Product	Standard Intersection	Row Average
G_1	0.10	0.22	0.33	0.2167
G_4	0.12	0.20	0.33	0.2167
G_5	0.25	0.43	0.75	0.5767
G_6	0.00	0.21	0.50	0.2367
G_8	0.50	0.60	0.72	0.6067
G_{10}	0.00	0.12	0.50	0.2067
G_{11}	0.00	0.28	0.50	0.2600
G_{12}	0.00	0.12	0.50	0.2067
G_{16}	0.85	0.85	0.85	0.8500
G_{17}	0.00	0.12	0.50	0.2067
Column Sum	1.82	3.15	5.48	3.5836

Table 3.1 AHP Method

The coefficients in the following equation are determined by dividing the corresponding entry in the row average column by the column sum.

$$G = 0.06G_1 + 0.06G_4 + 0.16G_5 + 0.07G_6 + 0.17G_8 + 0.06G_{10} + 0.07G_{11} + 0.06G_{12} + 0.24G_{16} + 0.06G_{17} \quad (3.1)$$

The following table is obtained from by dividing each entry in Table 3.1 by column sum of the column it appears.

Guiasu	Bounded Difference	Algebraic Product	Standard Intersection	Row Average
G_1	0.05	0.07	0.06	0.06
G_4	0.07	0.06	0.06	0.06
G_5	0.14	0.14	0.14	0.14
G_6	0.00	0.07	0.09	0.05
G_8	0.27	0.19	0.13	0.20
G_{10}	0.00	0.04	0.09	0.04
G_{11}	0.00	0.07	0.09	0.05
G_{12}	0.00	0.04	0.09	0.04
G_{16}	0.47	0.27	0.16	0.30
G_{17}	0.00	0.04	0.09	0.04
Column Sum				

Table 3.2 Guiasu Method

The coefficients in the following equation are the entries of the row average column.

$$G' = 0.06G_1 + 0.06G_4 + 0.14G_5 + 0.05G_6 + 0.20G_8 + 0.04G_{10} + 0.05G_{11} + 0.04G_{12} + 0.30G_{16} + 0.04G_{17} \quad (3.2)$$

The next table is determined by dividing each element in Table 3.2 by the largest element in its column.

Yen	Bounded Difference	Algebraic Product	Standard Intersection	Row Average
G_1	0.11	0.26	0.38	0.25
G_4	0.15	0.22	0.38	0.25
G_5	0.30	0.52	0.87	0.56
G_6	0.00	0.26	0.56	0.27
G_8	0.57	0.70	0.81	0.69
G_{10}	0.00	0.15	0.56	0.24
G_{11}	0.00	0.26	0.56	0.27
G_{12}	0.00	0.15	0.56	0.24
G_{16}	1.00	1.00	1.00	1.00
G_{17}	0.00	0.15	0.56	0.24
Column Sum				4.01

Table 3.3 Yen Method

The coefficients in the following able are determined by dividing the corresponding entries in the row average column by the column sum.

$$G'' = 0.06G_1+0.06G_4+0.14G_5+0.07G_6+0.17G_8+0.06G_{10}+0.07G_{11}+0.06G_{12}+0.25G_{16}+0.06G_{17} \quad (3.3)$$

We next present the degree to which the countries are achieving the SDGs as determined in [[10], pp. 69-72].

	G_1	G_4	G_5	G_6	G_8	G_{10}	G_{11}	G_{12}	G_{16}	G_{17}
Australia	.990	.928	.789	.970	.811	.770	.806	.409	.857	.611
Austria	.992	.966	.791	.949	.820	.874	.858	.455	.920	.680
Belgium	.995	.947	.839	.793	.814	.934	.823	.467	.869	.623
Canada	.992	.999	.804	.842	.840	.788	.804	.501	.881	.654
Chile	.989	.928	.705	.966	.807	.273	.807	.725	.759	.794
Czech Rep.	.994	.963	.711	.880	.851	.923	.894	.708	.827	.555
Denmark	.996	.983	.848	.907	.839	.965	.902	.498	.928	.898
Estonia	.997	.953	.753	.897	.848	.722	.903	.587	.878	.555
Finland	.998	.989	.892	.926	.825	.979	.883	.487	.929	.740
France	.995	.974	.865	.879	.781	.856	.870	.534	.766	.751
Germany	.996	.890	.770	.894	.844	.834	.909	.474	.834	.831
Greece	.967	.901	.626	.906	.630	.509	.821	.394	.728	.536
Hungary	.989	.904	.641	.890	.821	.756	.861	.710	.734	.515
Iceland	.997	.974	.855	.874	.830	.992	.899	.506	.930	.674
Ireland	.997	.952	.731	.820	.877	.848	.845	.463	.904	.334
Isreal	.992	.968	.752	.743	.850	.502	.801	.425	.736	.549
Italy	.973	.976	.712	.848	.787	.699	.740	.517	.752	.631
Japan	.990	.981	.585	.845	.885	.768	.754	.556	.903	.649

Table 3.4

	G_1	G_4	G_5	G_6	G_8	G_{10}	G_{11}	G_{12}	G_{16}	G_{17}
Korea Rep.	.990	.958	.639	.815	.862	.865	.803	.635	.754	.534
Latvia	.987	.957	.702	.890	.833	.765	.863	.679	.770	.504
Lithuania	.984	.987	.721	.857	.805	.496	.831	.674	.805	.516
Luxembourg	.999	.944	.746	.900	.699	.883	.945	.239	.902	.584
Mexico	.875	.926	.774	.791	.730	.146	.812	.788	.531	.602
Netherlands	.996	.942	.815	.927	.831	.946	.911	.440	.835	.537
N. Zealand	1	.981	.847	.907	.881	.733	.830	.515	.926	.649
Norway	.995	.999	.877	.875	.785	1	.861	.305	.849	.996
Poland	.999	.944	.711	.820	.844	.537	.785	.737	.814	.534
Portugal	.987	.955	.807	.870	.823	.573	.844	.548	.841	.587
Slovak Rep.	.982	.838	.689	.844	.807	.835	.820	.650	.799	.551
Slovenia	.997	.966	.753	.824	.847	1	.859	.608	.881	.576
Spain	.981	.954	.827	.881	.752	.692	.891	.534	.806	.591
Sweden	.990	.993	.889	.935	.835	1	.903	.522	.838	.982
Switzerland	.999	.919	,822	.955	.798	.800	.983	.279	.830	.533
Turkey	.995	.937	.453	.821	.738	.412	.704	.738	.681	.708
U. K.	.997	.994	.813	.951	.829	.714	.980	.429	.857	.489
U. S.	.989	.893	.734	.850	.852	.477	.825	.365	.761	.562

Table 3.4 continued

The numbers in the above table are substituted for the G_i in the AHP, Guiasu, and Yen formulas to obtain the following table. The second entry in each column is the rank of the country with respect to achieving the SDGs pertinent to human trafficking.

Country	AHP/Rank	Guiasu/Rank	Yen/Rank
Australia	0.81659 /17	0.80524 /18	0.80938 /18
Austria	0.85127 /7	0.83893 /6	0.84465 /7
Belgium	0.83226 /12	0.81924 /11	0.83417 /12
Canada	0.83414 /10	0.82434 /9	0.82687 /10
Chile	0.7788 /33	0.76315 /29	0.77229 /29
Czech Rep.	0.82967 /14	0.8114 /16	0.82372 /13
Denmark	0.88806 /1	0.86855 /1	0.88038 /1
Estonia	0.8302 /13	0.81998 /10	0.82392 /14
Finland	0.88414 /2	0.86649 /2	0.87559 /2
France	0.82404 /16	0.79833 /21	0.8144 /16
Germany	0.83455 /9	0.81567 /14	0.82749 /9
Greece	0.70129 /36	0.68803 /34	0.69605 /34
Hungary	0.7733 /30	0.75451 /30	0.76782 /30
Iceland	0.87379 /4	0.85849 /3	0.86599 /4
Ireland	0.8152 /18	0.81493 /15	0.80962 /17
Isreal	0.7557 /35	0.74992 /33	0.74802 /33
Italy	0.76711 /29	0.7529 /32	0.76039 /31
Japan	0.80934 /19	0.80693 /17	0.80667 /19

Table 3.5

Country	AHP/Rank	Guiasu/Rank	Yen/Rank
Korea Rep.	0.78192 /28	0.7672 /28	0.77668 /27
Latvia	0.79496 /26	0.77809 /25	0.78862 /24
Lithuania	0.78299 /27	0.77354 /26	0.77662 /28
Luxembourg	0.80278 /22.5	0.79191 /22	0.79686 /22
Mexico	0.68781 /34	0.66331 /36	0.67764 /36
Netherlands	0.83239 /11	0.8159 /13	0.82444 /11
N. Zealand	0.8618 /5	0.85417 /4	0.85412 /5
Norway	0.85676 /6	0.83296 /7	0.8477 /6
Poland	0.79001 /25	0.78169 /24	0.78393 /25
Portugal	0.80985 /20	0.80042 /19	0.80212 /21
Slovak Rep.	0.78703 /24	0.7714 /27	0.78124 /26
Slovenia	0.84254 /7	0.82841 /8	0.83629 /8
Spain	0.80276 /22.5	0.78536 /23	0.79428 /23
Sweden	0.88319 /3	0.8539 /5	0.87379 /3
Switzerland	0.81384 21	0.80014 /20	0.8057 /20
Turkey	0.69553 /33	0.68161 /35	0.69328 /35
U. K.	0.82924 /15	0.81801 /12	0.82155 /15
U. S.	0.75933 /34	0.75429 /31	0.75226 /32

Table 3.5 continued

5 Discussion

Uncertainty is essential to science and has a great utility. An important point in the evolution of the modern concept of uncertainty was the publication of a seminal paper by Lotfi Zadeh [15]. Fuzzy set theory provides a methodology for carrying out approximate reasoning processes when available information is uncertain, incomplete, imprecise, or vague. This is especially true when observations are expressed in linguistic terms. The success of this methodology has been demonstrated in a variety of fields such as control of complex system, where mathematical models are difficult to specify, and in expert systems, where rules express knowledge and facts that are linguistic in nature.

Due to the nature of the problem, accurate data concerning trafficking in persons is impossible to obtain. The goal of the trafficker is to be undetected. The size of the problem also makes it very difficult to obtain accurate data. We next illustrate the situation with some examples from the literature.

In [22], details of the reported trafficking in persons situation of the country or territory under analysis is provided. Linguistics were used to provide a measure as to whether a country ranks (very) low, medium, or (very) high as country of origin, transit or destination. These rankings turned out to be useful in determining the strength of various trafficking routes, [20, 23, 5, 4, 6]. These routes include trafficking networks through Mexico to the U.S and routes across the Mediterranean to Europe. This was accomplished by placing the rankings in the interval $[0, 1]$ by assigning the numbers $0.1, 0.3, 0, 5, 0.7.0, 9$ to the measures very low, low, medium, high, very high, respectively.

Another example is in [18, 10]. Here the colors red, orange, yellow and green are assigned to countries to provide a measure of their achievement for each of the 17 SDGs. These colors are assigned to the target values of each SDG. The worst two colors of a target were averaged to determine the color for its SDG. In this paper, we assigned the numbers $0.2, 0.4, 0.6, 0.8$ to the colors red, orange, yellow, and green, respectively. Thus the many techniques from mathematics of uncertainty become available to examine the SDGs.

In [16], a study of how governments are tackling modern slavery was undertaken. 161 countries were included in the assessment of government response. In [16], tables are provided giving measures of vulnerability to modern slavery by country with respect to four categories. Government response to human trafficking involved five categories. Tables providing measures for these five categories were also given. In

[3], the data in these tables were normalized. This allowed for the use of fuzzy logic techniques to be used to compare government's vulnerability and its response. It was shown in [7] that government response and vulnerability were opposites. Also, the vulnerability of routes could be measured by using techniques from fuzzy mathematics, [3, 7, 4, 6].

Another example is in [9]. Here a table presented the individual category scores and the overall scores for each goal and target. These were obtained by averaging the collective scores from the assessors. The scores given were out of a maximum of 2 for individual category scores and a maximum of 8 for overall scores. An overall score was then obtained for each target by multiplying the scores given to each of the three categories. Multiplication was used to emphasize that for a goal or target to score highly, it must meet all three criteria. In this paper, we normalized the data so that we could apply techniques from mathematics of uncertainty. It should be noted that expert opinion provided the rankings thus providing another reason to use mathematics of uncertainty. It should also be noted that the paper relies heavily on the notion of a t-norm because [9] used multiplication which is a t-norm. Hence we maintain the philosophy that for a goal or target to score highly, it must meet all three criteria.

Fuzzy hypergraphs

Let V be a finite set and E a set of fuzzy subsets of V such that $\cup_{\mu \in E} \text{supp}(\mu) = V$. Then (V, E) is called a **fuzzy hypergraph**. Now let M be an $m \times n$ matrix with entries from the closed interval $[0, 1]$. Let V denote the set of all row titles, say $V = \{R_1, ..., R_m\}$ and let E denote the set of fuzzy subsets of V which are described by the columns, say $E = \{\mu_{C_1}, ..., \mu_{C_n}\}$. If $\cup_{j=1}^{n} \text{supp}(\mu_{C_j}) = V$, then (V, E) is a fuzzy hypergraph.. Table 2.1, Tables 3.1-3.3, Table 3.4, and Table 3.5 all provide examples of fuzzy hypergraphs. As another example, let V denote a set of countries under consideration. Let E be the set of fuzzy subsets of V that are defined by the five government responses to human trafficking and the four vulnerabilities to human trafficking, [6, 16]. This and similarly related situations involving government response and vulnerability provide additional examples of fuzzy hypergraphs, [6]. The list of such examples could be quite long. Many can be found in [4].

6 Conclusions

We introduced a new approach to analyze the impact of the SDGs on trafficking in persons. Our goal was to introduce mathematics of uncertainty to the analysis of sustainable goals pertinent to trafficking in persons. This includes the important area of Dempster-Shafer theory. We considered countries that are members of the Organization for Economic Cooperation and Development (OECD). We found that Denmark, Finland, Iceland, and Sweden ranked the highest of the OECD counties in achieving the sustainable development goals pertinent to human trafficking.

In the future, we plan to examine the regions East and South Asia, Eastern Europe and Central Asia, Latin America and Caribbean, Middle East and North Africa, Sub-Saharan Africa. The purpose for the use of t-norms in this paper was to maintain the philosophy of [9, 10] that for a goal or target to score highly, it must meet all criteria. Other operators in mathematics of uncertainty can be used to examine other philosophies. For example, aggregation operators would measure the overall achievement of a country's success in achieving an SDG. Similarity measures can be used to make a wide variety of comparisons such as country rankings between years or comparison of regions. Once the door is open to techniques from fuzzy set theory, other areas such as rough sets and soft sets could come into play.

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