RISK SCORING METHODOLOGY C

In this screening procedure, the quantification of risk follows directly from the method used in FEMA 452, providing a consistent and logical link among the recently-published FEMA assessment guides for addressing terrorism risk.

This appendix contains a description of the step-by-step process used to develop the scoring procedure as a function of the Data Collection Form building characteristics and corresponding attribute options. It explains the logic and methodology embedded in the ratings contained within the forms. The process for developing the ratings contained within the Data Collection Form (and the companion electronic version of the procedure) is described in detail so that users can complete the scoring procedure in an informed and knowledgeable manner, which will result in ratings that are more reliable and consistent. An example of how screeners can use the Data Collection Form to develop a rating is provided at the end of this appendix.

Conceptually the risk scoring methodology has been developed so that each of the three factors (Consequences, *C*; Threat Rating, *T*; and Vulnerability Rating, *V*) is ultimately assigned a value in the range of 1 to 10, where 1 indicates the lowest value of the factor and 10 indicates the highest, in terms of contribution to the risk for a given threat scenario. Risk ratings for each of the nine threat scenarios are computed as the product of the assigned values (in the range, 1 to 10) for each of these three factors (*C*, *T*, and *V*). The methodology development process involved the following steps.

1. Building characteristics contributing to each of these three factors (*C*, *T*, and *V*) for the building systems considered (see Table 2), along with possible attribute options, were initially identified, based on the project team's knowledge and expert judgment.
2. For each set of possible attribute options for a given building characteristic (where each set ranges from two to five multiple-choice options – a., b., c., d., or e.) rating values were initially assigned based on a scale of 1 to 10, where 1 indicates the lowest level of hazard or risk and 10 the highest.
3. For each building characteristic in the subset corresponding to a given factor, the relative contribution of that building characteristic to the overall value of the given factor was then assigned. The

relative contribution was denoted by VH (very high), H (high), M (medium), or L (low).

Table C-1 illustrates the development of the scoring values, as prescribed in Steps 1 through 3 above, for building characteristics and attribute options initially assigned to Consequences (*C*). As indicated, the assigned values range from 1 to 10, and the relative contributions of each building characteristic are denoted with VH (very high), H (high), M (medium), or L (low).

Table C-1 Information Used in the Initial Risk Scoring Methodology Development for Consequences

BUILDING CHARACTERISTICS	a.	b.	c.	d.	e.	CONSE-QUENCES
1.1. Locality Type	Rural/ Suburban	Semi-urban/ Lt. Industrial	Industrial	Urban	Dense Urban	L
	1	3	5	7	10	
Non-Dense Urban	< 100	100 - 500	500 - 2000	2000 - 5000	> 5000	H
Dense Urban	< 1000	1000 - 3000	3000 - 7000	7000 - 10000	> 10000	
1.3. # Occupants	1	4	6	8	10	
Non-Dense Urban	< $1M	$1M - $20M	$20M – $100M	$100M – $500M	> $500M	M
Dense Urban	< $20M	$20M - $150M	$150M – $400M	$400M – $750M	> $750M	
1.5. Replacement Value	1	4	6	8	10	
1.7. Historic Value	No	Yes				L
	1	10				
1.8. Operational Redundancy	Very High	High	Moderate	Low	Very Low	M
	1	3	5	7	10	
1.9. Impact of Asset Physical Loss	Local	Regional	Statewide	National	Inter-national	VH
	1	4	6	8	10	

4. The results of Step 3 (the relative contribution of each relevant building characteristic to each factor) were used to develop weighting factors that essentially averaged the values associated with each attribute option (defined in Step 2) for the relevant building characteristics that comprise each factor.

Step 4 of the methodology can be illustrated by examining the information in Table C-1, which identifies six building characteristics pertinent to Consequences, one of which has a very high (VH) contribution, one a high (H) contribution, two a medium (M) contribution, and two a low (L) contribution. In this initial development of the scoring system, the weighting factors (six in this case) were normalized to sum to 1.0. For computing Consequences, VH was set to 0.44, H was set to 0.22, M to 0.11 and

L to 0.055 (this corresponded to un-normalized weighting factors of 8, 4, 2, and 1 respectively).

5. The results of Step 4 (the weighting factors) were used to normalize the values associated with each attribute option (defined in Step 1) for the relevant building characteristics that comprise each factor.

   Initially the normalization was essentially just the multiplication of the values from 1 to 10 for each multiple attribute option on the Data Collection Form (shown in the example in Table C-1) by the appropriate weighting factor for each building characteristic. For this example, the values of 1, 3, 5, 7, and 10 corresponding to attribute options for building characteristic 1.1 were multiplied by 0.055. Similarly the values of 1, 5, and 10 corresponding to attribute options for building characteristic 1.3 were also multiplied by 0.22, while the values for building characteristic 1.5 were multiplied by 0.11, the values for building characteristic 1.7 were multiplied by 0.055, the values for building characteristic 1.8 were multiplied by 0.11, and the values for building characteristic 1.9 were multiplied by 0.44. The result of this step is shown in Table C-2 for the example of Table C-1.

Table C-2: Example Initial Values in Risk Scoring Methodology for Consequences

BUILDING CHARACTERISTICS	a.	b.	c.	d.	e.	CONSE-QUENCES
1.1. Locality Type	Rural/ Suburban	Semi-urban/ Lt. Industrial	Industrial	Urban	Dense Urban	
	0.06	0.17	0.28	0.39	0.56	
Non-Dense Urban	< 100	100 - 500	500 - 2000	2000 - 5000	> 5000	
Dense Urban	< 1000	1000 - 3000	3000 - 7000	7000 - 10000	> 10000	
1.3. # Occupants	0.22	0.89	1.3	1.8	2.2	
Non-Dense Urban	< $1M	$1M - $20M	$20M – $100M	$100M – $500M	> $500M	
Dense Urban	< $20M	$20M - $150M	$150M – $400M	$400M – $750M	> $750M	
1.5. Replacement Value	0.11	0.44	0.67	0.89	1.1	
1.7. Historic Value	No	Yes				
	0.06	0.56				
1.8. Operational Redundancy	Very High	High	Moderate	Low	Very Low	
	0.11	0.33	0.56	0.78	1.1	
1.9. Impact of Asset Physical Loss	Local	Regional	Statewide	National	Inter-national	
	0.44	1.8	2.7	3.6	4.4	

6. The normalized factors from Step 5 for each building characteristic attribute option were inserted in an initial Data

Collection Form for use in the first pilot testing of the methodology in New York City. The pilot testing was designed to evaluate the:

- user-friendliness of the documentation and scoring forms;
- clarity of the description of the methodology;
- duration of typical building evaluation by newly-trained assessors;
- sensitivity of the scoring system to various building attributes;
- variation among resulting scores for different building types; and
- consistency (repeatability) in the assessment results.

The initial pilot testing involved the use of the initial Data Collection Form as well as the initial electronic version of the procedure, which is described in Appendix E. Attribute options for each building characteristic considered were selected based on observed features of the building, and the ratings for these options (normalized in Step 5 above) were entered on the open (un-shaded) cell in the Data Collection Form. The values of the cells in each column were totaled to compute one value for Consequences, one value for Threat Rating, and one value for Vulnerability Rating for each of the nine pertinent threat scenarios. As a result of the normalization of the attribute option ratings in Step 5 above, the resulting total values for each of the three factors (C, T, and V) range from 1 to 10, corresponding to the scales used in FEMA 452 to quantify Consequences rating, Threat Rating, and Vulnerability Rating.

The values of the factors (C, T, and V) were then copied into the Risk Scoring Worksheet in the appropriate columns for each threat scenario. The risk rating for each threat scenario, i, was computed using Equation C-1 for a given row in the Risk Scoring Worksheet.

$$R_i = C_i \times T_i \times V_i \qquad \text{(C-1)}$$

where:

C_i	=	Consequences rating for threat scenario i
T_i	=	Threat rating for threat scenario i
V_i	=	Vulnerability rating for threat scenario i

7. Threat scenario risk ratings from Step 6 were evaluated by participants in the initial Pilot Study, and used as a basis for adding,

deleting, and modifying, as required, the building characteristics for each factor as well as the ratings for each attribute option. The method for calculating the Total Risk Rating, *R*, for a given building was also evaluated and revised to increase the total score to match perceived levels of risk (for the buildings evaluated in the pilot testing). As a result, the method for calculating *R* was changed from a simple summation of the threat scenario risk ratings (for each of the nine threat scenarios considered) to incorporate a power summation formulation and a scaling factor, α, that together control the limits of R such that $9 \le R \le 9000$. The revised formulation for computing *R* is as follows:

$$R = \alpha \sqrt[n]{\sum_{i=1}^{9} \left(R_i\right)^n} \qquad \text{(C-2)}$$

where α equals 7.227 and $n = 10$.

A value of $n = 10$ was found to produce realistic results that avoids the apparent averaging results (when $n = 1$) that would imply direct correlation between all nine scenarios.

A revised Data Collection Form was then developed that incorporated the revised building characteristics, and corresponding attribute option ratings. The initial electronic version of the procedure was similarly updated to incorporate the changes to the initial Data Collection Form.

8. A pilot testing of the revised Data Collection Form (Version 2) was again conducted in New York City and included some of the same buildings tested previously and some that were new. The new buildings in the second Pilot Study were selected to exercise risk characteristics that had not been explored in the first Pilot Study, including a high-consequence, low-threat building and a low-consequence, low-threat building. Using data collected during the second pilot testing, threat scenario risk ratings and the Total Risk Rating, *R*, were again calculated (using equations C-1 and C-2), and the results were used as a basis for adding, deleting, and modifying, as required, the building characteristics for each factor as well as the ratings for each attribute option.

   As before, a revised Data Collection Form was again developed (Version 3) that incorporated the revised building characteristics, and corresponding attribute option ratings. The electronic version of the procedure was also updated to incorporate the changes to the Data Collection Form and the scoring process.

9. A final pilot testing of Version 3 of the Data Collection Form was then conducted in Las Vegas. Using data collected during the third pilot testing, threat scenario risk ratings and the Total Risk Rating, *R*, were again calculated (using equations C-1 and C-2), and the results were used as a basis for adding, deleting, and modifying, as required, the building characteristics and attribute options. Version 4 of the Data Collection Form (final version, as provided herein) was then developed, incorporating the revised building characteristics, and corresponding attribute option ratings. The electronic version of the procedure was again updated to incorporate the changes to the Data Collection Form.

Example Application of the Procedure

An example application of the scoring procedure for Consequences (C_i) for the nine threat scenarios (using Version 4 of the Data Collection Form) is provided below. In this example, surveyors of the example building selected the attribute options shown in Table C-3.

Table C-3 Building Characteristics and Selected Attribute Options

Building characteristic	Attribute Option
1.1 Locality Type	Semi Urban
1.2 # Occupants	Greater than or equal to 4,000 Less than 6,000
1.3 Replacement Value	Greater than or equal to $600 M Less than $800 M
1.4 Historic Value	No
1.5 Business Continuity	Moderate
1.6 Physical Loss Impact	National

To carry out the scoring procedure, the user circles the numeric values in the Consequences portion of the Data Collection Form (as shown in Tables C-4 and C-5) that correspond to the selected attribute options identified in Table C-3. Those numeric values are then transcribed into the corresponding locations for each of the nine scenarios, as shown on the right side of Tables C-4 and C-5. A simple sum over each column for each threat scenario results in the Consequence score for that particular threat scenario C_i.

The method for computing the values for Threat Rating and Vulnerability Rating follows the same process as described in the above example for computing Consequences.

Table C-4 Example Values in Risk Scoring Methodology of Consequences, Page 2

FEMA 455 DATA COLLECTION FORM, PAGE 2 **CONSEQUENCES**

BUILDING CHARACTERISTICS		ATTRIBUTE OPTIONS					CONSEQUENCES RATING FOR GIVEN THREAT SCENARIO								
							Internal			Explosive			CBR		
		a.	b.	c.	d.	e.	Intrusion	Explosive	CBR	Zone I	Zone II	Zone III	Zone I	Zone II	Zone III
1. CONSEQUENCES	1.1 Locality Type	Rural / Suburban	Semi-urban/ Lt. Industrial	Industrial	Urban	Dense Urban									
		0.06	0.46	0.53	0.58	0.63	0.46								
		0.04	0.32	0.37	0.40	0.43		0.32							
		0.17	1.23	1.41	1.55	1.67			1.23						
		0.04	0.32	0.37	0.40	0.43				0.32	0.32	0.32			
		0.17	1.23	1.41	1.55	1.67							1.23	1.23	1.23
	1.2 # Occupants	< 200	≥200 - < 400	≥400 - < 600	≥ 600 - < 800	≥800 - < 1000									
		0.25	1.21	1.52	1.74	1.92									
		0.17	0.84	1.06	1.21	1.33									
		0.33	1.61	2.03	2.32	2.55									
		0.17	0.84	1.06	1.21	1.33									
		0.33	1.61	2.03	2.32	2.55									
		≥ 1,000 - < 2,000	≥ 2,000 - < 4,000	≥4,000 - < 6,000	≥6,000 - < 8,000	≥ 8,000 - < 10,000									
		1.98	2.09	2.19	2.28	2.37	2.19								
		1.38	1.46	1.53	1.59	1.65		1.53							
		2.65	2.79	2.92	3.05	3.16			2.92						
		1.38	1.46	1.53	1.59	1.65				1.53	1.53	1.53			
		2.65	2.79	2.92	3.05	3.16							2.92	2.92	2.92
		≥10,000 - < 20,000	≥ 20,000 - < 40,000	≥ 40,000 - < 60,000	≥ 60,000 - < 80,000	≥ 80,000									
		2.41	2.44	2.46	2.48	2.50									
		1.68	1.69	1.71	1.72	1.74									
		3.22	3.25	3.28	3.31	3.33									
		1.68	1.69	1.71	1.72	1.74									
		3.22	3.25	3.28	3.31	3.33									
	1.3 Replacement Value	< $20 M	≥ $20 M - < $40 M	≥ $40 M - < $60 M	≥ $60 M - < $80 M	≥ $ 80 M - < $100 M									
		0.13	0.60	0.76	0.87	0.96									
		0.13	0.63	0.79	0.91	1.00									
		0.08	0.40	0.51	0.58	0.64									
		0.13	0.63	0.79	0.91	1.00									
		0.08	0.40	0.51	0.58	0.64									
		≥ $100 M - < $200 M	≥ $200 M - < $400 M	≥ $400 M - < $600 M	≥ $600 M - < $800 M	≥ $800 M - < $1 B									
		0.99	1.05	1.10	1.14	1.18	1.14								
		1.04	1.09	1.14	1.19	1.24		1.19							
		0.66	0.70	0.73	0.76	0.79			0.76						
		1.04	1.09	1.14	1.19	1.24				1.19	1.19	1.19			
		0.66	0.70	0.73	0.76	0.79							0.76	0.76	0.76
		≥ $1 B - < $2 B	≥ $2 B - < $4 B	≥ $4 B - < $6 B	≥ $6 B - < $8 B	≥ $8 B									
		1.21	1.22	1.23	1.24	1.25									
		1.26	1.27	1.28	1.29	1.30									
		0.80	0.81	0.82	0.83	0.83									
		1.26	1.27	1.28	1.29	1.30									
		0.80	0.81	0.82	0.83	0.83									

Table C-5 Example Values in Risk Scoring Methodology of Consequences, Page 3

FEMA 455 DATA COLLECTION FORM, PAGE 3 **CONSEQUENCES (continued)**

BUILDING CHARACTERISTICS		ATTRIBUTE OPTIONS					CONSEQUENCES RATING FOR GIVEN THREAT SCENARIO								
							Internal			Explosive			CBR		
		a.	b.	c.	d.	e.	Intrusion	Explosive	CBR	Zone I	Zone II	Zone III	Zone I	Zone II	Zone III
1. CONSEQUENCES	1.4 On Historic Registry	No	Yes												
		0.25	2.50				0.25								
		0.04	0.43					0.04							
		0.08	0.83						0.08						
		0.04	0.43							0.04	0.04	0.04			
		0.08	0.83										0.08	0.08	0.08
	1.5 Business Continuity	Very High	High	Moderate	Low	Very Low									
		0.13	0.92	1.05	1.16	1.25	1.05								
		0.09	0.64	0.73	0.81	0.87		0.73							
		0.17	1.23	1.41	1.55	1.67			1.41						
		0.09	0.64	0.73	0.81	0.87				0.73	0.73	0.73			
		0.17	1.23	1.41	1.55	1.67							1.41	1.41	1.41
	1.6 Physical Loss Impact	Local	Statewide	Regional	National	International									
		0.19	1.38	1.58	1.74	1.88	1.74								
		0.52	3.84	4.40	4.84	5.22		4.84							
		0.17	1.23	1.41	1.55	1.67			1.55						
		0.52	3.84	4.40	4.84	5.22				4.84	4.84	4.84			
		0.17	1.23	1.41	1.55	1.67							1.55	1.55	1.55
A.1 TOTAL RATING FOR CONSEQUENCES (C): Sum values in for Consequences and enter in column C on Risk Scoring Worksheet							6.84	8.66	7.95	8.66	8.66	8.66	7.95	7.95	7.95