VI. Risk Filtering, Ranking and Management

PROBLEM VI.1: Security at a Concert

Security at public places (i.e., football stadiums, airports, and concert halls) is a priority, since any accident could cause severe effects on those who are present.

DESCRIPTION

The objective of this problem is to identify and prioritize the potential risk scenarios that can disrupt the security at a concert event. The interim general managers of the concert hall are responsible for any problems at the events. Any accident would seriously affect their jobs as well as their future employment prospects. The following parameters apply:

Risks:

- Life loss of performers, personnel, and audience members.
- Property loss in the venue.
- Loss of public satisfaction with venue facilities and security.

Temporal domain:

- Short-term.

Level of decisionmaking:

- Interim general managers.

METHODOLOGY

Risk Filtering, Ranking, and Management (RFRM) is a helpful tool to diagnose risk scenarios on an ongoing basis. There are eight phases, or steps, in this methodology.

SOLUTION

Several phases of the RFRM as applied to the analysis of security at a concert venue will be discussed in the subsequent discussions.

Phase I: Hierarchical Holographic Modeling (HHM)

The preliminary phase in performing RFRM is a description of the system and all components with associated risks. Figure VI.1.1 depicts applicable risk scenarios using a hierarchical holographic model.

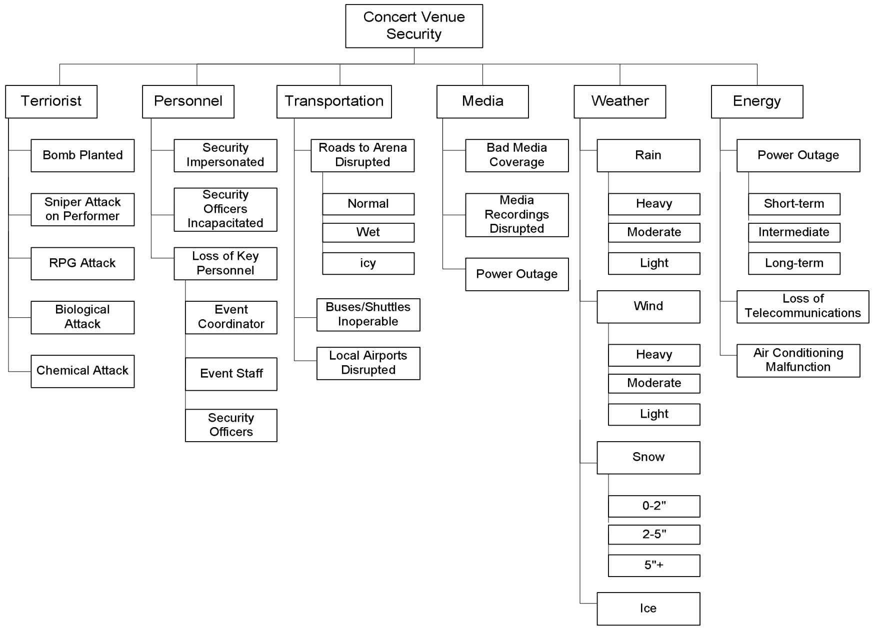

Figure VI.1.1. HHM for Concert Venue Security

Phase II: Scenario Filtering

After studying the HHM, the interim managers filter the subtopics down to the following:

1. Bomb planted
2. Sniper attack on performer
3. Biological attack
4. Chemical attack
5. Security officers incapacitated
6. Loss of security officers
7. Heavy rain
8. Icy road
9. Short-term power outage
10. Loss of telecommunications

Phase III: Bicriteria Filtering

The managers remove 2 subtopics evaluated as moderate, so the 8 remaining subtopics are: Bomb planted, Sniper attack on performer, Biological attack, Chemical attack, Loss of security officers, Icy road, Short-term power outage, and Loss of telecommunications.

These subtopics are placed into a matrix which visually indicates both the probabilities and which subtopics are high, moderate, or low risk (see Table VI.1.1).

Table VI.1.1. Risk Matrix for Phase III

Effect \ Likelihood	Unlikely	Seldom	Occasional	Likely	Frequent
A. Loss of life/asset	Bomb Biological attack Chemical attack	Sniper attack			
B. Loss of mission			Short-term power outage		
C. Loss of capability with some compromise of mission			Loss of Security Officers	Loss of Telecommunications	
D. Loss of some capability with no effect on mission				Icy Road	
E. Minor or no effect					

Qualitative Severity-scale Matrix

Low Risk	Moderate Risk	High Risk	Extremely High Risk

Phase IV: Multicriteria Filtering

The managers have defined the remaining risk scenarios as follows:

Table VI.1.2. Risk Scenarios for Remaining Subtopics

Subtopic	Risk Scenario
Bomb planted	Failure to detect any bomb before the concert
Sniper attack on performer	Failure to detect any pistol on snipers before the concert
Biological attack	Failure to detect any malicious biological materials before the concert
Chemical attack	Failure to detect any chemical weapons before the concert
Loss of security officer	Illness of security officer
Icy road	Failure to clear icy roads before and after the concert
Short-term power outage	Failure to have back-up generator
Loss of telecommunications	Failure to test telecommunications before the concert

The risk scenarios are further filtered down to the three considered most critical: bomb, sniper, or biological attack. Probabilities are assessed according to the risk matrix shown in Table VI.1.1, with Table VI.1.3 summarizing the results.

Table VI.1.3. Rating Risk Scenarios in Phase IV

Criteria	Bomb	Sniper	Biological attack	Chemical attack	Loss of Security officers	Icy Road	Short-term power outage	Loss of Telecom-munications
Undetectability	Low	Low	Low	Low	Med	Med	Med	High
Uncontrollability	Low	Low	Low	Low	Low	Low	Med	High
Multiple Paths to Failure	Low	Low	Low	Low	High	Med	High	Med
Irreversibility	High	High	High	High	Low	Low	Med	Low
Duration of Effects	High	Med	High	High	Low	Low	Low	Low
Cascading Effects	High	High	High	High	Low	Low	High	Med
Operating Environment	High	High	High	High	Med	High	High	Med
Wear and Tear	Low	Low	Low	Low	Low	Low	Med	Med
Hardware/Software /Human /Organizational	High	High	High	High	Low	Low	Med	Med
Complexity and Emergent Behaviors	High	High	High	High	Low	Low	Med	Med
Design immaturity	Low	Low	Low	Low	Low	Med	Med	Med

Phase V: Quantitative Ranking

With the quantitative severity scale matrix and the criteria assessment above, the managers focus on only 6 risk scenarios by excluding *Loss of security officers* and *Icy road*. The probability in the matrix is subjective, so we will use Bayes' theorem assuming the prior probability of $Pr(A_i) = 1/(6\text{-}i)$, where i stands for the Accident Likelihood (ranging from Unlikely: 1, Seldom: 2, …, Frequent: 5).

Following the notation for conditional probability typically used in Bayesian analysis, $Pr(E|A_i) = 0.01$ and $Pr(E|\text{not } A_i) = 0.995$ for all i. Then we can calculate P(E) by the theorem of Total Probability, where E indicates observing evidence of accident before the concert. The terms that represent the conditional probabilities, $Pr(A_i|E)$, are calculated as follows:

$Pr(E) = (0.01)*(0.2) + (0.995)*(0.8) = 0.002 + 0.786 = 0.798$

$Pr(A_1|E) = (0.01)*(0.2)/(0.798) = 0.0025$
$Pr(A_2|E) = (0.01)*(0.25)/(0.798) = 0.003$
$Pr(A_3|E) = (0.01)*(0.33)/(0.798) = 0.004$
$Pr(A_4|E) = (0.01)*(0.5)/(0.798) = 0.006$
$Pr(A_5|E) = (0.01)*(1)/(0.798) = 0.0125$

A quantitative version of the bicriteria risk matrix is presented below using the 6 remaining risk scenarios.

Table VI.1.4. Risk Matrix for Phase V

Effect \ Likelihood	0.0025≤Pr<0.003	0.003≤Pr<0.004	0.004≤Pr<0.006	0.006≤Pr<0.0125	0.0125≤Pr<1
A. Loss of life/asset	Bomb Biological attack Chemical attack	Sniper attack			
B. Loss of mission			Short-term power outage		
C. Loss of capability with some compromise of mission				Loss of Telecommu-nications	
D. Loss of some capability with no effect on mission					
E. Minor or no effect					

Qualitative Severity-scale Matrix

Low Risk	Moderate Risk	High Risk	Extremely High Risk

Phase VI: Risk Management

After following Phases I to V, the managers need to consider how to minimize the costs and/or maximize the benefits for the 6 risk scenarios. In Phase VI, they consider the tradeoffs between these benefits and costs and decide how to manage the risks with the most effective options.

Estimates of cost:

Install metal detector:

$100,000 ($10,000 × 10)

Implement booking system to check personal history with attendees' consent:

$50,000

Hire enough security officers to check hand baggage:

$100/(officer per day) × number of gates (i.e., 10) = $1,000

Install emergency power generator:

$50,000

Purchase microphone systems:

$10,000

Total estimated cost: $211,000

Benefits:

Monetary benefits:

Insurance premium deduction:

$10,000/event

Expected revenue from audience

1,000 × $100 = $100,000

Non-monetary:

Public confidence in secure environment

Risk reduction:

Implementing each option will reduce the probability of each accident by half

Management options:

As the managers' priority is to prevent any loss of life or injury, they will implement the first three options above, and then implement other options if enough resources are left.

Phase VII: Safeguarding Against Missing Critical Items

In Phase VII the managers need to consider previously eliminated risk scenarios, (e.g., a rocket-propelled grenade (RPG) attack in the case of an outdoor concert), and re-evaluate the options previously selected. Upon analyzing filtered scenarios and current options, they will update the risk matrix after every concert.

Phase VIII: Operational Feedback

The managers hired temporary security officers for the events in order to reduce costs, but received numerous complaints because their incompetence and inexperience in security checks delayed the entrance procedure. If this continues, they will consider employing a regular security staff or seek assistance from local police officers.

Collecting feedback is central for updating the HHM as well. The managers will rebuild the HMM by adding new scenarios, editing present scenarios, or deleting obsolete ones. For instance, they could add a risk scenario of a tornado if an occurrence is reported nearby, even though it rarely happens in this region.

PROBLEM VI.2: Risk to an Electric Power System

A consulting company analyses the risk associated within a large electric power system.

DESCRIPTION

A consulting company plans to submit a report to the Federal Utility Committee on an Electric Power System with respect to potential risk scenarios. Deploying the Risk Filtering, Ranking, and Management (RFRM) methodology, it could provide the Committee with an in-depth report to address all possible risk scenarios and suggest how to manage pertinent risks. Below is the analysis of the system.

METHODOLOGY

The eight phases of the RFRM will be implemented to identify and prioritize risks associated with operation of an electric power system.

SOLUTION

Phase I: Scenario Identification

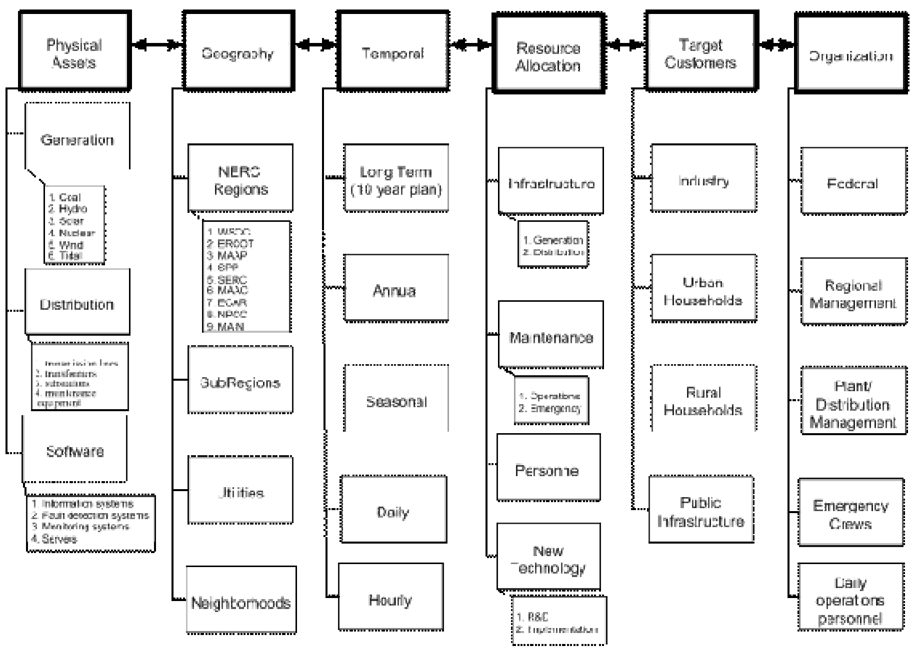

Figure VI.2.1. HHM for an Electric Power System

The first step of the RFRM is to develop a Hierarchical Holographic Model (HHM) where all possible sources of risk are identified in headtopics and subtopics. The resulting HHM is depicted in Figure VI.2.1.

Phase II: Scenario Filtering

According to interest, the consulting company will next assess the physical assets component of the HHM. The following subtopics will be considered:

- Coal
- Hydroelectric
- Solar
- Nuclear
- Wind
- Tidal
- Transmission Lines
- Transformers
- Substations
- Maintenance Equipment
- Information Systems
- Fault Detection Systems
- Monitoring Systems
- Servers

Out of these, it will filter out the risk scenarios that are not of immediate interest to the company. Thus, the new set of reduced scenarios is as follows:

- Coal
- Hydroelectric
- Nuclear
- Transmission Lines
- Maintenance Equipment
- Information Systems
- Fault Detection Systems
- Monitoring Systems

Phase III: Bicriteria Filtering and Ranking

To further reduce the number of risk scenarios, in this phase the company subjects the 8 remaining risk scenarios to the *Qualitative Severity Scale Matrix* as shown in Table VI.2.1 below. It is assumed that the decisionmaker's analysis of the risk scenarios resulted in removing those that received a moderate or low risk valuation from the subtopic set. Based on the decisionmaker's preferences, the subtopics *Maintenance Equipment, Information Systems,* and *Transmission Lines,* which were evaluated as low risks, were removed. The remaining five risk scenarios are: *Coal, Nuclear, Hydroelectric, Fault Detection System,* and *Monitoring System.*

Table VI.2.1. Qualitative Severity Scale Risk Matrix for Phase III

Likelihood / Effect	Unlikely	Seldom	Occasional	Likely	Frequent
A. Loss of life, plant, or environmental damage (Catastrophic Event)			Coal	Nuclear Hydroelectric	
B. Plant Shutdown	Fault detection system				
C. Prolonged power outage			Monitoring systems		
D. Partial loss of power generation and/or distribution capabilities	Maintenance equipment information system				
E. Minor or no effect				Transmission lines	

Qualitative Severity-scale Matrix

Low Risk	Moderate Risk	High Risk	Extremely High Risk

Phase IV: Multicriteria Evaluation

More specific definition is then given to each remaining subtopic as shown in Table VI.2.2.

Table VI.2.2. Risk Scenarios for 5 Remaining Subtopics

Subtopic	Risk Scenario
Coal	Failure of any portion of the Coal power plant for more than 24 hours
Nuclear	Failure of any portion of the Nuclear power plant for more than 24 hours
Hydroelectric	Failure of any portion of the Hydroelectric power plant for more than 24 hours
Fault Detection System	Failure of the Fault Detection System for more than 8 hours
Monitoring System	Failure of the Monitoring System for more than 8 hours

Next, the remaining subtopics are assessed in terms of 11 criteria defined in Table VI.2.3 below. The table summarizes these assessments.

Table VI.2.3. Scoring of Subtopics Using the Criteria Hierarchy

Criteria	Coal	Nuclear	Hydroelectric	Fault Detection System	Monitoring System
Undetectability	Low	High	Med	High	Low
Uncontrollability	Med	High	Med	Med	Med
Multiple Paths to Failure	High	High	High	Med	Med
Irreversibility	Med	High	Med	Low	Low
Duration of Effects	High	High	High	High	High
Cascading Effects	Med	High	Med	Med	Med
Operating Environment	Med	High	Med	Med	Med

Criteria	Coal	Nuclear	Hydroelectric	Fault Detection System	Monitoring System
Wear and Tear	Med	Med	Med	Low	Low
Hardware/Software/Human/ Organizational Errors	Med	High	Med	High	High
Complexity and Emergent Behaviors	High	High	High	Med	Med
Design Immaturity	Med	Med	Med	Low	Low

Phase V: Quantitative Ranking

The set of scenarios are now reduced further using a *Quantitative Severity Scale Matrix.* In other words, this new matrix expresses the likelihood quantitatively.

Table VI.2.4. Quantitative Severity Scale Risk Matrix

Likelihood / Effect	$0.001 \le Pr < 0.01$	$0.01 \le Pr < 0.02$	$0.02 \le Pr < 0.1$	$0.1 \le Pr < 0.5$	$0.5 \le Pr < 1$
A. Loss of life, plant, or environmental damage (Catastrophic Event)			Coal	Nuclear Hydroelectric	
B. Plant Shutdown	Fault detection system				
C. Prolonged power outage			Monitoring systems		
D. Partial loss of power generation and/or distribution capabilities	Maintenance equipment information system				
E. Minor or no effect				Transmission lines	

Qualitative Severity-scale Matrix

Low Risk	Moderate Risk	High Risk	Extremely High Risk

The results of the quantitative matrix are expressed as follows:

Coal:

Likelihood of Failure = 0.1; Effect = A (Loss of Life);
Risk = Extremely High

Historical coal mining incidents demonstrated potential loss of lives. Based on the consulting team's brainstorming and surveying, it seems that *Coal* failure is occasional. Therefore, they assign only 10% probability to this scenario.

Nuclear:

Likelihood of Failure = 0.25; Effect = A (Loss of Life);
Risk = Extremely High

Nuclear power generation failure is prone to loss of lives. It appears that the chance of *Nuclear* failure is higher than that of any other type of power plant failure. They assigned 25% probability to this scenario.

Hydroelectric:

Likelihood of Failure = 0.2; Effect = A (Loss of Life);
Risk = Extremely High

Though the probability of hydroelectric failure (and consequently loss of life) is not as high as for *Nuclear* plant failure, it is higher than a *Coal* power plant failure. They assigned 20% probability to this scenario.

Fault Detection System:

Likelihood of Failure = 0.01; Effect = B (Plant Shutdown);
Risk = High

The failure of the *Fault Detection System* will cause plant shutdown, but such a failure is highly unlikely. They assign 1% probability to this failure.

Monitoring System:

Likelihood of Failure = 0.07; Effect = C (Prolonged Power Outage);
Risk = Moderate

The failure of the *Monitoring System* will cause a prolonged power outage. The chances of such a failure are more than those of the *Fault Detection System* failure. They assign 7% probability to this failure.

The firm decided to filter out all risk scenarios which have moderate or low risk. Thus, the *Monitoring System* is filtered out at this stage. Based on the Quantitative Severity Scale Matrix and the above analysis, it is clear that resources should be concentrated on protecting the remaining four critical risk scenarios—*Coal, Nuclear, Hydroelectric,* and *Fault Detection System.*

Phase VI: Risk Management

In this phase a complete quantitative analysis should be performed. This involves estimating cost, performance benefits and risk reduction, and different management options for dealing with the remaining scenarios.

Phase VII: Safeguarding Against Missing Critical Items

In Phase VII, the performance of each option selected in Phase VI is evaluated against the scenarios previously filtered out during Phases II to V.

Phase VIII: Operational Feedback

This last phase represents the operational stage of the system under consideration, during which the experience and information gained is used to continually update the scenario filtering and decision processes.

PROBLEM VI.3: Launching an Online Banking System

A bank has invested significant monetary and human resources into an online banking system but the system seems to be complicated for the employees to understand and manage.

DESCRIPTION

The internal and external risks pertinent to this system have not yet been verified. The bank called upon a well-known IT company to analyze its system intensively.

METHODOLOGY

The company will use the Risk Filtering, Ranking, and Management (RFRM) methodology to identify all of the feasible risk scenarios. There are eight phases in this process, and the first step is to develop a Hierarchical Holographic Model (HHM)

SOLUTION

Phase I: HHM Development

The five head topics and many subtopics in the HHM cover the multiple and varied aspects of the banking system, as shown in Figure VI.3.1.

Phase II: Scenario Filtering by Domain of Interest

For an online banking system, there are two major levels of decisionmakers: strategic and operational. Strategic decisionmakers determine the goal and purpose of the system, available functionality, the importance of online banking in the organization, etc. Operational decisionmakers establish how the online banking system is developed, maintained, and supported. For the purpose of this analysis, the company will filter risk scenarios based on the interests and responsibilities of operational decisionmakers. The following surviving set of risk scenarios becomes the input to Phase III: *Server Storage, Memory, CPU, Power Supply,* and *Fan; Network Switch, Router,* and *Cable; Physical Power, Temperature Control, Air Quality Control,* and *Network;* and under *Software, Vendor-Provided* and *In-house-Developed Application,* as well as *Vendor-Provided Database, Database Program, OS, Clustering, Vendor-Provided Network Management,* and *Network Management Developed In-house.*

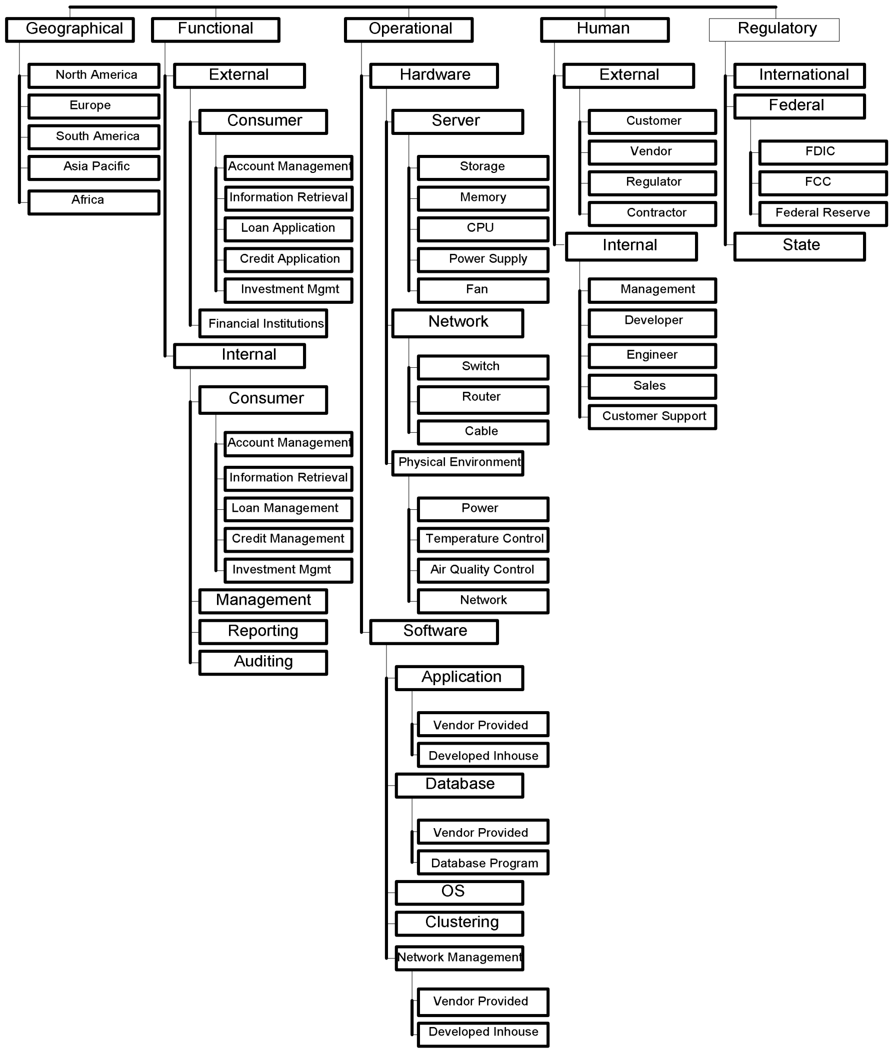

Figure VI.3.1. HHM for online banking system

Phase III: Bicriteria Filtering

The company considers the likelihood and effects of each risk scenario on a graphic matrix as shown below in Figure VI.3.2. Most of the scenarios are easy to place in the matrix, so consultants from the company will only touch on some important and perhaps less obvious points. There are strict regulations regarding privacy and security when it comes to online banking systems and banking systems in general. A program that corrupts the database or misplaces information in it will result in a security breach and perhaps the illegal release of personal information. Similarly, in-house developed applications can result in the same scenario. On the other hand, if the cause of such a breach is due to vendor-provided software, there will be a loss of customers but no regulation would be violated since it would be the vendor's mistake. In Figure VI.3.2, the shades correspond to extremely high risk, high risk, moderate risk, and low risk, with *extremely high risk* the lightest shade. Therefore, what remain at the end of this phase are the scenarios that have extremely high and high risks. So *Storage, Power, Network, In-house Developed Application, Database Program, OS, Clustering, Vendor Provided Database,* and *Network Management Developed In-house* are classified in these categories.

Likelihood / Effects	**Unlikely**	**Seldom**	**Occasional**	**Likely**	**Frequent**
A. Violation of laws and regulations			- Database Program - Inhouse Developed Application		
B. Loss of customers		-Power -Network -Vendor Provided Database - OS		-Network Management Developed Inhouse	- Storage
C. Loss of capability with some negative impact on the performance		- Power Supply - Temperature Control - Air Quality Control - Clustering	- Cable - Switch - Router -Vendor-Provided Application -Vendor-Provided Network Management		
D. Loss of capability with no negative impact on performance			- Memory - CPU - Fan		
E. Minor or no effect					

Qualitative Severity-scale Matrix

Low Risk	**Moderate Risk**	**High Risk**	**Extremely High Risk**

Figure VI.3.2. Risk Matrix for Phase III

Phase IV: Multicriteria Filtering

In Table VI.3.1, this phase identifies the risk scenarios for those subtopics classified as high and extremely high-risk in the Table VI.3.1 Risk Matrix.

These subtopics are then scored for *low, medium,* or *high risk* using the hierarchy of seven criteria in Table VI.3.2.

Table VI.3.1. Risk Scenarios for Remaining Subtopics

Subtopics	Risk Scenario
Storage	Failure of any storage with no redundancy
Power	Failure of any power outage for over 15 minutes
Network	Failure of the external network for more than an hour
In-house Developed Application	Malfunction that affects bank operation
Database Program	Malfunction that leads to data corruption or data mismanagement

Subtopics	Risk Scenario
OS	Malfunction that leads to computer not operable
Clustering	Failure of clustering for over an hour
Vendor-Provided Database	Failure of database for more than an hour
Network Management Developed In-house	Failure of internal network for more than 30 minutes

Table VI.3.2. Scoring of Subtopics

Criteria	Storage	Power	Network	Application	Database Program
Undetectability	L	L	L	M	H
Uncontrollability	H	H	H	L	L
Multiple Paths to Failure	H	L	H	M	H
Irreversibility	H	L	L	L	H
Duration of Effects	H	L	L	H	H
Cascading Effects	L	H	H	H	H
Wear and Tear	H	L	L	L	H

Criteria	OS	Clustering	Database	Network Management
Undetectability	H	M	L	M
Uncontrollability	H	L	H	L
Multiple Paths to Failure	H	M	H	M
Irreversibility	L	L	H	L
Duration of Effects	M	H	H	M
Cascading Effects	H	H	H	H
Wear and Tear	L	M	H	L

Phase V: Quantitative Ranking Using the Cardinal Version of the Risk Matrix

Next, using the effects listed in the Figure VI.3.2 Risk Matrix, the company performs quantitative ranking of the nine remaining scenarios. Since it does not actually have any conditional probability distribution, it does not use Bayes' Theorem here. Instead, it obtains the likelihood of failure for each of the subtopics in Table VI.3.1 directly from past experience.

Storage:

Likelihood of failure 0.3; Effect = B; Risk = High

Power:

Likelihood of failure 0.009; Effect = B; Risk = High

Network:

Likelihood of failure 0.09; Effect = B; Risk = High

In-house Developed Application:

Likelihood of failure 0.025; Effect = A; Risk = Extremely High

Database Program:
Likelihood of failure 0.025; Effect = A; Risk = Extremely High

OS:
Likelihood of failure 0.02; Effect = B; Risk = High

Clustering:
Likelihood of failure 0.02; Effect = B; Risk = High

Vendor-Provided Database:
Likelihood of failure 0.015; Effect = B; Risk = High

Network Management Developed In-house:
Likelihood of failure 0.3; Effect = B; Risk = Extremely High

These scenarios are summarized in Figure VI.3.3.

Likelihood / Effect	P<0.01	0.01 ≤P<0.02	0.02≤P<0.1	0.1≤P<0.5	0.5≤P<1
A. Violation of laws and regulations			- Database Program - In-house Developed Application		
B. Loss of customers	- Power	- Vendor-Provided Database - OS	- Database - OS - Network - Clustering	- Storage - Network Management	
C. Loss of capability with some negative impact on the performance					
D. Loss of capability with no negative impact on the performance					
E. Minor or no effect					

Qualitative Severity-scale Matrix

Low Risk	**Moderate Risk**	**High Risk**	**Extremely High Risk**

Figure VI.3.3. Quantitative Severity Scale Matrix

Phase VI: Risk Management

The IT company found that four scenarios constituted most of the risk for the online banking system from the operational decisionmaker's point of view. These were: the *Database Program, In-House Developed Application, Network Managemen*t, and *Storage*. Next it recommended solution options and the respective costs, benefits, and risks for each.

For *Database Programs*, the most important solution option is implementing a rigorous testing process. The cost consists of designing and maintaining a separate test database that can be used for testing only. Testing may prolong the development of database programs. However, the benefits outweigh the costs for online banking systems because database program failure is so detrimental. For *In-house Developed Applications,* the option is the same as for the *Database Program.* The analysis is similar.

For *Storage,* the most widely-used option is to have a lot of redundancy. *Clustering* within individual servers and also within the network provides sufficient redundancy. There are costs associated with the extra hardware and the extra complexity in terms of design and maintenance. Again, this is probably worthwhile in this situation as storage recovery typically is fairly unlikely and it is important to be able to fall back onto the backup as soon as possible. For *Network Management,* the analysis is the same as for storage above.

Phase VII: Safeguarding against Missing Critical Items

For Phase VII, the bank would consider how the options proposed in Phase VI can affect the risk scenarios that were filtered out in the previous phases. For example, the decisionmaker may opt for an alternate design for hard disks in any single server. This greatly increases a single server's need for power. Consequently, power supply then may become critical. Additionally, the alternate design will also increase the internal temperature of a given server; therefore fans and other server cooling components may become critical. Another example is when clustering is chosen to increase redundancy. Obviously clustering then would become a critical item. (Note that clustering as a risk scenario refers to the clustering software rather than the concept of clustering.) Clustering servers together requires much more interconnection between servers and also additional network equipment. All of this may lead to additional critical items such as cables, switches, and routers. Many other items would not become critical even though their locations in these matrices may change. For example, hardware failures such as CPU and memory would be less critical now that the system is clustered.

Phase VIII: Operational Feedback

In Phase VIII, the bank utilizes the operational feedback received during the deployment to further refine the HHM and the benefits, costs, and risks of risk management options. Probably the most obvious result is the better assessment of failure likelihood for various hardware and software. As the online banking system operates, there would be better statistics regarding how various hardware and software behave. Consequences of these behaviors would also be available, such as how long it will take the server to reach critical temperature if the fans fail or what kind of capacity loss the bank will face if a server should drop out of the cluster. This would enable the bank to do a better analysis of the earlier phases starting from Phase III. Additional feedback will come from the online banking system's customers. They will report experiences that do not meet their standards as a result of network outages, application malfunction, or just slow servers. They may also require more functionality, which would surely alter the subtopics from the *Functional* perspective in the HHM.

PROBLEM VI.4: Safety Issues on Nanomaterials

Because nanomaterials are new, government agencies need to decide what, if any, regulations need to be changed or implanted for the safe manufacture and use of nanomaterials and nanomaterial-based products.

DESCRIPTION

The major products that may need regulation are *cosmetics, deodorant sprays,* and *bone and tooth implants.*

METHODOLOGY

Risk Filtering, Ranking, and Management (RFRM) can be used to assess, evaluate, and manage the risk scenarios in this problem. RFRM consists of eight phases.

SOLUTION

Phase I: Develop a Hierarchical Holographic Model (HHM)

The following head topics and subtopics are the various risk scenarios involved in the production and use of nanomaterials and nanomaterial-based products:

Contact during manufacture of nanoparticles:
- Particles escaping into the air during packaging - Inhalation
- Gloves and masks - Absorption into the skin

Accidental Ingestion
- High temperatures – fires, blasts, etc.

Transport of nanoparticles to various places of product manufacture
- Particles escaping into the air during manufacture - Inhalation
- Gloves and masks - Absorption into the skin, inhalation
- High temperatures – fires, blasts, etc.

Direct usage
- Applying into the skin – absorption in skin
- Spraying in the air – inhalation (lungs)
- Implants in the body – absorption in blood
- Cellular and genetic structure – nanoparticles might get absorbed into the cells and cause irreversible damage
- Handling – accidental ingestion (babies/adults who are ignorant of the hazards)

Transport through the environment
- Product washed off while taking a shower – Transport through water and sewer
- Nanoparticles in sewer go into waste streams – Transport through soil
- Spraying into the air – Transport through air
- Soil quality, Water quality

Indirect contact with nanoparticles
- Animals – drink contaminated water
- Plants – absorb nanoparticles in soil and water

Disposal of containers
- Landfills – soil quality, groundwater quality
- Incineration – air quality

Phase II: Filter out scenarios that are not likely to be controlled by regulation

From the scenarios enumerated in Phase I, and based on talks with environmental health and safety experts, the following have been identified as scenarios that can be controlled by regulation:

1. Contact during manufacture of nanoparticles
   - 1.a. Particles escaping into the air during packaging – Inhalation
   - 1.b. Gloves and masks – Absorption into the skin
   - 1.c. Accidental ingestion
   - 1.d. High temperatures – fires, blasts etc
2. Transport of nanoparticles to various places of product manufacture
   - 2.a. Particles escaping into the air during manufacture – Inhalation
   - 2.b. Gloves and masks – Absorption into the skin, inhalation
   - 2.c. Accidental ingestion
   - 2.d. High temperatures – fires, blasts etc
3. Direct usage
   - 3.a. Applying into the skin – absorption in skin
   - 3.b. Spraying in the air – inhalation (lungs)
   - 3.c. Implants in the body – absorption in blood
   - 3.d. Handling – accidental ingestion (babies/adults ignorant of the product)
4. Disposal of containers
   - 4.a. Landfills or incineration– soil quality, ground water quality

For ease of usage, we will use a mnemonic for each scenario, as enumerated in Table VI.4.1. Each of these 13 risk scenarios will now be filtered further based on a variety of criteria in the subsequent phases, leading to a short list of most important risk scenarios which need to be addressed for risk mitigation.

Table VI.4.1. Specific scenarios filtered out for consideration from Phase I

Specific Scenario	*Identifier*
Manufacture – Inhalation: Workers inhaling particles which escape into the air during manufacture and packaging due to ineffective masks.	1.a
Manufacture – Absorption: Nanomaterials being absorbed into workers' skin due to ineffective gloves and filters.	1.b
Specific Scenario	*Identifier*
Manufacture – Ingestion: Accidental ingestion of nanoparticles during manufacture.	1.c
Manufacture - Explosion: Blasts in the manufacture chamber due to improper regulation of temperature/pressure and inadequate safety.	1.d
Production - Inhalation: Workers inhaling particles that escape into the air during	2.a

manufacture and packaging of the nanomaterial based product due to ineffective masks.	
Production - Absorption: Nanomaterial being absorbed into workers' skin due to ineffective gloves and filters during manufacture of the nanomaterial based product.	2.b
Production – Ingestion: Accidental ingestion of nanoparticles during manufacture of the nanomaterial based product.	2.c
Production – Explosion: Blasts in the manufacture chamber due to improper regulation of temperature/pressure and inadequate safety during manufacture of the nanomaterial based product.	2.d
Skin Absorption: Effect of absorption of the nanomaterial in the skin during application of the product.	3.a
Consumer Inhalation: Effect of inhalation of nanomaterial when spray products are used.	3.b
Blood Absorption: Effects of absorption of nanomaterial in the blood from the body implants.	3.c
Ignorance – Ingestion: Accidental ingestion of products due to ignorance of handling the products.	3.d
Environment: Effect of improper disposal of the nanomaterial based products on soil, water and air quality.	4.a

Phase III - Bi-Criteria Ranking and Filtering

For this phase, each of the scenarios selected in Phase II will be evaluated based on two criteria – severity of the consequences and their frequency of occurrence as seen in Figure VI.4.1:

Effect \ Likelihood	**Unlikely**	**Seldom**	**Occasional**	**Likely**	**Frequent**
Loss of life	1.d; 2.d				
Serious Injury	3.c	2.a		1.a	
Minor injury	1.c; 2.c; 3.d				3.b
Environmental Damage					4.a
Minor of no effect		2.b		1.b	3.a

Qualitative Severity-scale Matrix

Low Risk	**Moderate Risk**	**High Risk**	**Extremely High Risk**

Figure VI.4.1. Qualitative severity scale matrix

Some risk scenarios are eliminated due to lack of severity and frequency of occurrence. The scenarios that make it to the next phase of the risk filtering and ranking are:

1.a. Manufacture - Inhalation
1.d. Manufacture - Explosion
2.a. Production - Inhalation
2.d. Production - Explosion
3.b. Consumer – inhalation (lungs)

3.c. Blood absorption
4.a. Environment

Phase IV – Multi-criteria evaluation

The risk scenarios which were the top 7 from Phase III are now evaluated against 11 criteria which are based on the properties of robustness, resilience and redundancy of the system under study. Results appear below in Table VI.4.2.

Table VI.4.2. Scoring of subtopics for the safe use of Nanomaterials

Criterion	1.a	1.d	2.a	2.d	3.b	3.c	4.a
Undetectability	High	Low	High	Low	High	High	High
Uncontrollability	Low	Low	Low	Low	High	Low	Low
Multiple paths to failure	Low	High	Low	High	Low	Low	High
Irreversibility	High	High	High	High	High	High	High
Duration of effects	High	High	High	High	High	High	High
Cascading effects	Med	High	Med	High	Low	Low	High
Operating environment	Low	Med	Low	Med	Low	Med	Med
Wear and tear	Low	Low	Low	Low	Low	Med	High
HW/SW/HU/OR	Med	High	Med	High	Med	N/A	High
Complexity and Emergent behaviors	High	Med	High	Med	Low	Low	Med
Design immaturity	High	Low	High	Low	High	High	High

This assessment is derived from examining columns from left to right and ranking the scenarios in order according to those determined highest to lowest in severity based on the eleven criteria.

Phase V - Quantitative Ranking

1.a Manufacture - Inhalation: Likelihood = 0.05; Effect = Serious Injury; Risk = High

Inhalation occurs due to improper or ineffective masks and filters provided to the workers. OSHA has stringent regulations for masks usage. Hence the probability of an improper mask being used is pretty low and we assign a probability of 0.05 to this scenario. From Phase IV we see that this scenario is largely undetectable although controllable.

1.d Manufacture - Explosion: Likelihood = 0.013; Effect = Loss of Life; Risk = Extremely High

Nanoparticles are manufactured using a technique called Physical Vapor Synthesis which needs high temperatures and pressures. The presence of such high temperatures and pressures creates a high risk situation wherein a slight leakage or loss of insulation can cause fatal explosions. We were told that current systems are leak proof and hence the chances of a leakage occurring is very slim.

Let L denote the event of leakage and E denote the event of explosion. The probability of an explosion occurring due to various reasons is about 0.05 which was gathered from previous statistical data. In other words, P(E)=0.05. The probability that there is a leakage given that there has been an explosion is 0.1 (that is, P(L|E)=0.1). Also, the probability of leakage given that there is no explosion is known to be 0.4, so that P(L| not E)=0.4. Thus using Bayes' theorem we can find the probability of explosion using the fact that the current system is leak proof as follows.

$$P(E|L) = P(E)P(L|E)/P(L)$$

$$\text{where } P(L) = P(L|E)*P(E)+P(L|\text{not } E)*P(\text{not } E)$$

$$= 0.05*0.1+0.95*0.4$$

$$= 0.385.$$

Hence P(E|L)=0.05*0.1/0.385=0.013.

Thus the likelihood of an explosion occurring is 0.013, and the explosion is detectable but not controllable.

2.a Production - Inhalation: Likelihood = 0.01; Effect = Serious Injury; Risk = High

Again, like inhalation during manufacture of nanoparticles, inhalation during production of the product (cosmetics, sprays etc) occurs due to a lack of proper filters etc. Since OSHA regulates masks at production facilities and since the nanoparticles are dispersed in a solution, the likelihood of occurrence of this scenario is very low, say 0.01.

2.d Production - Explosion: Likelihood = 0.001; Effect = Loss of Life; Risk = Extremely High

Explosion during production of products containing nanoparticles occurs for reasons similar to explosions during manufacture of the nanoparticles itself but at much less temperatures and pressures. Thus the likelihood of an explosion at this stage is much less than explosion during manufacture of the nanoparticles. Hence we give a likelihood of 0.001 to this scenario.

3.b Consumer - Inhalation: Likelihood = 0.45; Effect = Minor Injury; Risk = Extremely High

Inhalation occurs when nanomaterials sprays are used to deodorize the air in a room. Since there can be no control on inhalation of a room freshener, the likelihood of occurrence of this scenario is pretty high. Hence we assign a probability of 0.45 for this scenario.

3.c Blood Absorption: Likelihood = 0.01; Effect = Serious Injury; Risk = Med

Nanoparticles would get into the blood stream of the person who has a nano composite implant only if the nanocomposite has not been produced properly so that loose nanoparticles are still present in the composite. Since nanocomposite making is highly regulated, the likelihood of producing an improper composite is very low. Hence we assign a probability of 0.01 to this scenario. Absorption of nanoparticles in the blood would not trigger any other failures to occur hence we can consider this scenario to be only of medium or moderate risk.

4.a Environment: Likelihood = 0.05; Effect = Environmental Damage; Risk = High
The product containers can be treated to remove the nanomaterial that sticks to the containers before they are either land filled or incinerated, thus decreasing the likelihood of occurrence of this scenario. Hence we assign a probability of only 0.05 to this scenario. Also, this scenario is controllable although not detectable.

Likelihood / Effect	0.001<Pr<0.01	0.01<Pr<0.02	0.02<Pr<0. 1	0.1<Pr<0. 5	0.5<Pr<1
Loss of life	2.d	1.d		3.b	
Serious Injury		2.a	4.a; 1.a		
Minor injury		3.c			
Environmental Damage					
Minor of no effect					

Qualitative Severity-scale Matrix

Low Risk	**Moderate Risk**	**High Risk**	Extremely High Risk

Figure VI.4.2. Quantitative severity scale matrix

From Figure VI.4.2 above, it can be concluded that scenario 3.c, effects of absorption of nanomaterial in the blood from the body implants, can be eliminated since it is of a moderate overall risk. The other scenarios would then be considered for subsequent phases.

Phase VI: Risk Management

In this phase a complete quantitative analysis should be performed. This involves estimating cost, performance benefits and risk reduction, and different management options for dealing with the remaining risk scenarios associated with nanomaterial production. The identification of risk management options is beyond the scope of the current analysis.

Phase VII: Safeguarding Against Missing Critical Items

In Phase VII, the efficacy of the options (identified from the risk management phase) is evaluated.

Phase VIII: Operational Feedback

This last phase represents the operational stages of nanomaterial production, during which the experience and information gained from empirical results are continually updated through the scenario filtering and decision processes.

PROBLEM VI.5: Department of Statistics Assessment

A Department of Statistics wishes to maintain its prominence among universities that offer a statistics program.

DESCRIPTION

The Department of Statistics at a university wishes to be more successful in attracting students by hiring more professors and offering innovative courses. Success criteria include being more equipped with physical resources (e.g., computer laboratories) to enhancements in course curricula.

METHODOLOGY

This exercise can be analyzed by using the eight phases of the RFRM. In going through the phases of RFRM, the Department of Statistics can determine how to maintain success.

SOLUTION

Phase I: Scenario Identification

A Hierarchical Holographic Model (HHM) was developed to describe a university's Department of Statistics' "as planned" or "success" scenario. The HHM in Figure VI.5.1 identifies the system's risk scenarios.

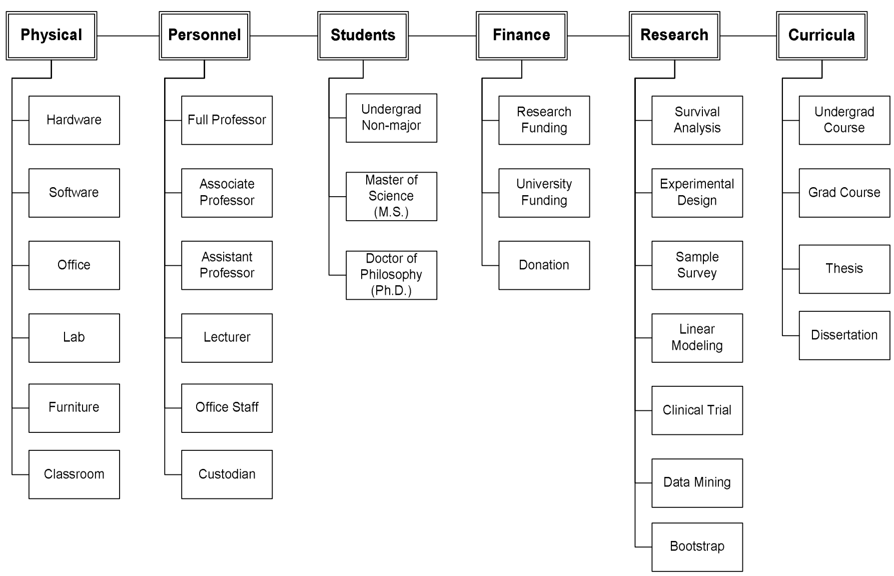

Figure VI.5.1. HHM for Department of Statistics' Risk Identification

Phase II: Scenario Filtering by Domain of Interest

Phase II is concerned with filtering the risk scenarios identified in the HHM to match the perspective of the current system user, or decisionmaker. In this case, it is the Chair of the Department, who is concerned with both short-term and long-term viability.

Eleven subtopics survived the filtering. The subtopics of importance in this view are: Hardware, Software, Full Professors, Associate Professors, Assistant Professors, Undergraduate Students, Master's Students, Ph.D. Students, Research Funding, Graduate Courses and Undergraduate Courses.

Phase III: Bicriteria Filtering and Ranking Using the Ordinal Version of the US Air Force Risk Matrix

The remaining scenarios are further filtered using qualitative likelihoods and consequences. There are two different types of information: the likelihood of what can go wrong, and the associated consequences. Their joint contributions are estimated on the basis of the available evidence and are displayed in a risk matrix in Table VI.5.1.

Table VI.5.1. Risk Matrix for Phase III

Likelihood / Effect	**Unlikely**	**Seldom**	**Occasional**	**Likely**	**Frequent**
A. Loss of department		-Full Prof. -Assoc. Prof. -Asst. Prof.		-Grad. Courses	
B. Loss of mission			-Ph.D. Student	-M.S. Student	
C. Loss of compatibility with some compromise mission	-Undergrad. Courses	-Undergrad. Student	-Hardware -Software		-Research Funding
D. Loss of capability with no effect on mission					
E. Minor or no effect					

Qualitative Severity-scale Matrix

Low Risk	**Moderate Risk**	**High Risk**	**Extremely High Risk**

Phase IV: Multicriteria Evaluation

In Phase III, the Department of Statistics judged the individual risk sources by the consequence and likelihood categories and placed them into a risk matrix. In Phase IV, the process is taken one step further. The ability of a risk scenario to defeat the defenses of the system is tested against a set of eleven criteria (see Table VI.5.3). Each scenario of interest is rated as "high," "medium," or "low" against each criterion.

The first step was to define the most likely risks among the scenarios shown in the above matrix. These are listed in Table VI.5.2.

Table VI.5.2. Risk Scenarios for the Identified Subtopics

Subtopic	Risk Scenario
Grad. Courses	Failure of the department to offer sufficient graduate courses.
Research Funding	Failure to secure funds to support research activities.
Professors	Failure to hire and keep competent and active professors.
Grad. Students	Failure of graduate students to enroll in graduate courses or to apply for the graduate program.

These risk scenarios were then rated against the eleven criteria shown below in Table VI.5.3.

Table VI.5.3. Phase IV: Rating Risk Scenarios against Eleven Criteria

Criteria	Grad. Courses	Research Funding	Professors	Grad. Students
Undetectability	Low	Low	Medium	Low
Uncontrollability	Medium	Medium	Medium	Low
Multiple Paths to Failure	Low	High	High	Medium
Irreversibility	n/a	Low	High	Medium
Duration of Effects	Medium	High	High	Low
Cascading Effects	High	High	High	High
Operating Environment	High	Medium	Medium	Medium
Wear and Tear	n/a	n/a	n/a	n/a
Hardware/Software/Human/ Organizational Errors	Low	n/a	Medium	Medium
Complexity and Divergent Behaviors	Low	Low	Medium	Medium
Design and Maturity	Low	High	Low	Medium

Phase V: Quantitative Ranking Using the Cardinal Version of the Risk Matrix.

In Phase V, filtering and ranking of scenarios continue based on quantitative and qualitative matrix scales of likelihood and consequence. Table VI.5.4 shows the risk matrix for this phase.

Table VI.5.4. Risk Matrix for Phase V

Effect \ Likelihood	$0.001 \le Pr < 0.01$	$0.01 \le Pr < 0.02$	$0.02 \le Pr < 0.1$	$0.1 \le Pr < 0.5$	$0.5 \le Pr < 1$
A. Loss of department		-Full Prof. -Assoc. Prof. -Asst. Prof.		-Grad. Courses	
B. Loss of mission			-Ph.D. Student	-M.S. Student	
C. Loss of compatibility with some compromise mission	-Undergrad. Courses	-Undergrad. Student	-Hardware -Software		-Research Funding
D. Loss of capability with no effect on mission					
E. Minor or no effect					

Qualitative Severity-scale Matrix

Low Risk	Moderate Risk	High Risk	Extremely High Risk

The results of the risk filtering and ranking point to the following likelihoods of failure, the effects, and the degree of risk for each:

Professors (Full, Associate, Assistant):

Likelihood of Failure = .0197; Effect = A (Loss of department); Risk = Extremely High.

The faculty ranks are currently depleted. Should more professors choose to leave, the department will no longer be able to operate. The remaining faculty members appear intent on staying, so the department has assigned a probability of 1.5% to this scenario. The department will be notified if any professors decide to leave.

The Bayesian reasoning behind this assignment is as follows: Let A denote the remaining faculty choosing to leave. Let E denote the relevant evidence—that the current professors intend to stay.

By Bayes' theorem, then:

$$Pr\ (A \mid E) = Pr\ (A)\ Pr\ (E \mid A) / Pr\ (E)$$

$$Pr\ (E) = Pr\ (E \mid A)\ Pr\ (A) + Pr\ (E \mid \text{not } A)\ Pr\ (\text{not } A)$$

A prior state of knowledge about A, before receiving the evidence is $P_0(A)=0.5=P(\text{not } A)$

The probability of seeing evidence E, i.e., no intention of leaving, is small. The department takes it as $P(E|A) = 0.02$. The probability of not knowing they will leave given that they are presently not leaving is high $P(E|\text{not } A) = 0.995$.

Therefore:

$$\Pr(E) = (0.02)(0.5) + (0.995)(0.5) = 0.01 + 0.4975 = 0.5075$$
$$\Pr(A \mid E) = (0.5)(0.02) / (0.5075) = .0198$$

PhD Students:

Likelihood of Failure = 0.05; Effect = B (Loss of mission); Risk = High.

PhD students are a driving force in maintaining an academic department. Without these students there will be a loss of mission. Given the current crop of PhD students, the department believes there to be a 5% likelihood that they will leave.

Graduate-level Courses:

Likelihood of Failure = 0.30; Effect = A (Loss of department); Risk = Extremely High.

Currently, the demand for graduate-level classes offsets the lack of sponsored research in the department. If the demand from non-major students for Statistics graduate classes were to fail, the department would shut down. Based on current declining enrollments, the department assigned this scenario a likelihood of 30%.

MS Students:

Likelihood of Failure: 0.40; Effect = B (Loss of mission); Risk = High.

Educating master's students is part of the reason the department exists. The departure of the current MS students would result in a failure to accomplish the mission. Based on our assessment of the current crop of MS students, the department believes it is 40% likely that they will leave.

Research Funding:

Likelihood of Failure: 1.00; Effect = C (Loss of capability with some loss of mission); Risk = Extremely High.

There is currently no research funding available in the Statistics department. This makes it extremely difficult to give the graduate students the level of academic experience that the department would like to give them. They can carry on as teachers' assistants in some cases. Because there is no research funding available, this scenario is a certainty and the department has assigned it a likelihood of 1.

Phase VI: Risk Management

Based on the results of the quantitative ranking in the previous phase, risk management options can be identified and developed to mitigate the critical risk scenarios. Tradeoff analysis needs to be performed to account for the performance of each option relative to cost, performance benefits and risk reduction criteria.

Phase VII: Safeguarding Against Missing Critical Items

In Phase VII, the performance of each option developed in Phase VI is evaluated against the scenarios previously filtered out during Phases II to V.

Phase VIII: Operational Feedback

This last phase represents the operational stage of the system under consideration, during which the experience and information gained is used to continually update the scenario filtering and decision processes.

PROBLEM VI.6: Risk Assessment and Management of Acquisition Investment

Investors analyze risk of acquiring an existing company.

DESCRIPTION

A group of investors is considering a major investment. It is looking at the possibility of buying out a company and needs a framework to evaluate any offers. In particular, a method is needed to allow risk assessment of the company from all angles, in order to guarantee that all of the risks involved are considered. Thus, they would like to identify a set of risks for the company, prioritize them, and decide what they would do to manage these risks if they were indeed to buy the company.

METHODOLOGY

Hierarchical Holographic Modeling (HHM) and Risk Filtering, Ranking, and Management (RFRM) are two methodologies that provide the analytical framework for this risk assessment and management problem. The following documentation describes an implementation of these tools.

SOLUTION

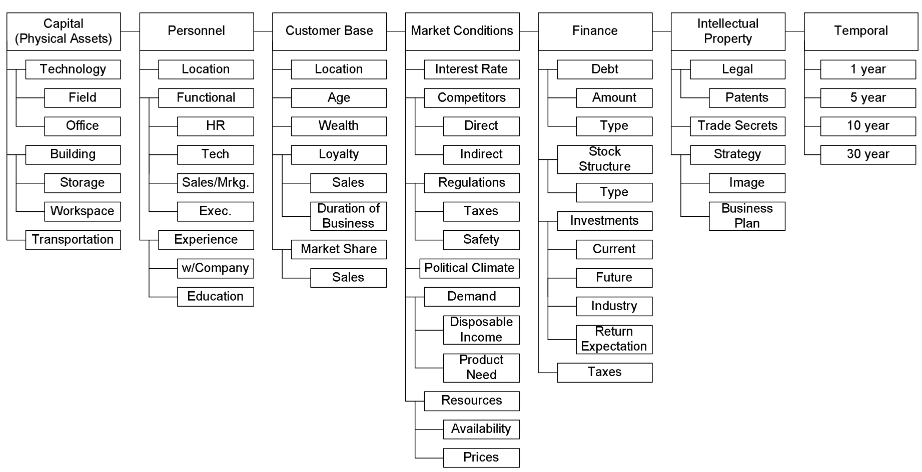

Figure VI.6.1. HHM Diagram

Phase I: Hierarchical Holographic Modeling (HHM)

To help answer their question of business value, the investors must construct a Hierarchical Holographic Model (HHM), which will allow them to decompose the system at hand, (i.e., the company they are evaluating) from multiple perspectives. Figure VI.6.1 displays the resulting HHM where each subtopic represents a risk scenario.

Now that the investors have their HHM, they use the remaining phases of the Risk Filtering, Ranking, and Management (RFRM) technique to filter, rank, and create ideas for managing the company's risks.

Phase II: Scenario Filtering

In Phase II, the investors take the risk scenarios identified in the HHM subtopics and filter them according to the investors' interests and responsibilities, temporal considerations, domain expertise, and desired system functionality. Based on the scope of their analysis, the investors narrowed the 28 initial subtopics (see Figure VI.6.1) down to 12 items of top concern. Clearly, not all of the initial HHM subtopics can be of immediate concern to all levels of decisionmaking at all times.

The 12 items are detailed below:

- *Technology* is physically used to manufacture the product as well as for communication within the office.
- *Personnel function* involves the different employment sectors of the company. The interrelatedness of these sectors and their abilities to respond to various hits or increased demand is important to the company's performance.
- *Personnel experience* is important because it indicates the value of the employees within the company. The workforce is what drives the company and it must be able to identify and adapt to new options in the future.
- *Market share* represents how much of the current market the company holds and implies both its present strength and its potential for future growth through capturing more market share.
- *Trade secrets* (e.g., the Coca-Cola formula) are inside information, hidden beyond patents, which ensure value to the business because they provide a unique product to the consumer.
- The *strategy,* the organizational and future business plan of the company, must also be considered so that its future value and success can be predicted.
- *Debts* strongly reflect the company's financial situation, as their magnitude and terms can dictate available business options.
- *Stock structure* examines how the company is owned and which voting rights will be important for major company decisions. It explicitly states who "owns" the company.
- *Investments* will show how the company plans to make money and must be evaluated when considering profitability.
- Current *interest rates* also must be considered as they affect previous subtopics such as debts and investments and also drive business activity.
- *Competitors* are also a huge factor, perhaps the most important, as company performance can really be seen as a function of how well it does relative to other companies in the same field. Future competitor strengths and weaknesses will strongly affect company profitability.
- Finally, the *5-year temporal domain* is considered because this is the most applicable time frame for the potential investment. Five years gives enough time to see how the company is currently doing as well as how it positions itself for future

growth. After this period, another decision will be made by investors: either to stick with the current company or reinvest the money.

Phase III: Bicriteria Filtering

In Phase III, the investors give qualitative assessments of the likelihood and consequences of failure of the subtopics already filtered through Phase II. They define failure as the subtopic contributing negatively towards profits, i.e., costing the firm money. The subtopics listed above have different specifications, and in some cases it is necessary to clarify how a subtopic was assessed. For instance, it is obvious how the leaking of trade secrets would hurt the firm's profitability. However, how does a "5-Year Time Frame" fail? The following further describes some risks of failure.

- *Personnel Experience*: failure when costly mistakes are made due to a staff's lack of practice
- *Debts* and *Stock Structure*: failure when the amount or structure of each subtopic burdens the company's ability to finance itself
- *5-Year Time Frame*: failure when the company will profit only if decisions are made based on time frames shorter or longer than 5 years

The categories for *likelihood* are:

1. Unlikely
2. Seldom
3. Occasional
4. Likely
5. Frequent

The categories for *consequence* are:

1. 0% Investment Loss
2. 25% Investment Loss
3. 50% Investment Loss
4. 75% Investment Loss
5. 100% Investment Loss—i.e., bankruptcy or business failure

Table VI.6.1 and Figure VI.6.2 show how the investors assessed the subtopics filtered from Phase II.

Table VI.6.1. Phase III Risk Assessments

Subtopic	Likelihood Subtopic Failure	Consequence of Failure
Technology	4	5
Personnel Function	3	3
Personnel Experience	2	2
Market Share	3	4
Trade Secrets	2	5
Strategy	3	4
Debts	2	4
Stock Structure	2	4
Investments	4	5
Interest Rates	2	2
Competitors	5	5
5-Year Time Frame	1	2

Likelihood / Effect	Unlikely	Seldom	Occasional	Likely	Frequent
A. Business failure (Catastrophic)		Trade Secret		Technology Investment	Competitors
B. 75% Investment Loss		Debts Stock Structure	Market Share Strategy		
C. 50% Investment Loss			P. Function	Loss of Telecommunications	
D. 25% Investment Loss		P. Experience Interest Rates		Icy Road	
E. No Effect		5-year TF			

Qualitative Severity-scale Matrix

Low Risk	Moderate Risk	High Risk	Extremely High Risk

Figure VI.6.2. Phase III Risk Matrix with Qualitative Probabilities

The risk matrix shown in Figure VI.6.2 is used to again filter out any failure scenarios that the investors deem to be of a low priority. From their value judgments, they declare that the criteria for filtering (i.e., for a failure to "move on" to Phase IV) is as follows: greater than 75% investment loss or 75% or more investment loss with likelihood of occasional failure. Based on these criteria, they refocus their analysis on the following subtopics: *competition, technology, investments, trade secrets, market share,* and *strategy.*

Phase IV: Multicriteria Evaluation

In Phase III, the investors placed the individual risk sources into the risk matrix, using the consequence and likelihood categories as described above. This matrix gave them an intuitive feel for those scenarios requiring priority attention, and narrowed their focus down to six components. They chose the four subtopics that could lead to business failure (catastrophic) and the two topics that had a consequence of 75% investment loss with probability assessments of occasional or above.

In Phase IV, they take the process one step further by reflecting on the ability of each scenario to defeat three defensive properties of the underlying system: *resilience*, *robustness,* and *redundancy*, defined as follows:

- Redundancy refers to the ability of extra components in the system to assume the function of failed components.
- Robustness refers to the insensitivity of system performance to external stresses.
- Resilience is the ability of a system to recover following an emergency.

Scenarios able to defeat these properties are of greater concern, and thus are scored as more severe. As an aid to this reflection, they considered the set of eleven criteria explained in Table VI.6.2 below.

Table VI.6.2. Eleven Criteria for Rating the Ability of a Risk Scenario to Defeat the Defenses of the System

Undectability	the absence of modes by which the initial events of a scenario can be discovered before harm occurs
Uncontrollability	the absence of control modes that make it possible to take action or make an adjustment to prevent harm
Multiple paths to failure	the multiple and possibly unknown ways for the events of a scenario to harm the system, such as circumventing safety devices, for example
Irreversibility	the adverse condition cannot be returned to the initial, operational (pre-event) condition
Duration of effects	a long duration of adverse consequences
Cascading effects	the effects of an adverse condition readily propagate to other systems or subsystems, i.e., cannot be contained
Operating environment	external stressors that affect the system
Wear and tear	the effects of use, leading to degraded performance
HW/SW/HU/OR interfaces	the adverse outcome is magnified by interfaces among diverse subsystems (e.g., hardware, software, human, and organizational)
Complexity/emergent behaviors	the potential for system-level behaviors that are not anticipated even with knowledge of the components and the laws of their interactions
Design immaturity	there are adverse consequences related to the newness of the system design or other lack of a proven concept

Table VI.6.3 shows how high-, medium-, and low-risk scenarios are rated against the 11 criteria in Table VI.6.2.

Table VI.6.3. Rating Risk Scenarios in Phase IV against the Eleven Criteria

Criterion	High	Medium	Low	Not Applicable
Undetectability	Unknown or undetectable	Late detection	Early detection	Not applicable
Uncontrollability	Unknown or uncontrollable	Imperfect control	Easily controlled	Not applicable
Multiple Paths to Failure	Unknown or many paths to failure	Few paths to failure	Single path to failure	Not applicable
Irreversibility	Unknown or no reversibility	Partial reversibility	Reversible	Not applicable
Duration of Effects	Unknown or long duration	Medium duration	Short duration	Not applicable
Cascading Effects	Unknown or many cascading effects	Few cascading effects	No cascading effects	Not applicable
Operating Environment	Unknown sensitivity or very sensitive	Sensitive to operating environment	Not sensitive to operating environment	Not applicable
Wear and Tear	Unknown or much wear and tear	Some wear and tear	No wear and tear	Not applicable
Hardware/ Software/Human/ Organizational	Unknown sensitivity or very sensitive	Sensitive to interfaces	No sensitivity to interfaces	Not applicable

Criterion	High	Medium	Low	Not Applicable
Complexity and Emergent Behaviors	Unknown or high degree of complexity	Medium complexity	Low complexity	Not applicable
Design Immaturity	Unknown or highly immature design	Immature design	Mature design	Not applicable

Finally, Table VI.6.4 shows how the six subtopics of concern score against the 11 criteria defined by Table VI.6.2. Now that the risk scenarios have been narrowed down to a more manageable set, the decisionmakers can perform a more thorough analysis of each subtopic.

Table VI.6.4. Scoring of Subtopics for Business Evaluation Using the Criteria Hierarchy

Criteria	Technology	Trade Secrets	Market Share	Strategy	Investments	Competitors
Undetectability	Low	Low	Med	High	Low	High
Uncontrollability	Med	Med	High	High	Med	High
Multiple Paths to Failure	High	Med	High	High	Med	High
Irreversibility	Med	High	Med	High	High	Low
Duration of Effects	High	High	High	High	High	High
Cascading Effects	Med	Med	Low	Low	High	High
Operating Environment	High	High	High	High	Med	High
Wear and Tear	Med	High	Low	High	Med	High
Hardware /Software/Human/ Organizational	High	High	Med	High	High	High
Complexity and Emergent Behaviors	Med	High	Low	High	High	High
Design Immaturity	Med	High	Med	High	High	Med

Phase V: Quantitative Ranking

During Phase V, the investors typically use data (e.g., historical data, event probability distributions) to determine numerical probabilities. These probabilities are then used to replace the qualitative probability descriptions from the matrices in Phase III. However, in an example there is very little data that can guide the choice of numerical probabilities. Therefore, the matrices from Phase III will again be utilized here and a risk matrix with quantitative probabilities will not be developed.

Phase VI: Risk Management

Phase VI requires the investors to conduct a thorough analysis of the quantitative aspects of their decisions. This involves calculating costs, benefits, risk reduction, and options for managing the most dire subtopic scenarios. Completing Phase VI requires expert analysis of the scenario subtopics to help devise risk management options.

Phase VII: Safeguarding Against Missing Critical Items

During Phase VII, the performance of the management options from Phase VI is compared with the scenarios that were filtered out between Phases II and V.

Phase VIII: Operational Feedback

In this final phase, investors would update their scenario filtering dynamically while acquiring evolving data about market trends, business cycles, and stock fluctuations. This data would allow them to improve the quality and accuracy of their HHM and RFRM analyses.

PROBLEM VI.7: Healthcare System Modeling

Modeling the US healthcare system is vital. The risks in healthcare are immense because everyone is affected by it and it deals with human lives.

DESCRIPTION

The healthcare system in the United States is a very complex industry with high levels of interaction between the government, private companies, and the public.

METHODOLOGY

This example demonstrates applying Risk Filtering, Ranking, and Management (RFRM) to model the healthcare system.

SOLUTION

Phase I: Scenario Identification with HHM

The first step is to develop a complete Hierarchical Holographic Model (HHM) for the healthcare system, as shown in Figure VI.7.1.

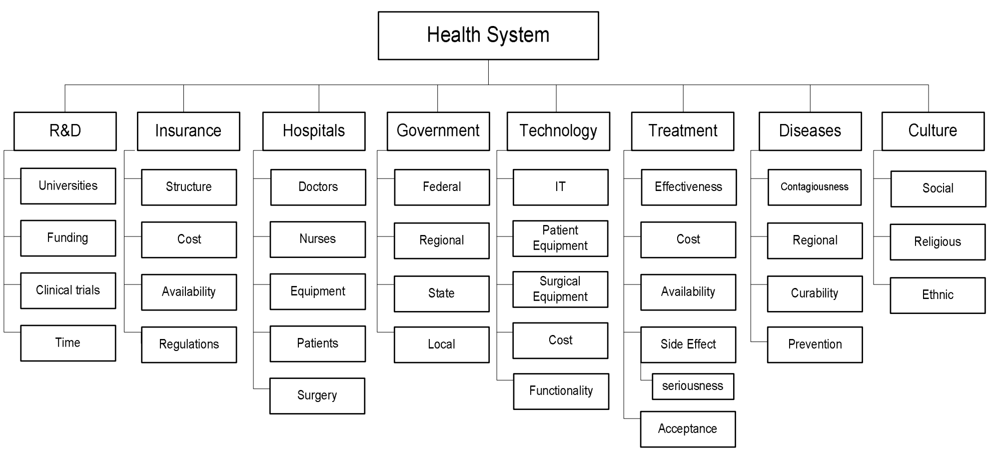

Figure VI.7.1. HHM for healthcare system

Phase II: Scenario Filtering

Let us suppose that the National Science Foundation (NSF) seeks to fund research and development for new technology in healthcare. They are concerned with the risks in three different types of technology—*IT, surgical equipment,* and *patient equipment.* Thus, for the purpose of this analysis, we will focus only on the technology aspect of the HHM.

Phase III: Bicriteria Filtering and Ranking

Figure VI.7.2 below shows the risk matrix for the technology risk scenarios (IT, surgical equipment, and patient equipment risks). The technology may be some sort of surgical equipment or perhaps something implanted into a patient's body, such as a pacemaker. Clearly, the worst thing that could happen is for the technology to fail, causing a patient to lose his/her life. Figure VI.7.2 clearly shows which consequences, along with the probability of those consequences, constitute different levels of risk.

Effect / Likelihood	**Unlikely**	**Seldom**	**Occasional**	**Likely**	**Frequent**
A. Loss of life				Surgical Equipment	
B. Major injuries occur					
C. Minor injuries occur					Patient Equipment
D. Technological problems with no harmful effects			Information Technology		
E. Few problems					

Qualitative Severity-scale Matrix

Low Risk	**Moderate Risk**	**High Risk**	**Extremely High Risk**

Figure VI.7.2. Qualitative risk matrix

Phase IV: Multicriteria Evaluation

Table VI.7.1 contains more specific definitions of each of the three remaining risk scenarios.

Table VI.7.1. Risk Scenarios for Remaining Subtopics

Subtopic	**Risk Scenario**
Information Technology	Failure to collect or transmit information technology into a designated database for more than 24 hours.
Surgical Equipment	Failure of any part of surgical equipment during surgery for any amount of time.
Patient Equipment	Failure of a patient's equipment for any amount of time.

Table VI.7.2 scores the Healthcare subtopics using the 11 criteria.

Table VI.7.2. Rating Risk Scenarios in Phase IV

Criteria	IT	Surgical Equipment	Patient Equipment
Undetectability	High	Med	Med
Uncontrollability	Med	Low	Low
Multiple Paths to Failure	Med	High	High
Irreversibility	Low	Med	Med
Duration of Effects	Med	Med	Med
Cascading Effects	High	High	High
Operating Environment	Med	Med	Med
Wear and Tear	Low	High	High
Hardware/Software /Human/Organizational	Med	High	High
Complexity and Emergent Behaviors	Low	Med	High
Design Immaturity	Med	Med	Med

Phase V: Quantitative Ranking

Based on Phases III and IV, it appears that failure of information technology is not serious compared to failures of surgical and patient equipment. Thus, for the rest of the analysis, IT will not be considered.

Surgical Equipment:

Likelihood of Failure = .05; Effect = A (Loss of life);
Risk= Extremely High

A failure of surgical equipment during an operation can definitely cause the loss of a patient's life. Based on hospital protocols for inspecting surgical equipment, this risk scenario is assigned a probability of .05. Should a technological malfunction occur, a failure would be detectable.

Patient Equipment:

Likelihood of Failure = .15; Effect = C (Minor injuries occur);
Risk = Extremely High

A failure of a patient's equipment (such as pacemaker, oxygen) may be detrimental to the individual and cause serious injury. However, in most cases minor injuries will occur. Since many patients are not supervised when using this equipment, there is a significant probability of failure, which was assigned .15. Failure of this equipment would be detectable in most cases.

Effect \ Likelihood	0.001≤Pr<0.01	0.01≤Pr<0.02	0.02≤Pr<0.05	0.05≤Pr<0.1	0.1≤Pr<1
A. Loss of life				Surgical Equipment	
B. Major injuries occur					
C. Minor injuries occur					Patient Equipment
D. Technological problems with no harmful effects					
E. Few problems					

Qualitative Severity-scale Matrix

Low Risk	Moderate Risk	High Risk	Extremely High Risk

Figure VI.7.3. Quantitative scale matrix

Phase VI: Risk Management

This section briefly describes the trade-offs, costs, and benefits associated with this analysis.

In terms of technology, there are clearly some options that are available. There is most likely a trade-off between cost and quality. The higher the cost of developing a healthcare technology, the greater the work and quality that go into the product. Thus, to reduce the risk associated with equipment failure, a greater investment is usually needed. Of course, a lower cost is a benefit, but if the quality of a product is not great, then the risks are immense. In healthcare, peoples' lives are at stake, and it is nearly impossible to put a value on them. This may make it very difficult to compromise quality for cost. However, companies have no motivation if they cannot make money on a product, and thus the trade-off still exists. The clear benefit of a high-quality product is saving peoples' lives. It appears that in these scenarios, a large increase in cost would greatly reduce the risk. To keep costs relatively low, one option is exactly what the NSF does: it funds universities to do research.

Phase VII: Safeguarding Against Missing Critical Items

The risk management options developed in Phase VI interact with information technology, which was discarded in an earlier phase. This is especially true of the patient equipment. Generally, this equipment is attached to the patient, and measurements are taken to show how it is helping the patient's body. For example, continuous glucose monitors measure and keep track of the amount of glucose in a diabetes patient. Thus, this equipment helps to inject the patient with the correct amount of insulin, and it also provides information to doctors and clinicians about the patient's general glucose trends. The information works along with the physical equipment to improve the quality of the patient's life. If either of these fails, it compromises the importance of the other.

The option suggested in Phase VI, to fund universities to develop new healthcare technologies, can be revised to include the full integration of information technology with physical technology. This helps to make sure of the most efficient and effective outcome. While one can operate without the other, the full potential can only be realized when these two parts work together. However, this creates another trade-off. When funding research and development, how much effort and cost should be put towards the IT part, and how much towards the physical part? There is a delicate balance here, and it would not be beneficial to lean too far towards one side. Clearly, the physical technology grants should be directed towards biomedical and electrical engineers, while the IT grants should be directed towards systems and computer science engineers. Getting various views on the same problem can improve the probability of scenario success and decrease the chance of catastrophic failure.

Phase VIII: Operational Feedback

Going through the process of developing healthcare technology will allow us to recognize other potential risks that may occur. One important Head Topic to discuss is Culture, because it affects every other subtopic. Different groups of people have varying beliefs on the types of medicine and treatments they should take. Thus, when considering risk scenarios of the healthcare system, it is always important to evaluate these different cultural perspectives.

Another possible subtopic that could be added to the HHM is *epidemics.* Although *disease* is currently included as a subtopic, epidemics may have significantly different effects and should be a separate subtopic. The possible risk scenarios from epidemics are immense and are definitely a concern to the entire country. Finally, to perhaps better understand the healthcare system as a whole, the entire world should be considered, not just the United States. This may produce a whole new set of risk scenarios.

PROBLEM VI.8: Disaster Relief Risk Analysis

After the disaster caused by Hurricane Katrina, the city of New Orleans needs to evaluate its preparedness to handle any future natural disasters.

DESCRIPTION

New Orleans needs to minimize the possibilities of disaster in an extreme event. However, the city wants to gain insight into which risks are of highest priority, and how these and other risks should be effectively managed given the city's finite resources.

METHODOLOGY

A Risk Filtering, Ranking, and Management (RFRM) approach is taken to rank and order risks.

SOLUTION

Phase I: Scenario Identification (HHM)
A Hierarchical Holographic Model (HHM) is developed to describe the systems' "as planned" or "success" scenario.

The resulting perspective of scenarios surrounding natural disasters in New Orleans is depicted in Figure VI.8.1. This example does not address the crucial and complex issue of rebuilding levees.

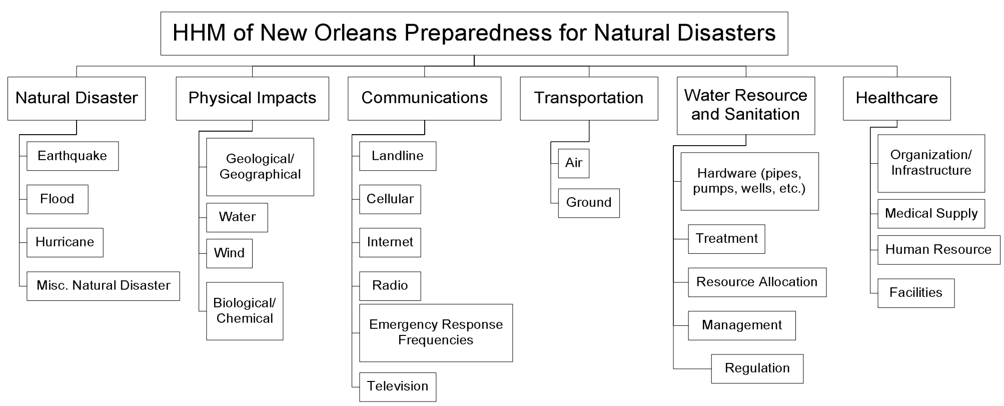

Figure VI.8.1. Hierarchical Holographic Model for natural disasters

Phase II: Scenario Filtering

The risk scenarios identified in Phase 1 are filtered according to the responsibilities and interests of the current system user.

A group of experts is asked to determine which subtopics, or sources of risk, are of greatest concern. The priority ordering of the sources of risk can be seen in the filtered version of the HHM in Figure VI.8.2. Given the limited resources, some subtopics, or sources of risk, are deleted as the decisionmakers and experts determine that they are not of utmost importance to address.

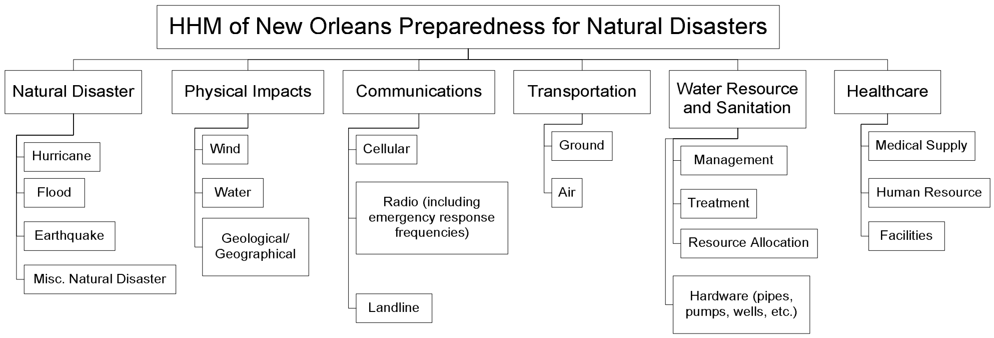

Figure VI.8.2. Filtered Hierarchical Holographic Model

Phase III: Bicriteria Filtering and Ranking

The ranking risk scenarios are further filtered using qualitative likelihood and consequences. Two different types of information—the likelihoods of what can go wrong and the associated consequences—are estimated on the basis of available evidence.

The following figure was determined using the likelihoods and the consequences:

Effect / Likelihood	**Unlikely**	**Seldom**	**Occasional**	**Likely**	**Frequent**
Death	Misc. Natural Disaster	Earthquake	Hurricane		
Sickness or injury		Air, Water, Hardware, Facilities, Medical Supply	Ground Support, Water Management, Human Resource, Medical Supply	Water Treatment, Medical Supply	
Loss of Property	Misc. Natural Disaster	Earthquake	Hurricane		Flood
Some sickness of loss of property			Landline	Radio	Cellular
Minor/no effect					

Qualitative Severity-scale Matrix

Low Risk	**Moderate Risk**	**High Risk**	**Extremely High Risk**

Figure VI.8.3. Qualitative severity scale matrix

Phase IV: Multicriteria Evaluation

Eleven criteria are developed that relate the ability of an at-risk scenario to defeat the defenses of the system.

The 11 criteria listed in Table VI.8.1 were used to further rank and sort the risk scenarios on a scale of 1 (low) to 3 (high).

Phase V: Quantitative Ranking

Filtering and ranking of scenarios continues based on quantitative and qualitative matrix scales of likelihood and consequence.

Using prior knowledge of distribution and probabilities, Figure VI.8.4 is constructed to demonstrate the probabilities of events occurring.

Effect \ Likelihood	$0.001 \le Pr < 0.01$	$0.01 \le Pr < 0.02$	$0.02 \le Pr < 0.1$	$0.1 \le Pr < 0.5$	$0.5 \le Pr < 1$
Loss of life	Misc. Natural Disaster	Earthquake	Hurricane		
Serious Injury		Air, Water, Hardware, Facilities,– Medical Supply	Ground Transport, Water Management, Human Resource, Medical	Water Treatment, Medical Supply	
Minor injury	Misc. Natural Disaster	Earthquake	Hurricane		Flood
Environmental Damage			Landline	Radio	Cellular
Minor of no effect					

Qualitative Severity-scale Matrix

Low Risk	**Moderate Risk**	**High Risk**	Extremely High Risk

Figure VI.8.4. Probability of Events Occurring

Phase VI: Risk Management

Risk management options are identified for dealing with the filtered scenarios, and the cost, performance, benefits, and risk reduction of each are estimated.

It seems that the scenarios of highest risk in the system are those concerning a flood and cellular communication. Thus, the city must ensure that it is adequately prepared for such an event occurring. A flood management plan for New Orleans would include the following elements:

Risk Scenario / Criteria	Misc. Natural Disaster	Earthquake	Hurricane	Air, Water, Hardware, Facility -	Flood	Ground Transport, Water Management, Human Resource	Water Treatement, Medical Supply	Landline	Radio	Cellular
Undetectability	2	2	2	2	3	1	3	1	2	1
Uncontrollability	3	1	2	2	3	1	1	1	1	2
Multiple Paths to Failure	1	3	2	2	3	3	3	2	2	1
Reversibility	1	3	2	1	2	2	2	1	3	2
Duration of Effects	3	2	2	3	3	2	3	2	2	2
Cascading Effects	1	2	2	2	3	2	1	1	1	3
Operation Environment	2	1	2	2	2	1	1	3	2	1
Wear and Tear	2	3	2	1	3	1	2	2	3	1
W/SW/HU/OR	3	2	2	3	3	1	1	2	3	3
Complexity/Emergent Behaviors	1	1	2	2	2	2	1	3	2	1
Design Immaturity	1	2	3	3	2	3	3	3	1	1
Total	20	22	23	23	29	19	21	21	22	18

Table VI.8.1. Evaluation of Risk Scenarios

1. *Communication:* Adequate emergency communication ability to coordinate disaster relief.
2. *Medical:* Medical facilities and personnel that can respond to the crisis situation and are prepared for such natural disaster scenarios.
3. *Transport:* Adequate transportation to relocate large numbers of displaced persons.
4. *Housing:* Emergency housing options to accommodate temporary displaced persons.

All of these would be needed in order to adequately address the highest-risk scenario—another flood in New Orleans.

Phase VII: Safeguarding against Missing Critical Items

The performance of the options selected in Phase VI is evaluated against the scenarios previously filtered out during Phases II to V.

Phase VII is essential to ensure the relative accuracy of the multiple solutions of the model. One of the main purposes of both HHM and RFRM is to be used as a tool for learning more about the system under study. During this modeling/learning process, some discoveries may in fact change prior assumptions or assertions. Phase VII ensures that important critical items have not been overlooked.

In the case of the New Orleans flood scenario, the options identified in Phase VI map well with the options selected in Phases II through V.

Phase VIII: Operational Feedback

Experience and information gained during the application are used to refine the scenario filtering and decision processes of earlier phases.

The purpose of the original HHM is the ability to learn about the system itself. Through "flipping," the analyst is able to switch perspectives and viewpoints and discover additional relevant information. Similar to Phase VII, this phase reevaluates and interprets the final results of the model. In other words, this phase provides the analyst and the decisionmaker with an iterative process to evaluate the solutions and assumptions of the model.

The ultimate purpose of the HHM/RFRM model is not to output a single answer, but rather to give decisionmakers a greater understanding of the system itself. In addition, cursory Bayesian analysis could also be applied to the final results. Such application of knowledge gained would greatly increase the value and meaning of the risk management plan suggested in Phase VI.

PROBLEM VI.9: Risk Modeling a University Athletics Program

A small university needs to update its athletic program to attract more students.

DESCRIPTION

A few of the concerns that face the new Athletics Director as he plans the next season are fundraising, attracting good athletes, and stadium security.

METHODOLOGY

This example demonstrates the Risk Filtering, Ranking, and Management (RFRM) process to model the university-wide athletics program. This methodology progresses through eight phases to identify and filter all possible risk scenarios.

SOLUTION

Phase I: Scenario Identification

The first step is to develop a Hierarchical Holographic Model (HHM) to identify all relevant scenarios under head topics and subtopics. For brevity, the Phase I HHM is not shown here in order to focus on the filtered HHM (Phase II).

Phase II: Scenario Filtering

The following head topics and their subtopics were of greatest interest to the Athletics Director.

- Athletics
  - Fundraising/Boosters
    - Alumni
  - Athletes
    - Scholarships
    - Academic Performance
    - Injuries
  - Coaches, Staff
    - Recruiting
    - Competence
    - Salaries
- Transportation
  - University Parking & Transportation
    - Parking Lots
    - Sidewalks
    - Bus Routes
- Structural Engineering
  - Aesthetic Design
  - Size
  - Practical Design
    - Signage
    - Ingress/Egress

- Maintenance and Operations
    - Communications
        - Media
        - PA System
        - Event Advertising
- Safety and Security
    - Game Security
        - Surveillance
- Sports Facility Staff
    - Ticket Takers
    - Concessions
    - Ushers
- Economy
    - Businesses
        - Services Industry
    - Food/Refreshments (at game)

Phase III: Bi-Criteria Ranking and Filtering

The topics in Phase II are further filtered down into a risk matrix showing consequences and likelihoods, as shown in Figure VI.9.1.

Effect \ Likelihood	**Unlikely**	**Seldom**	**Occasional**	**Likely**	**Frequent**
Loss of life/asset (catastrophic event)				Practical Design	
Loss of mission					Game Security Facility Staff Food/Refreshments
Loss of capability with some compromise of mission			Parking & Transportation Economy/Hotels	Coaches, Staff Communications	Alumni
Loss of some capability with no effect on mission				Facility Size	Athletes
Minor or no effect	Aesthetic Design				

Qualitative Severity-scale Matrix

Low Risk	**Moderate Risk**	**High Risk**	**Extremely High Risk**

Figure VI.9.1. Risk Matrix for Phase III

Phase IV: Multi-Criteria Evaluation

The subtopics are further filtered down to the five that are shown to be extremely high risks in the matrix above. These risks, spelled out more specifically in Table VI.9.1, are scored against the 11 criteria listed in Table VI.9.2.

Table VI.9.1. Risk Scenarios for Five Remaining Subtopics

Subtopic	Risk Scenario
Practical Design	Failure to provide safe emergency exit
Game Security	Failure to provide adequate security for a game
Facility Staff	Failure to provide adequate personnel to staff game
Food/Refreshments	Contaminated food or water supply
Alumni	Loss of alumni support for an extended period

Table VI.9.2. Scoring of Subtopics for Sports Facility

Criteria	Practical Design	Game Security	Facility Staff	Food/Refreshments	Alumni
Undetectability	Low	Low	Medium	High	Medium
Uncontrollability	Low	Low	Low	High	High
Multiple Paths to Failure	High	High	High	High	High
Irreversibility	High	Low	Low	High	Low
Duration of Effects	High	Low	Low	Medium	Medium
Cascading Effects	High	Medium	Medium	High	High
Operating Environment	Low	High	High	Medium	Medium
Wear and Tear	High	Medium	Medium	Low	N/A
HW/SW/Human/Org.	Low	High	Low	High	N/A
Complexity and Emergent Behaviors	High	High	Low	Low	Medium
Design Immaturity	Low	Low	Low	Low	Low

Phase V: Quantitative Ranking

In this phase, the five issues of greatest interest are ranked quantitatively and their severity is graphically illustrated in a matrix, as in Figure VI.9.2 below.

Effect \ Likelihood	0<Pr<0.01	0.01≤Pr<0.02	0.02≤Pr<0.1	0.1≤Pr<05	0.5≤Pr<1
Loss of life/asset (catastrophic event)		Practical Design			
Loss of mission			Game Security Food/Refreshments Facility Staff		
Loss of capability with some compromise of mission	Alumni				
Loss of some capability with no effect on mission					
Minor or no effect					

Qualitative Severity-scale Matrix

Low Risk	**Moderate Risk**	**High Risk**	Extremely High Risk

Figure VI.9.2. Quantitative severity-scale matrix

Phase VI: Risk Management

Performing the quantitative ranking in the previous phase indicates the critical risk scenarios that need to be managed. Hence, risk management options should be developed and prioritized according to the categories of risk as follows:

Extremely High Risk Category:

- *Practical Design:* The probability of this is believed to be low, due to the fact that failure to provide safe emergency exits can be detected and corrected early. However, there could be unexpected events that could prove them to be insufficient. Thus, the assignment of a probability of 1/100.

High Risk Category:

- *Game Security:* Because of factors such as health, weather, game schedule, stress, etc., there could be a lack of adequate security for a game. We assigned this a probability between 0.02 and 0.1
- *Food/Refreshments*: Because of the high consumption of food and the risk associated with contamination, we assigned this a probability between 0.02 and 0.1.
- *Facility Staff*: Providing adequate personnel to staff a game depends on the same factors as those affecting Game Security, namely, the operating environment: health, weather, game schedule, stress, etc. We assigned this scenario a probability between 0.02 and 0.1.

Moderate Risk Category:

- *Alumni*: Probability of loss of alumni support is extremely low (<1/1000) based on historical data of alumni. Combined with the potential effect (loss of capability with some compromise of mission), the overall risk is assessed as moderate.

Phase VII: Safeguarding Against Missing Critical Items

The entire athletics program is examined by taking into account the risk management policies identified in the previous phase. The effectiveness of these policies is re-evaluated by considering the additional impacts of the filtered-out risk scenarios. This provides insight into a number of alternative management options that otherwise might have been overlooked.

Given additional resources for risk management, an analyst can further consider risk scenarios filtered out in Phase III. For example, looking at Figure VI.9.1, risk management options may be expanded to include scenarios such as parking and transportation, economy/hotels, coaches, staff communications, facility size, and athletes.

Phase VIII: Operational Feedback

This phase looks at the methodology as a whole in terms of the dynamic nature of risk assessment and management. The experience and information gathered from the previous phases of RFRM helps refine and update the prioritization of the risk scenarios and improves the decisionmaking process. The process needs to be continuously updated and evaluated as risk categories may evolve over time. Furthermore, previously unforeseen risk scenarios (e.g., facility degradation) may become more critical over time.

PROBLEM VI.10: Providing a Home Security System

A couple wants to install the best security system possible in their home.

DESCRIPTION

To protect their family, the homeowners need to consider all possible characteristics of both their home and the security system.

METHODOLOGY

This example demonstrates implementing the Risk Filtering, Ranking, and Management (RFRM) method to choose the most effective system. The eight phases of RFRM begin with developing a Hierarchical Holographic Model (HHM) to identify all sources of risk.

SOLUTION

Phase I: Hierarchical Holographic Modeling (HHM)

An HHM for a home security system is shown in Figure VI.10.1.

Phase II: Scenario Filtering

Scenarios may be filtered out according to the following questions:

- What classes of occupants are at what levels of risk according to their lifestyles and asset values?
- Given that risk assessment, is a home security system justified, and if yes, what is the appropriate level of security needed?

Phase III: Scenario Ranking

In this phase, a risk matrix as depicted in Table VI.10.1 is used to describe the likelihood and consequence levels for the risk scenarios being considered. The possible intersections of these levels are used to determine the severity of a particular risk scenario. Because the assessment is concerned with the high-severity risk scenarios, those that fall into low-risk categories are set aside. However, the low-severity risk scenarios are not permanently disregarded because they might be of interest in a later RFRM process.

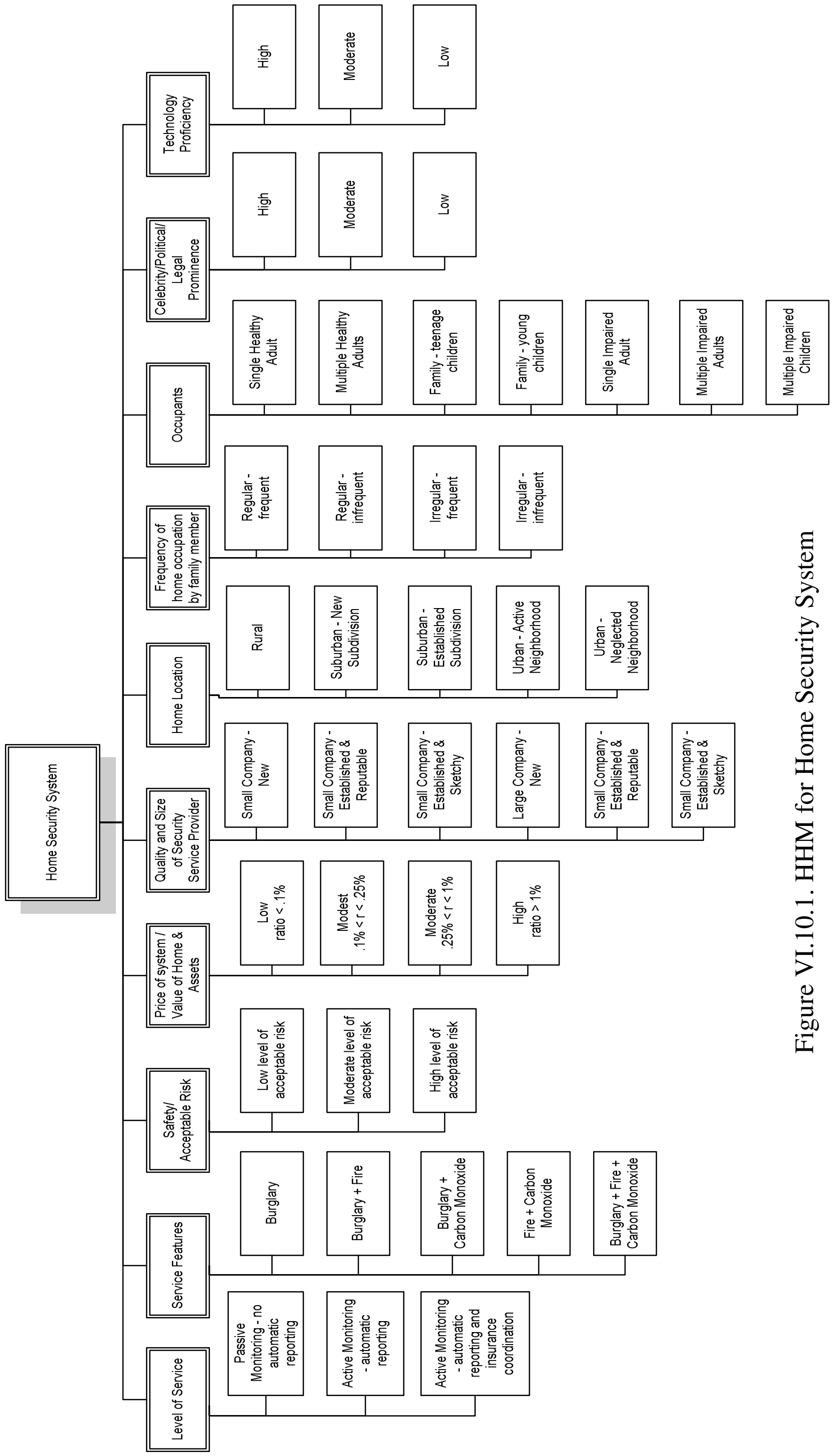

Figure VI.10.1. HHM for Home Security System

Table VI.10.1. Qualitative Severity Scale Matrix for Home Security System

	Frequent/Likely	Occasional	Seldom	Unlikely
Death	Single elderly person who smokes in bed.	Retired prison warden living in Mobile.	Elderly couple with approximately $200k in assets, with erratic schedule, not prominent, living in Hampton.	Young family with approximately $150k in assets, with regular schedule is a local prosecutor, living in the Fan district (Richmond).
Loss of > $100k	Young family with approximately $150k in assets, with regular schedule, is a local prosecutor, living in the Fan district (Richmond).	Wealthy art collector who travels often and lives alone.	Elderly couple with approximately $200k in assets, with erratic schedule, not prominent, living in Hampton.	
Loss of ~ $10k	Well-known rare coin collector who keeps regular hours and lives in Manhattan.	Multiple university students with approximately $10k in assets, with regular schedules, are not prominent in community, living in Lynchburg.		Multiple young professionals in apartment with approximately $20k in assets, with erratic schedules, not prominent in community and living in Charlottesville.
Loss of ~ $1000	Single university student with approximately $5k in assets, has erratic schedule, not prominent in community, living in Harlem.		Single university student with approximately $5k in assets, has erratic schedule, not prominent in community, living in Lynchburg.	
No effect	Single day laborer with $500 assets living in Newark.			

Key (Note: Scenario position in table reflects risk over time of home occupancy without security system.):

Extreme Low Risk	Low Risk	Moderate Risk	High Risk	Extremely High Risk

Phase IV: Multicriteria Evaluation

This phase requires the use of several reliability criteria (robustness, resilience, and redundancy) to evaluate the impact of the risk scenarios against the defensive abilities of the underlying system.

Robustness – The degree to which the home occupant follows security-aware practices and maintains a reasonable level of fire safety. For example, a person who routinely dead-bolts the door and has timer switches on lamps may be less prone to attempted burglary. Likewise, a person who maintains smoke alarms and fire suppression devices throughout the home may be less prone to fire damage.

Resilience – The ability of an occupant to respond to an emergency (fire or burglary) in a timely manner. For example, frequent vacationers may not be as resilient with respect to burglary or fire as a regular home occupant.

Redundancy – The degree to which a loss is replaceable. For example, occupants who keep all important documents in a single non-fireproof location would not be exhibiting redundancy in their security protocol.

Table VI.10.2. Multicriteria Evaluation with Respect to Robustness, Resilience, and Redundancy

	Frequent/Likely	**Occasional**	**Seldom**	**Unlikely**
Death	Single elderly person who smokes in bed. → Not Robust, Resilient or Redundant	Retired prison warden living in Mobile → Robust, Resilient and Redundant	Elderly couple with approximately $200k in assets … → Robust, but not Resilient or Redundant	Young family with approximately $150k in assets… → Robust, Resilient, but not Redundant
Loss of > $100k	Young family with approximately $150k in assets… → Robust, Resilient, but not Redundant	Wealthy art collector who travels often and lives alone. → Robust, but not Resilient or Redundant	Elderly couple with approximately $200k in assets … → Robust, but not resilient or redundant	
Loss of ~ $10k	Well-known rare coin collector who keeps regular hours and lives in Manhattan → Robust, Resilient but not Redundant	Multiple university students with approximately $10k in assets… → Robust, Resilient and Redundant		
Loss of ~ $1000	Single university student with approximately $5k in assets… → Robust, Resilient and Redundant			
No effect				

Legend:

Extreme Low Risk	Low Risk	Moderate Risk	High Risk	Extremely High Risk

Phase V: Quantitative Scenario Ranking

This version of the ranking uses a diagram similar to Table VI.10.2; however, numbers (i.e., probabilities) are used instead of qualitative likelihood categories in the columns of the matrix. The remaining risk scenarios are entered into the matrix and are filtered and ranked in terms of severity as in Phase III.

Table VI.10.3. Quantitative Severity Scale Matrix for Home Security System

	$1 > Pr > 0.5$	$0.5 > Pr > .1$	$0.1 > Pr > .01$	$0.01 > Pr > 0$
Death	Single elderly person who smokes in bed.	Retired prison warden living in Mobile.	Elderly couple with approximately $200k in assets, with erratic schedule, not prominent, living in Hampton.	Young family with approximately $150k in assets, with regular schedule, is a local prosecutor, living in the Fan district (Richmond).
Loss of > $100k	Young family with approximately $150k in assets, with regular schedule, is a local prosecutor, living in the Fan district (Richmond).	Wealthy art collector who travels often and lives alone. He has $2M in assets.	Elderly couple with approximately $200k in assets, with erratic schedule, not prominent, living in Hampton.	
Loss of ~ $10k	Well-known rare coin collector who keeps regular hours and lives in Manhattan. He has $50k in assets.	Multiple university students with approximately $10k in assets, with regular schedules, are not prominent in community, living in Lynchburg.		Multiple young professionals in apartment with approximately $20k in assets, with erratic schedules, not prominent in community and living in Charlottesville.
Loss of ~ $1000	Single university student with approximately $5k in assets, has erratic schedule, not prominent in community, living in Harlem.		Single university student with approximately $5k in assets, has erratic schedule, not prominent in community, living in Lynchburg.	
No effect	Single day laborer with $500 assets living in Newark.			

Legend:

Extreme Low Risk	Low Risk	Moderate Risk	High Risk	Extremely High Risk

Phase VI: Risk Management

After Phase V, only a few risk scenarios remain. The aim of Phase VI is to generate several options to reduce, if not eliminate the risk scenarios. Also embedded in this phase is the evaluation of the effectiveness of the identified options in relation to conflicting goals, such as costs and benefits.

Table VI.10.4. Examples of Risk Management

Single elderly person who smokes in bed → Fire + CO with Passive Monitoring	Retired prison warden living in Mobile → Fire + Burglary with Active Monitoring and Auto Report	Elderly couple with approximately $200k in assets → Fire + Burglary + CO with Active Monitoring and Auto Report and Insurance coordination
Young family with approximately $150k in assets → Fire + Burglary + CO with Active Monitoring and Auto Report	Wealthy art collector who travels often and lives alone → Fire + Burglary with Active Monitoring and Auto Report	
Well-known rare coin collector who keeps regular hours and lives in Manhattan → Burglary with Passive Monitoring	Multiple university students with approximately $10k in assets → Fire with Passive Monitoring	

Phase VII: Safeguarding Against Missing Critical Items

In this phase, scenarios previously filtered out are again explored to expand the currently identified set of risk scenarios. The effectiveness of these policies is re-evaluated by considering the additional impacts of the filtered-out risk scenarios. For example, by revisiting Table VI.10.3, an analyst may consider a filtered-out risk scenario whose consequence is categorized within the "no effect" category (i.e., single day laborer with $500 assets living in Newark).

Phase VIII: Operational Feedback

This phase is devoted to operational feedback to test the efficacy of risk management over time, or to continue to investigate previously filtered-out risk scenarios. For example, current fire + burglary monitoring technologies may become obsolete over time, or may need significant upgrades to include other functions.

PROBLEM VI.11: Planning a Party

Two students want to give a large party, and want to be sure that it is a success.

DESCRIPTION

There are many elements that can either make or break a good party. The students want to spend some time on risk mitigation to make sure that they are focusing their efforts efficiently.

METHODOLOGY

The students decide to use Risk Filtering, Ranking, and Management (RFRM) to analyze all the components of the party. There are eight phases in the RFRM process.

SOLUTION

Phase I: Hierarchical Holographic Modeling (HHM)
The first phase of RFRM involves identifying risk scenarios via a hierarchical holographic model (HHM), as in Figure VI.11.1 below.

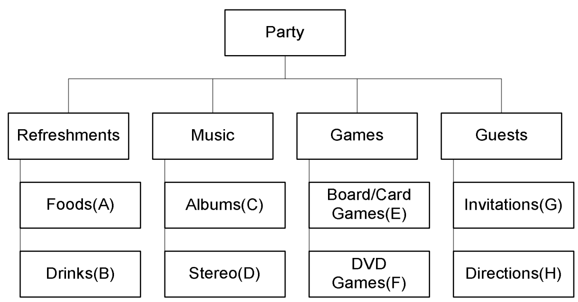

Figure VI.11.1. HHM for party planning

Based on this HHM, the following list of risk scenarios was generated:

Table VI.11.1. Risk Scenarios

Subtopic ID	Scenario ID	Description
A	A1	Food runs out - guests disappointed
A	A2	Food burnt/tastes bad - guests disgruntled
A	A3	Food spoiled - guests get sick
B	B1	Drinks run out – guests disappointed
B	B2	Guests overindulge - get alcohol poisoning
C	C1	Music outdated - guests mock hostess
C	C2	CDs all scratched – guests disappointed
D	D1	Stereo breaks - guests bored
E	E1	Game cards/pieces missing - guests disappointed
F	F1	DVD broken/scratched - guests disappointed
F	F2	DVD player broken - guests bored
G	G1	Invitations lost in mail - guests don't come
G	G2	Invitations misprinted – guests show up on wrong day
H	H1	Directions misleading - guests get lost and don't come

Phase II: Scenario Filtering

The second phase of RFRM involves scenario filtering by the decisionmaker(s). Here, they will choose the items they feel are important for further study. Based on past experience, the probability of the hosts serving bad-tasting food is approximately zero. Therefore, it is not worthwhile to concern themselves with this possibility and they take A2 from the list of considered scenarios. Likewise, C2 will not be considered due to the extremely low probability that ALL of the CDs will be unplayable. Also, since they will not be inviting heavy drinkers, they need not fear that their guests will get alcohol poisoning. Therefore, risk scenario B2 will not be considered.

Phase III: Bicriteria Filtering

The third phase of RFRM involves a qualitative ranking of scenarios by likelihood and effect. Each risk scenario was placed into the matrix below. The scenarios in the upper row and far right column are of the most concern. They have decided to focus on scenarios above the bold line drawn through the matrix.

Likelihood / Effect	**Unlikely**	**Seldom**	**Occasional**	**Likely**	**Frequent**
Guests Get Sick	A3				
Hostess Mocked					C1
Guests Do Not Come		H1	G1	G2	
Guests Bored	F2			D1	
Guests Disappointed		F1	A1	B1	E1

Qualitative Severity-scale Matrix

Low Risk	**Moderate Risk**	**High Risk**	**Extremely High Risk**

Figure VI.11.2. Phase III Risk Matrix with Qualitative Probabilities

Phase IV: Multicriteria Filtering

In the fourth phase of RFRM, the remaining risk scenarios are evaluated in regard to their ability to defeat the three basic defenses of a system: resilience, robustness, and redundancy. There are a total of eleven risk-related criteria and each risk scenario will be noted as having a Low (L), Medium (M), or High (H) level of impact on this aspect of defensiveness. These scoring results are in the following table.

Table VI.11.3. Rating Risk Scenarios in Phase IV

Criteria\Scenario	A3	C1	D1	E1	G1	G2
Undetectability	H	M	L	L	H	L
Uncontrollability	M	L	H	L	H	L
Multiple Paths to Failure	M	H	H	H	H	L
Irreversibility	H	M	H	H	M	H
Duration of Effects	M	H	M	H	H	M
Cascading Effects	M	M	L	M	L	H
Operating Environment	H	L	M	L	H	M
Wear and Tear	H	L	L	L	L	M
Hardware/Software Human /Organizational	H	H	L	M	M	H
Complexity and Emergent Behaviors	M	M	L	L	L	M
Design Immaturity	H	L	L	L	L	L

Phase V: Quantitative Ranking

The fifth phase of RFRM involves a quantitative version of the ranking matrix used in Phase III. The Phase V matrix is in Figure VI.11.3 below.

Effect \ Likelihood	Pr≤0.01	0.01≤Pr<0.02	0.02≤Pr <0.1	0.1 ≤Pr<0.5	0.5≤Pr<1
Guests Get Sick	A3				
Hostess Mocked					C1
Guests Do Not Come		H1, G1	G2		
Guests Bored	F2		D1		
Guests Disappointed		F1	A1, B1	E1	

Qualitative Severity-scale Matrix

Low Risk	**Moderate Risk**	**High Risk**	**Extremely High Risk**

Figure VI.11.3. Risk Matrix with Numerical Values in Phase V

After determining the actual probabilities, they can see that there are only three scenarios they want to focus on:

1. Food poisoning causes guests to get sick
2. Music is outdated and the hosts are mocked
3. Invitations are misprinted and guests show up on the wrong day or don't come at all

Phase VI: Risk Management

The sixth phase of RFRM is Risk Management. This is where they decide how to manage the risks they have identified, focusing on one risk scenario at a time.

Food poisoning causes guests to get sick:

What can be done?

To guard against food poisoning, they can avoid foods that may spoil quickly or that need special care to insure safety. For example, they will not serve pork since it can be dangerous if not heated through to the correct temperature. They will also not serve mayonnaise-based sauces since mayonnaise can spoil quickly.

What are the costs and design modifications needed?

Considering the possibility of food poisoning in menu planning need not result in any additional costs. More time may need to be spent on careful menu planning, however.

Music is outdated and the hosts are mocked:

What can be done?

They can buy more CDs or ask friends or relatives for suggestions. If they follow their advice, they can be sure of not being mocked.

What are the costs and design modifications needed?

If, the hosts have the suggested CDs, there will be no extra costs. If they need to purchase more CDs, the cost will be about $60 dollars.

Invitations are misprinted and guests show up on the wrong day or don't come at all:

What can be done?

After checking the wording, have another person proofread them before giving them to the printer. Check the printed invitations carefully to be sure they are correct before you pay for them.

What are the costs and design modifications needed?

Proofreading the directions will not result in any additional cost. The invitations will have to be prepared earlier however, to allow time for any mistakes to be corrected.

Phase VII: Safeguarding Against Missing Critical Items

This phase of RFRM deals with safeguarding against missing critical items. Here, they revisit the risks that were included in the Phase I HHM, but were discarded in Phases II to V. For instance, consider again the filtered-out risk of guests being disappointed from bad-tasting food. Maybe, because of unforeseen events, this can be reclassified as being unlikely but still possible. The quality of the food may not necessarily be related to the hosts' cooking skills. It could be that the some of the ingredients were not fresh, or that they tried a new recipe that did not work out well.

Even the comprehensiveness of the HHM prepared in Phase I should be revisited. Phase VII addresses the dynamism/robustness of the entire RFRM. By checking the HHM, they can determine and add the "emergence of new or undetected" critical items. For example, under the head topic of Guests, they may add the scheduling (date and time) of the party to be a critical item. If many of the invited guests cannot attend due to schedule conflicts, short notice, or mere impracticality of the time, then fewer guests would translate to less fun at the party.

Phase VIII: Operational Feedback

The last phase of the RFRM deals with operational feedback. This closes the process loop and at the same time ensures the continuous update and refinement of the risk mitigation process.

Since RFRM is started before preparations are done and, of course, some days before the actual party, it should be updated as the days draw to a close. Most likely, the hosts would not be able to do all the necessary preparations in a single day. They should review their resources (money, time, etc.) throughout the preparation process to determine whether they need to allocate more funds, and to which items in the HHM they should allocate them for optimal risk reduction. They should also communicate with all the guests through conversations or e-mail to elicit comments, suggestions, and requests.

As noted in the class textbook, the HHM is never considered complete. More head topics can be added as new risk factors emerge or are recognized. Finally, it should be remembered that one of the strengths of RFRM is its dynamism with respect to current and future circumstances.