PROCEEDINGS OF THE WORKSHOP ON STRUCTURAL HEALTH MONITORING AND ITS ROLE IN ENHANCING BRIDGE SECURITY

Edited by
MOHAMMED ETTOUNEY & SREENIVAS ALAMPALLI

Sponsored by
NEW YORK STATE
DEPARTMENT OF TRANSPORTATION

STRUCTURAL HEALTH MONITORING
VIRTUAL TEAM OF THE FHWA

WEIDLINGER ASSOCIATES, INC.

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EXECUTIVE SUMMARY

The role of Structural Health Monitoring (SHM) in the Bridge Security arena is not well defined or understood. In order to investigate this issue, a workshop was held with representative members including bridge owners, academia/researchers, consultants, and security personnel. This workshop was sponsored by the New York State Department of Transportation, Federal Highway Administration and Weidlinger Associates. The workshop deliberated several aspects of the structural health monitoring in the bridge security arena, including various SHM technologies, measurement methods, hazards that affect bridge security, temporal nature of security (before, during and after event), interaction between hazards, bridge components and disciplines, and interaction between stakeholders. A summary of the workshop deliberations along with the relevant results, obtained using statistical analyses, are reported in this proceedings. Such results can be of help to the SHM and Security communities in understanding the role of SHM in enhancing bridge security and to focus/prioritize their efforts in this field to reduce costs while improving safety and security.

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1 INTRODUCTION

1.1 Overview

Bridge security has emerged as an important subject. Protecting our bridge structures, which represent key components of our transportation infrastructure, is essential for national security, mobility and economic vitality. Direct attacks on critical structures could lead to casualties and profound damage to regional and national economies. However, because each bridge is unique and complex, defining and securing vulnerable components against varied threats presents a challenge. Securing structural components of a bridge is only one part. Overall site conditions and lifelines often carried by bridges also need to be protected. (see Figure 1). The threats our bridges face are complex in nature and can vary significantly in severity. These coupled with numerous stakeholders (see Figure 2) who must interact efficiently in times of crisis makes "bridge security" a complex subject frequently not well understood, while its importance to the national well being is highly acknowledged. Thus, ensuring bridge security for public safety is a technically challenging undertaking, potentially involving immense financial loss/cost.

Structural Health Monitoring (SHM) has also emerged recently as a viable engineering field with the potential of helping bridge owners increase safety while reducing operating and maintenance costs, and thereby increasing the service life of bridges. SHM has been shown to be of help in normal bridge operating conditions, for monitoring corrosion and fatigue, and for monitoring structural behavior under abnormal hazards such as earthquakes, high wind and scour. Numerous SHM methodologies, techniques, hardware and software have been developed and utilized to achieve different bridge management goals, improving informed decision making processes, thus increasing safety and reducing costs.

Given the emerging complex needs of bridge security and the tools and techniques of SHM, we can ask the following questions:

- How pertinent is the use of SHM tools to the subject of bridge security?
- Even if SHM tools are pertinent for bridge security, how important are they in resolving bridge security issues?
- What is the current availability of SHM tools that can enhance bridge security?
- Is there a value (cost–benefit) in using SHM for enhancing bridge security?
- What are the needs of various stakeholders for efficient interaction of SHM-Bridge security demands (multidisciplinary issues)?
- Can SHM tools that have been developed for other hazards be utilized efficiently to enhance bridge security (multihazards issues)?

It is obvious that finding detailed answers to the above questions involve immense effort and research. The recently formed Bridge Security subcommittee of the FHWA Virtual Team on SHM embarked on an effort to address some of the above questions.

A workshop of the Bridge Security subcommittee of the SHM and Bridge Security virtual team was convened at the offices of Weidlinger Associates, New York, NY on January 12, 2006. The one-day workshop was limited to ten attendees and was attended by representative stakeholders. The number of attendees and length of the workshop was limited by available resources. The deliberations of the attendees during the workshop proved to be very valuable and useful to all the attendees and this report's contents reflect the width and breadth of the deliberations. It is believed that this workshop report should help decision makers, who are responsible for enhancing bridge security and prioritizing their available resources to get optimal value.

1.2 Acknowledgements

This workshop was sponsored by the SHM Virtual Team of the Federal Highway Administration (FHWA), New York State Department of Transportation (NYSDOT) and Weidlinger Associates, Inc (WAI). Editors thank all the experts who attended the workshop for their time and valuable input. Editors acknowledge the support received from Dr. Hamid Ghasemi of FHWA and Dr. Raymond Daddazio of WAI in organizing this workshop; and George Christian of NYSDOT in publication of the proceedings. Editors acknowledge the assistance provided by Linda Banks of NYSDOT and Sharada Alampalli in preparing the proceedings. All the views presented in this paper are those of the editors and attendees and not necessarily of the organizations they represent.

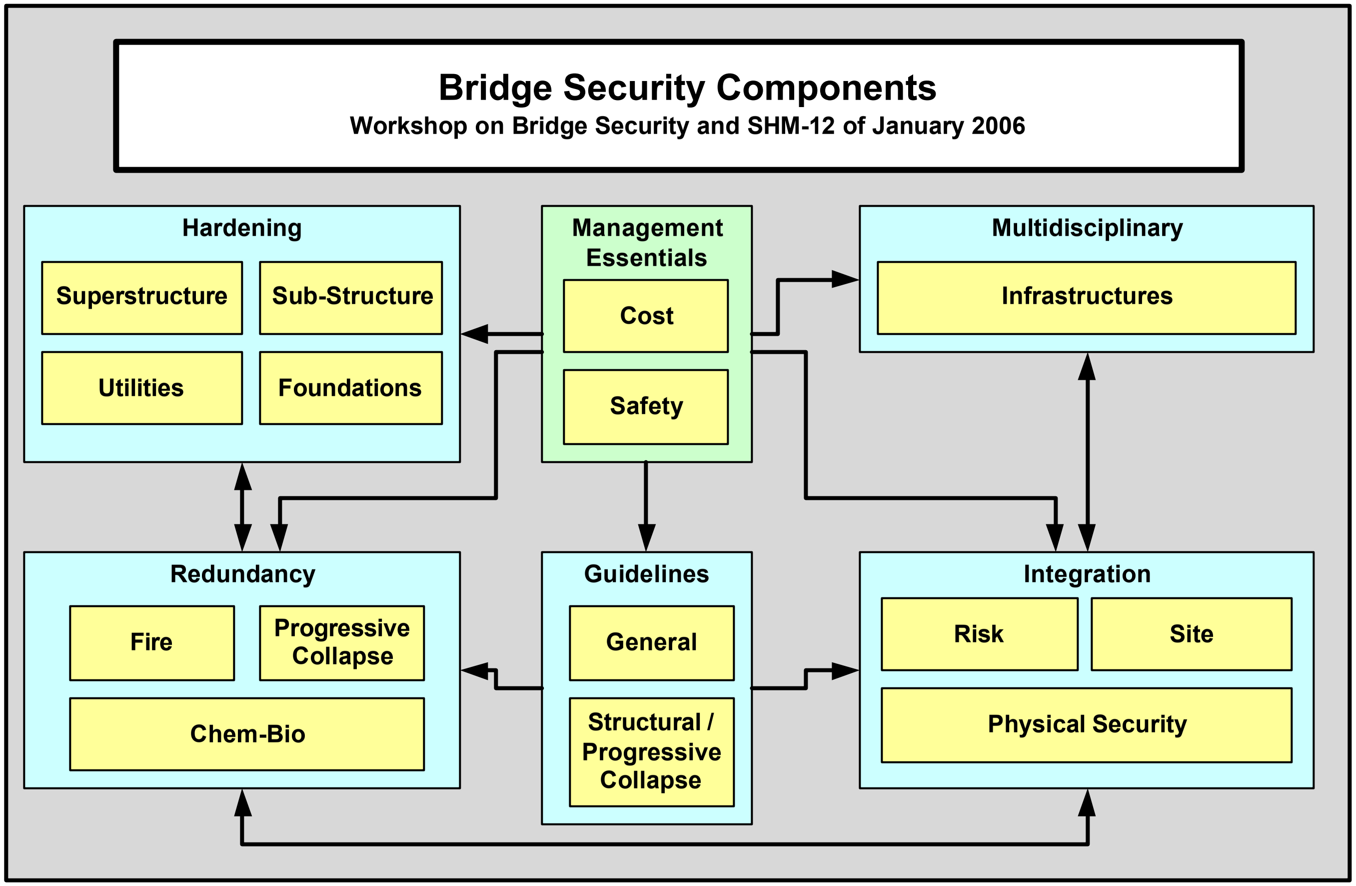

Figure 1 – Components of Bridge Security

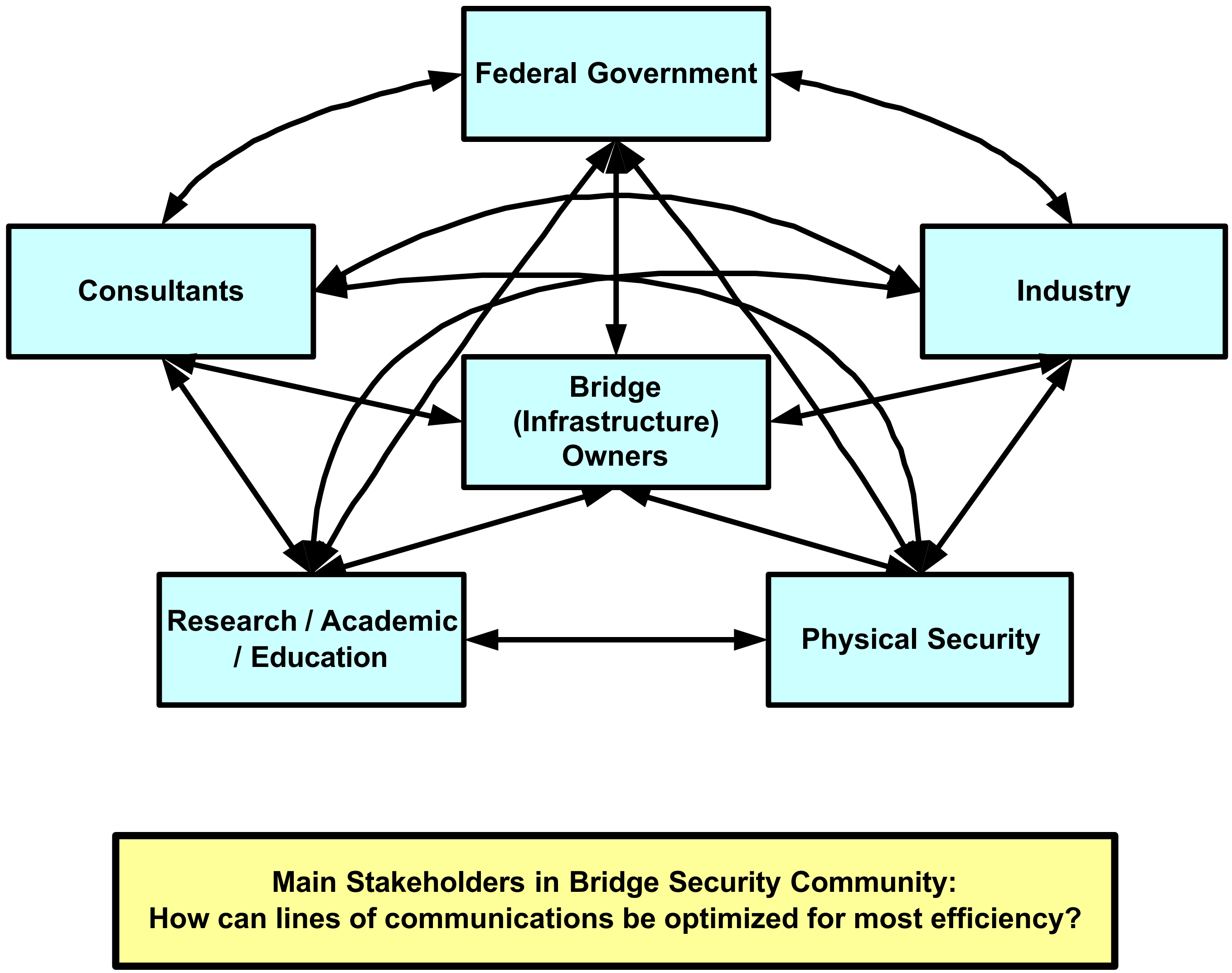

Figure 2 – Interaction Between Bridge Security Stakeholders

2 WORKSHOP DETAILS

2.1 Attendees

1. Dr. Sreenivas Alampalli, P.E.
   Director, Bridge Evaluation Services Bureau
   New York State Department of Transportation
   New York, NY 12232

2. Dr. Raimondo Betti
   Professor
   Department of Civil Engineering and Engineering Mechanics
   Columbia University
   New York, NY 10027

3. Harry Capers Jr., P.E.
   Corporate Bridge Engineer
   Arora and Associates, P.C.
   Lawrenceville, NJ 08648
   (Formerly Manager of the Office of Transportation Security at NJDOT)

4. Dr. Raymond Daddazio, P.E.
   President
   Weidlinger Associates, Inc.
   New York, NY 10014

5. Dr. John DeWolf, P.E.
   Department of Civil & Environmental Engineering
   University of Connecticut
   Storrs, CT 06268

6. Sheila Rimal Duwadi, P.E.
   Team Leader, Bridge Safety, Reliability & Security
   Office of Infrastructure R&D
   Federal Highway Administration
   McLean, VA 22101

7. Milagros-Nanita Kennett, AEI
   Architect/Project Manager Risk Management Series
   Mitigation Division
   Department of Homeland Security/FEMA
   Washington, DC 20472

8. Arturo Mendez
   Detective / Security Specialist
   New York City Police Department
   New York, NY

9. Dr. Waider Wong
   Structural Engineer
   Federal Highway Administration
   Baltimore, MD 21201

10. Dr. Bojidar Yanev, P.E.
    Director
    New York City Department of Transportation
    New York, NY 10006

11. Dr. Mohammed Ettouney, P.E. (Moderator and Organizer)
    Principal
    Weidlinger Associates, Inc.
    New York, NY 10014

2.2 Sessions

The agenda for the workshop is shown in Appendix I. It should be noted that due to resource limitations, the workshop was only designed as a one day event. Given the fact that SHM and bridge security are emerging subjects and are complex in nature, a one-day event that deliberates SHM use in bridge security is indeed not sufficient. It is recommended to convene another workshop of longer duration that can offer more depth and breadth of deliberations.

2.3 Handouts

Several handouts were given to participants for their input (both qualitative and quantitative) based on their knowledge and experience in the subject areas. All the handouts are shown in the report. These scores form a major basis for several of the conclusions made at the end of the report.

3 DELIBERATIONS AND RESULTS

3.1 Overview

This section discusses the workshop structure. First, the metrics that govern SHM-Bridge Security are defined. This is followed by a description of SHM technologies and bridge components; both subjects were discussed in length during the workshop. The statistical rules followed in producing the quantitative results of the workshop are then presented. Finally the organization of the rest of the section is discussed.

3.1.1 Metrics

3.1.1.1 Applicability

As the title implies, the applicability issue explores whether one item (usually a SHM technology) is applicable for use with another item (usually related to bridge security).

3.1.1.2 Importance

The importance metrics explores the question that if the use of two items in a relationship to each other is applicable, how important is such a use? The answers and scores of this question can help decision makers in prioritizing their efforts so that important issues are accommodated first.

3.1.1.3 Availability

The availability issue explores whether a specific SHM technology is available for use in a given bridge security area. The answers and scores of this metric can help manufacturers, researchers, owners and government agencies in prioritizing research and development efforts.

3.1.1.4 Current Practice and Future Needs

When two items are judged to be applicable and relevant to each other, sometimes it is beneficial to explore the adequacy of current practices in using a specific item (e.g., SHM technology) to improve another issue (e.g., particular bridge security issue). In addition, the future needs of this issue were also explored.

The current and future needs help the decision makers in understanding the present conditions and plan for the future.

3.1.1.5 Cost – Benefit and Value

The cost and benefit metrics were used in some of the questions during the workshop. Cost of several SHM activities is usually measured in monetary units and, sometimes, in non-monetary units (such as social and psychological costs). Benefits of the SHM measures are generally measured in terms of increased security. The value, for the purpose of this workshop, was defined as the benefit-to-cost ratio.

All parameters (cost, benefit and value) were qualitative. Two types of value were considered: perceived value and actual value. A perceived value is the value as perceived by the public as a whole. Actual value is the value as judged by experts. Since all attendees in this workshop are considered experts in their field, it is assumed that they can estimate reasonably accurate evaluations (both perceived and actual values) of various SHM techniques in the bridge security field.

3.1.2 SHM Technologies

It was argued[1] that SHM (or Structural Health in Civil Engineering) community includes four major components: measurements (sensors and instrumentations), structural identification, damage identification and decision-making. Due to the time and resource limitations, the current workshop was limited to the measurements component. As such, several technologies were identified that can be used in the bridge security field and include, but were not limited to the following:

- Strains / Stresses
- Motion (including displacements, velocities and accelerations)
- Chem. – Bio.
- Remote Monitoring
- Imaging Techniques
- Electromagnetic
- Biometric

Some of the above technologies overlapped; however, it was felt that during deliberations, the attendees could overcome such overlap. During the workshop, it was also observed that the above categorization mixes *measured subjects* (such as motion and strains) with *technology* (such as electromagnetic). Such a shortcoming should be corrected in the future activities.

[1] Alampalli and Ettouney, "Observations, Recommendations and Items of Interest to the Health Monitoring Community," Structural Health Monitoring Workshop 2004 Proceedings, ISIS Canada Research Network, Winnipeg, Manitoba, September 2004.

3.1.3 Bridge Components

Bridge security is a broad and complex subject. Hence, it was decided to divide it into five broad areas. Each issue, in turn, was subdivided as given below.

- Hardening
  - Superstructure
  - Substructure
  - Utilities (such as water, electric, gas lines, etc.)
  - Foundations

- Redundancy
  - Fire
  - Total collapse (or partial collapse)
  - Chem.-Bio.

- Integration issues
  - Risk (Management and Assessment)
  - Site Considerations
  - Physical Security

- Guidelines
  - General
  - Structural
  - Geotechnical

- Management / Owners
  - Safety
  - Cost

3.1.4 Analysis (Statistical) Procedure

In all averaging processes, any blank entry was assigned a zero. There were several "NA" (Not Applicable) entries. However, the "NA" entries were not used consistently among the workshop participants, thus reflecting varying opinions regarding different issues. It would be more accurate to study the "NA" entries more closely, since they imply a different meaning than a zero entry. However, due to the time limits, an "NA" entry is treated in the averaging process as a zero.

3.1.5 Organization of this Section

The remainder of this section presents the following five topics that were explored during the workshop.

- Bridge Components
- Sequence of Events During Hazards
- Multihazards and Multidisciplinary Factors
- Current and Future use of SHM Technologies
- Interaction between Stakeholders

Each topic looked at the interrelationship of SHM and bridge security from pertinent viewpoints. A form (questionnaire) was distributed at the beginning of each topic for participants input. The deliberations and the input summary for each topic are then presented. The averages of the numerical scores of those questions are included in different appendices. Some illustrative graphics and discussions are presented. Finally, important observations and conclusions derived from these efforts are given.

3.2 Bridge Components

The interrelationships between bridge components and SHM technologies were the subject of this part of the workshop. A blank form related to SHM technology and bridge security components (see in Figure 3) was given to all participants for their input. For each cell in the form, the following questions were presented to the attendees and they were asked to individually give their input to those questions in the form of a number between 0 (minimum) to 10 (maximum).

- **Applicability:** How applicable is the utilization of security-related SHM technologies for a given bridge component?
- **Importance:** How important is the utilization of security-related SHM technologies for a given bridge component?
- **Availability:** How available is the utilization of security-related SHM technologies for a given bridge component?

The average scores of different cells of Figure 3 are shown in Table 1, Table 2 and Table 3 of Appendix II. To understand these results in simple terms, it was integrated vertically across the bridge components rows. These Tables show the resulting average score for each of the SHM technologies in terms of applicability, importance and availability. The strains, motion and imaging techniques scored highest in applicability and importance. The attendees indicate that current technologies for strains and motion are adequate. However, the availability of imaging techniques is lower, indicating a need for developing or implementing these technologies to meet security needs.

Figure 4, Figure 5, Figure 6, and Figure 7 show how the attendees scored for different aspects of bridge security components. For hardening, (see Figure 4) the superstructure, substructure and utilities were fairly similar in availability, importance and applicability. The foundations scored consistently lower. This is not surprising considering that bridge foundations are not easily accessible and hence do not pose a big threat from a security point of view. This is perhaps one of the differences between bridge security as a hazard and other natural hazards, such as earthquakes and scour, where bridge foundations would be of utmost importance.

Of the three issues that constitute redundancy (see Figure 5) the fire issue ranked highest in applicability, importance and availability. The Chem.-Bio issue seemed to rank fairly low. This is also understandable, since the Chem.-Bio hazard is not a major bridge security related issue. The low ranking of the total collapse is puzzling. Total or progressive collapse is an important issue for all infrastructures. One possible reason for such a low ranking might be the fact that this issue has not had as much publicity as it has in the building community. More attention should be given to this issue within the bridge community.

The attendees' perception on guidelines in the field of bridge security is shown in Figure 6. This figure shows the clear need for general guidelines. Secondly, the structural guidelines scored a bit lower than the general guidelines. This indicated the recognition of the attendees of the importance of other issues, in addition to the structural issues, for bridge security. In all situations, it is acknowledged that the availability of such guidelines is not as widespread as they should be; there is a definite need for bridge security guidelines.

Finally, Figure 7 shows management goals and bridge security. The safety and cost are usually the most important management goals. The attendees indicated that safety concerns are more important than cost concerns. In both issues, the availability seems to be lacking when compared with importance.

Bridge Security Components - SHM Technology
Rate: Applicability / Importance / Availability: 0 (min) - 10 (max)

Security Components		Strains / Stresses	Motion (Disp, Vel, Acc)	Chem.-Bio Agents	Remote Monitoring	Imaging Techniques	Electromagnetic	Biometric
Hardening	Superstructure							
	Substructure							
	Utilities							
	Foundations							
Redundancy	Fire							
	Total Collapse							
	Chem.-Bio							
Multidisciplinary	Infrastructures							
Integration	Risk (management and assessment)							
	Site Considerations							
	Physical Security							
Guidelines	General							
	Structural							
	Geotechnical							
Management	Safety							
	Costs							

Figure 3 – Form for SHM Technology and Bridge Security Components

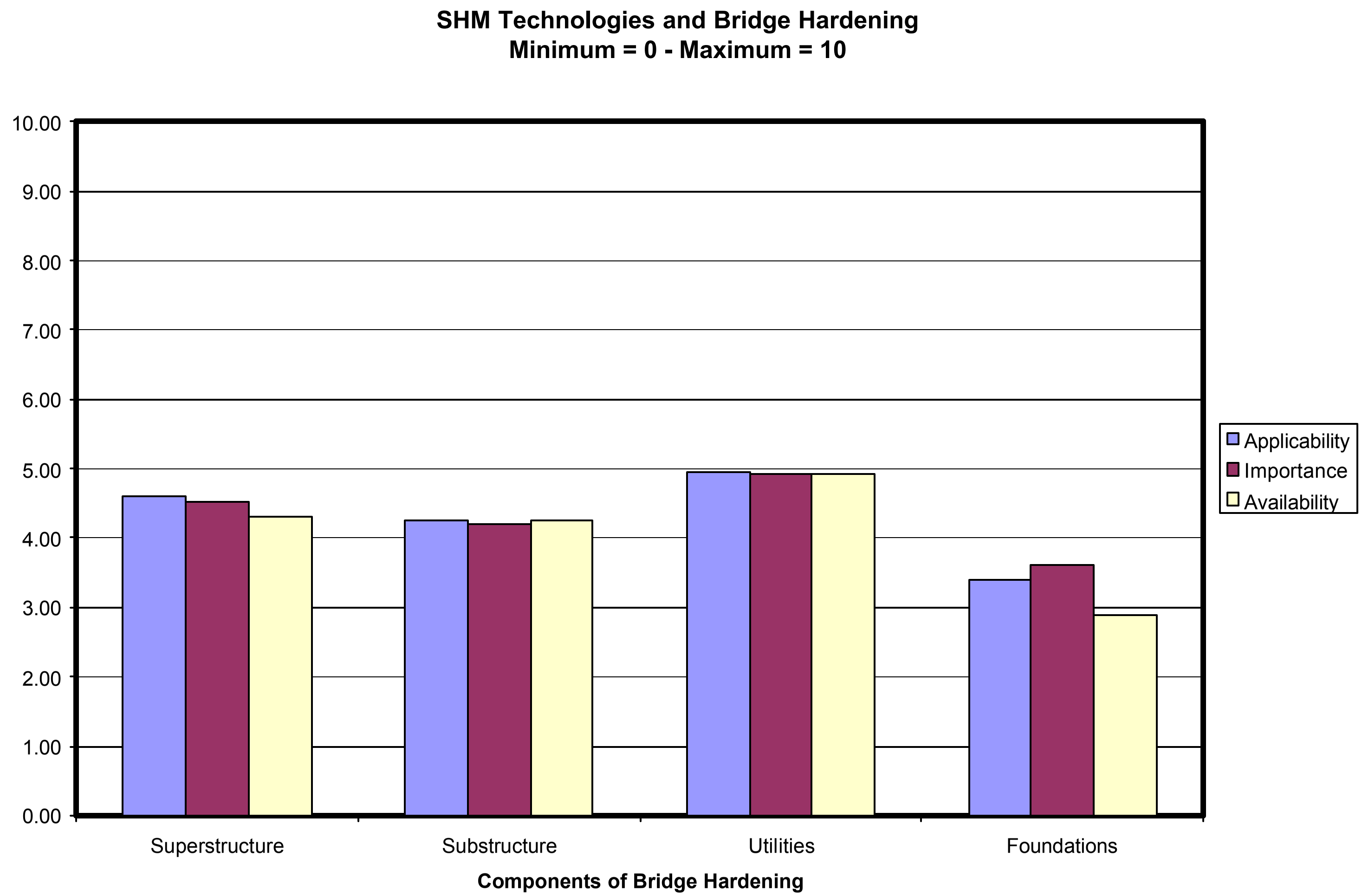

Figure 4 - Scores for SHM Technologies and Bridge Hardening

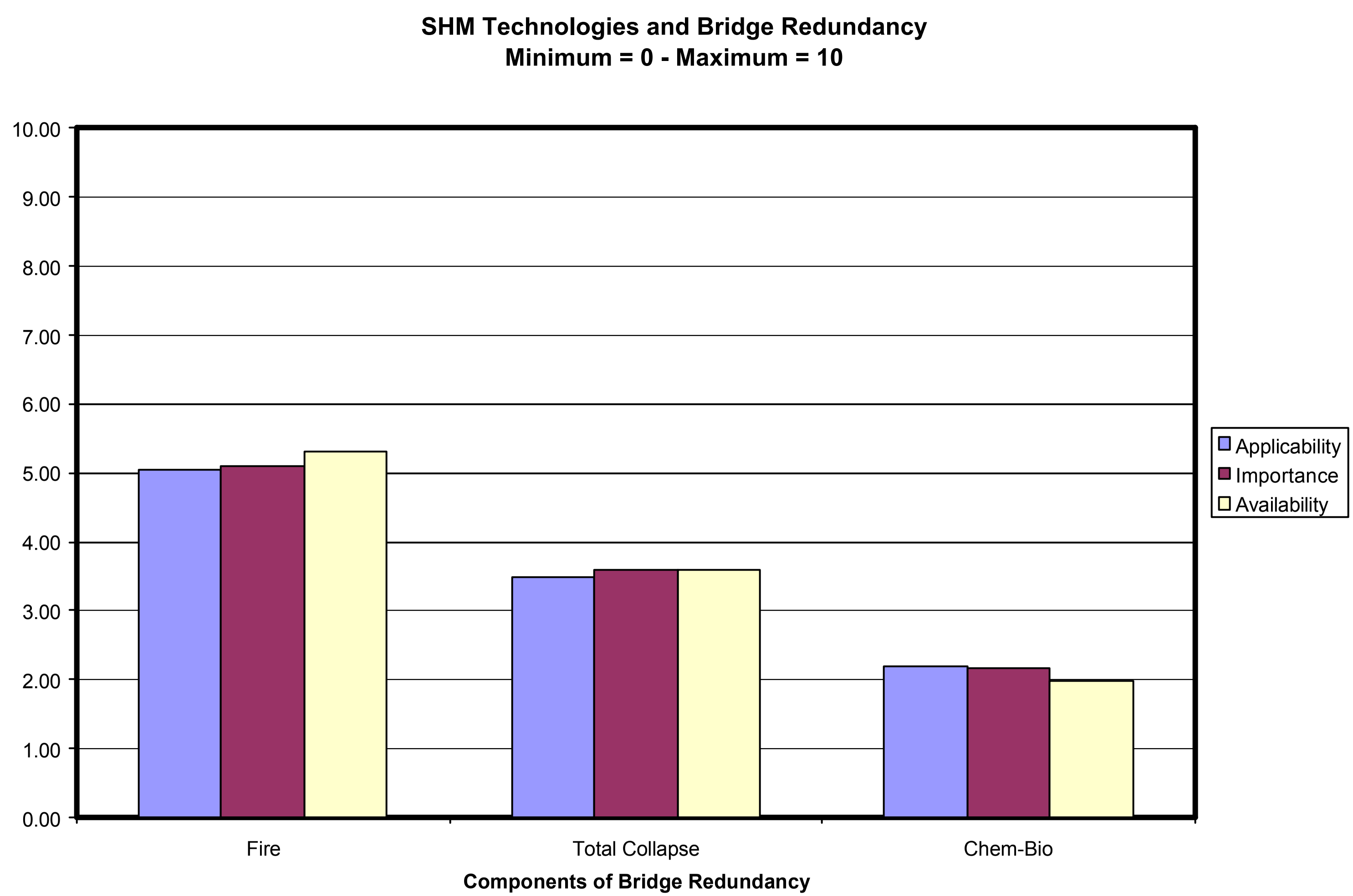

Figure 5 – Scores for SHM Technologies and Bridge Redundancy

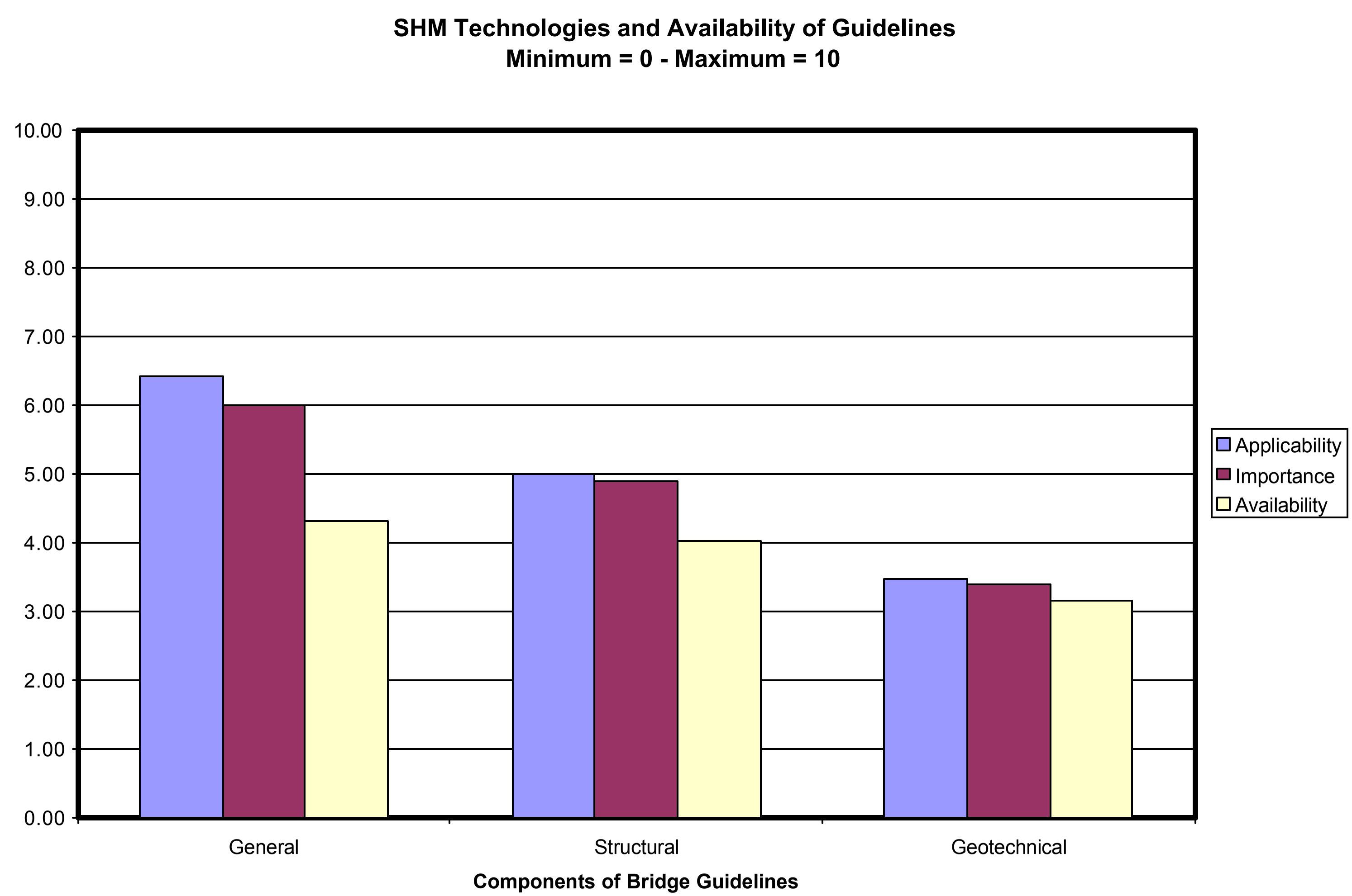

Figure 6 - Scores for SHM Technologies and Bridge Guidelines

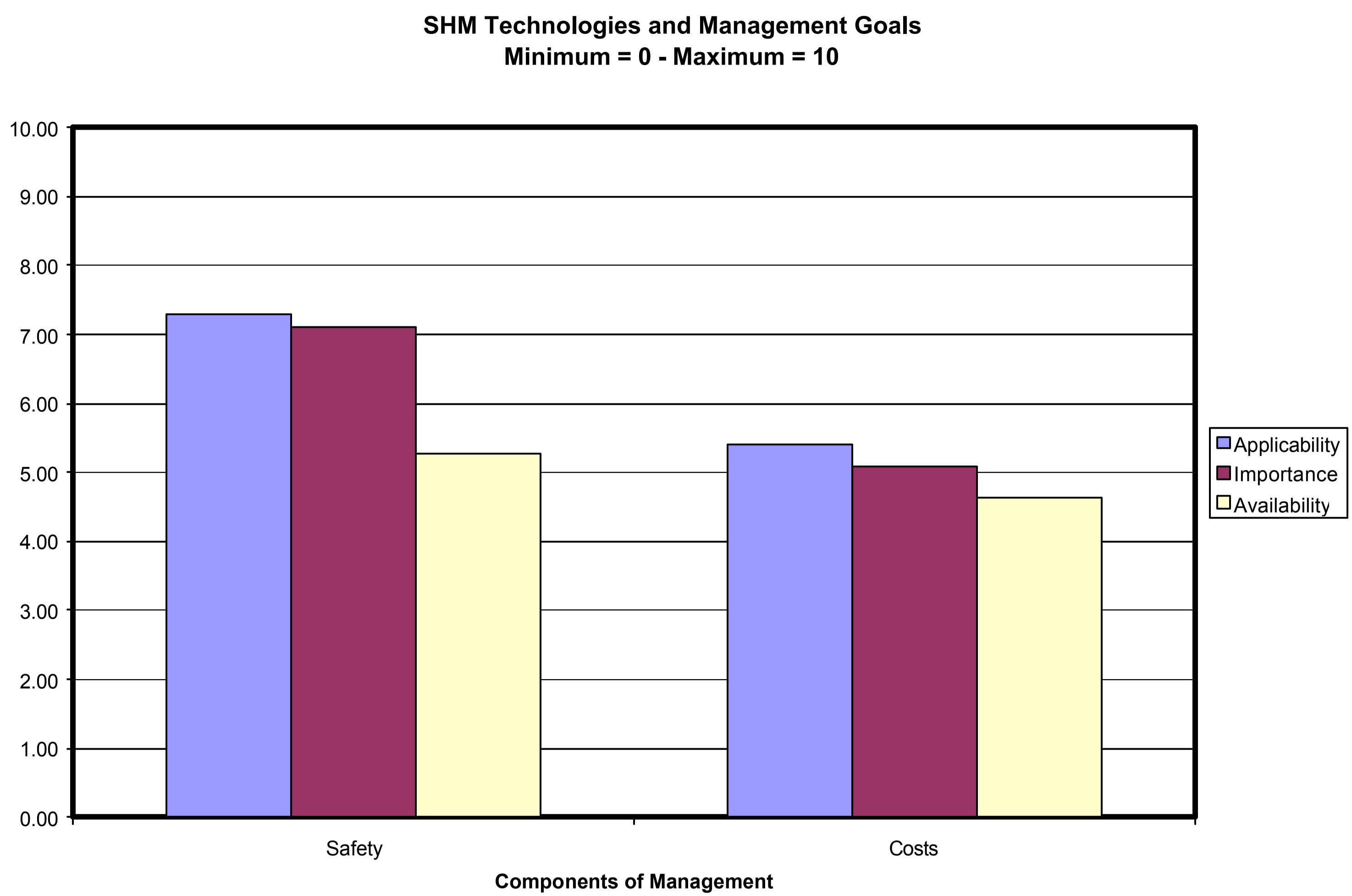

Figure 7 - Scores for SHM Technologies and Bridge Management Goals

3.3 Sequence of Events during Hazards

Most security related hazards involve a temporal sequence. Such a sequence can be simply subdivided into three parts:

- Before event
- During event
- After event

The role of SHM will vary depending on the sequence. To assess different roles of SHM technologies for the security-related hazard and the event sequencing, the following questions were presented to the attendees in a tabular format (see Figure 8).

- **Applicability:** How applicable is the utilization of security-related SHM technologies for a given security-related event *before, during and after* such an event?
- **Importance:** How important is the utilization of security-related SHM technologies for a given security-related event *before, during and after* such an event?
- **Availability:** How available is the utilization of security-related SHM technologies for a given security-related event *before, during and after* such an event?

Each attendee was asked to give an answer to the question with a number between 0 (minimum) and 10 (maximum).

The averages of scores given by the attendees are shown Table 4, Table 5 and Table 6 of Appendix III. It should be noted that the initial handouts specified only two temporal hazards: Bomb Blast and Chem-Bio attacks. It was left to the attendees to add other temporal hazards as they saw fit. Three additional hazards were added by the attendees. They are radiation, ramming (impact) and fire.

In order to explore the ratings given by the attendees visually, they were plotted in three dimensional graphs. Figure 9, Figure 10 and Figure 11 show the scores for bomb blast sequences for applicability of SHM technologies, importance of SHM technologies and availability of SHM technologies. Figure 12, Figure 13 and Figure 14 show similar graphs for Chem-Bio. For Fire Hazard, the scores are shown in Figure 15, Figure 16 and Figure 17. The scores for Ramming/Impact Hazards are shown in Figure 18, Figure 19 and Figure 20. Finally, for Radiation Hazards, the scores are shown in Figure 21, Figure 22 and Figure 23. In general, the graphs show that SHM technologies can be of help in all of those hazards at all sequences of the hazard. The information presented in the above figures can assist decision makers and bridge security officials in prioritizing funding for bridge security related issues.

Timeline of Events - SHM Technology

Applicability, Importance, and Availability (Minimum = 0 - Maximum = 10)

Hazard (Security)		SHM Technology						
		Strains / Stresses	Motion (Disp, Vel, Acc)	Chem-Bio Agents	Remote Monitoring	Imaging Techniques	Electromagnetic	Biometric
Bomb Blast	Before Event							
	During Event							
	After Event							
Chem. Bio	Before Event							
	During Event							
	After Event							
Other?	Before Event							
	During Event							
	After Event							
Other?	Before Event							
	During Event							
	After Event							

Figure 8 - Form for SHM Technology and Timeline of Events

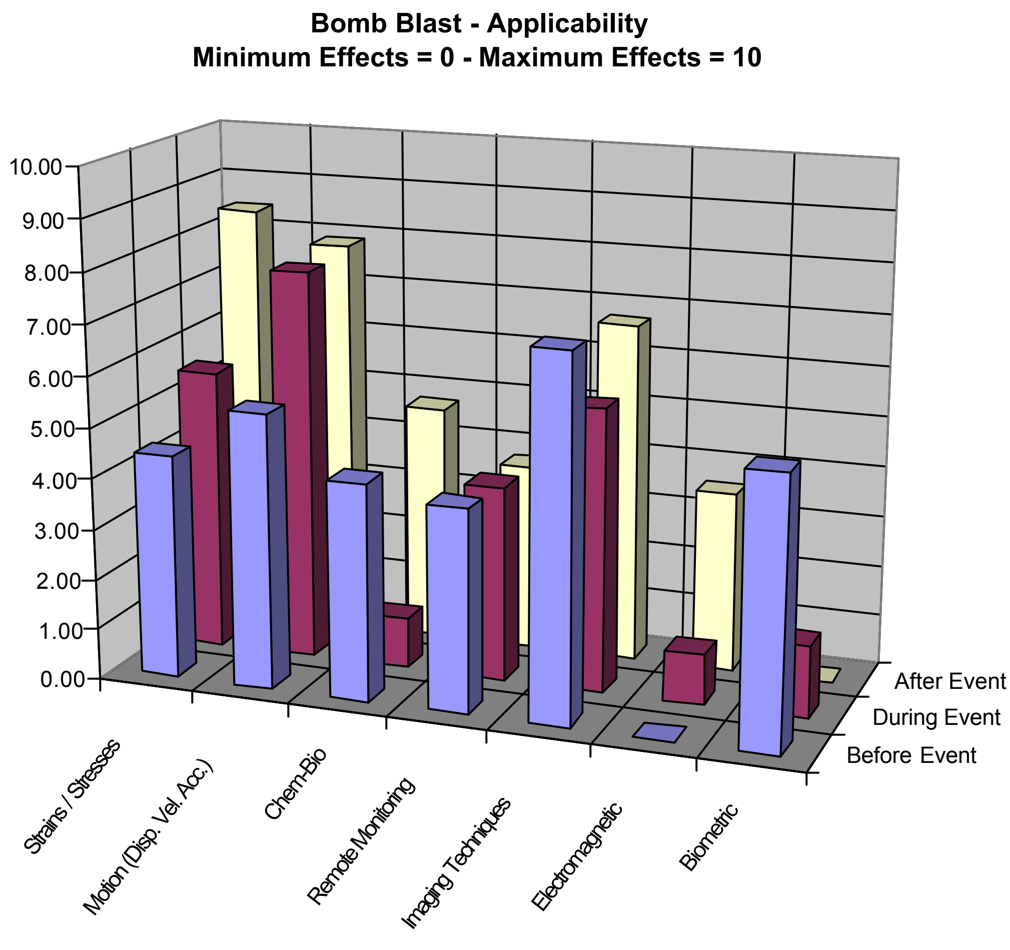

Figure 9 – Scores for Applicability of SHM for Bomb Blast Events – Timeline Issues

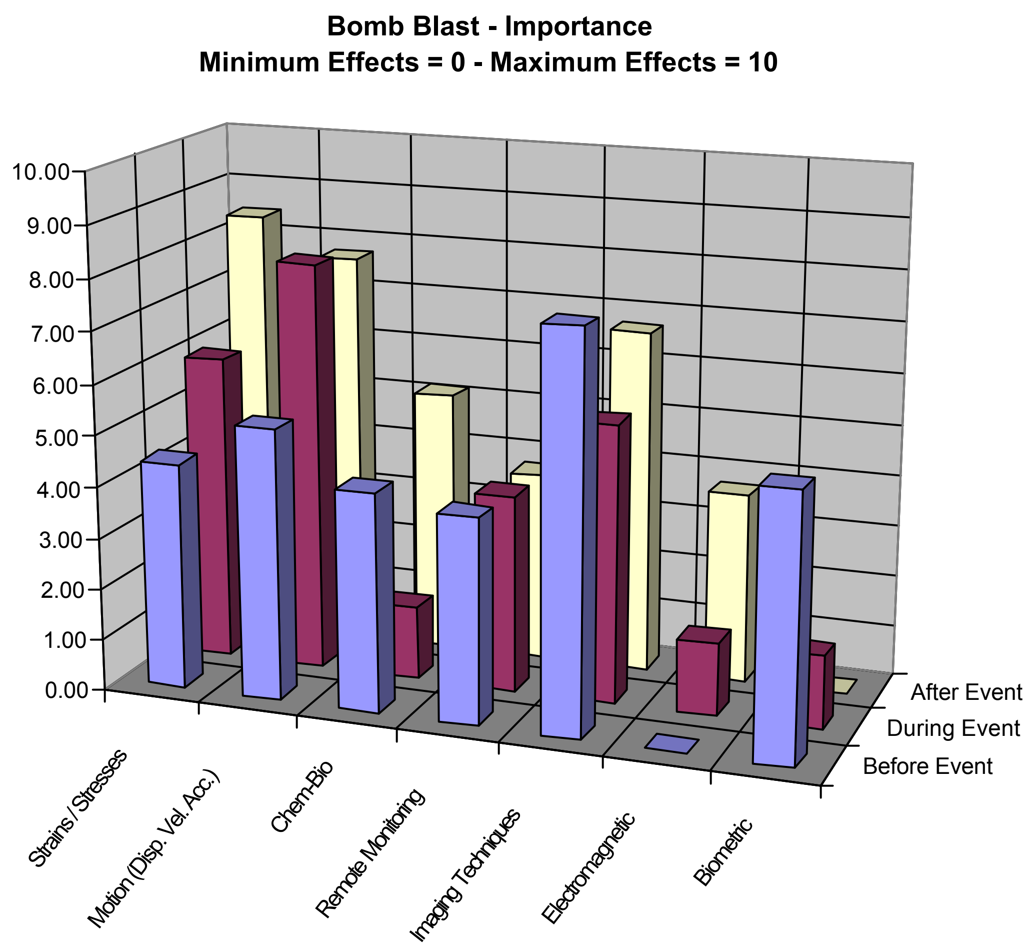

Figure 10 Scores for Importance of SHM for Bomb Blast Events – Timeline Issues

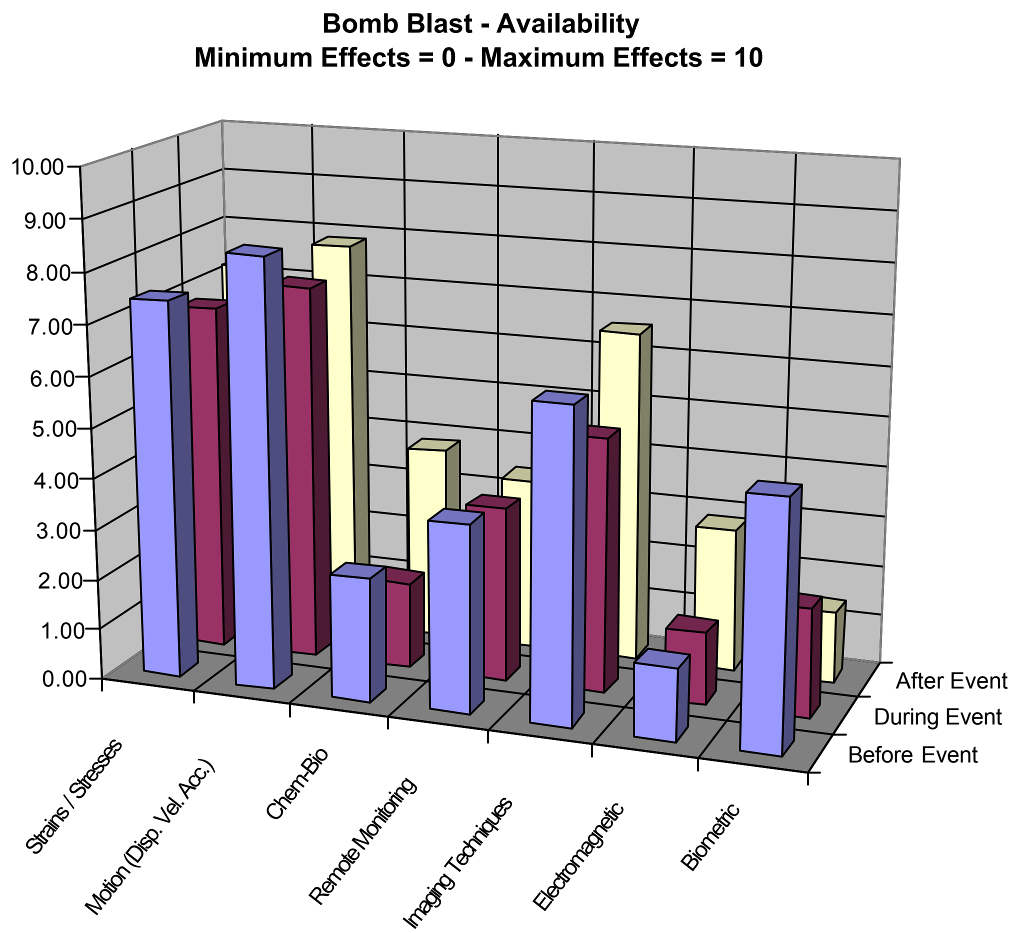

Figure 11 - Scores for Availability of SHM for Bomb Blast Events – Timeline Issues

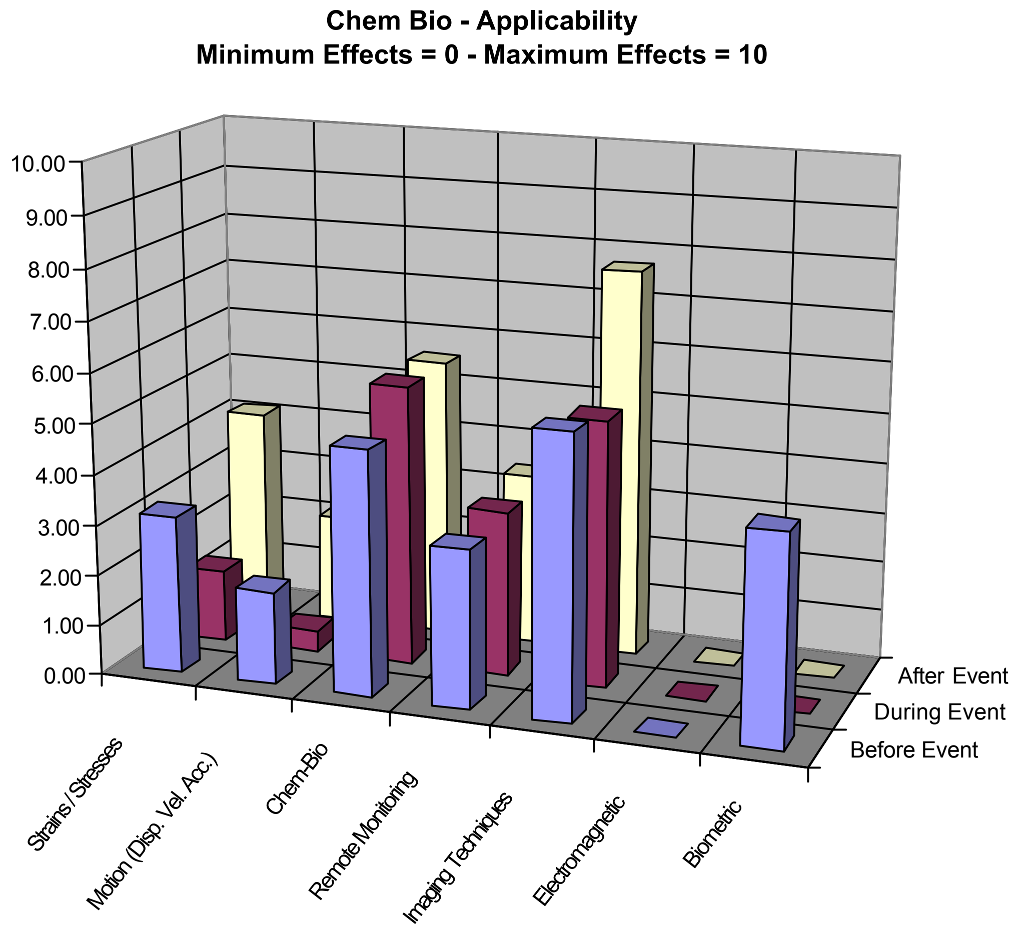

Figure 12 - Scores for Applicability of SHM for Chem-Bio Events – Timeline Issues

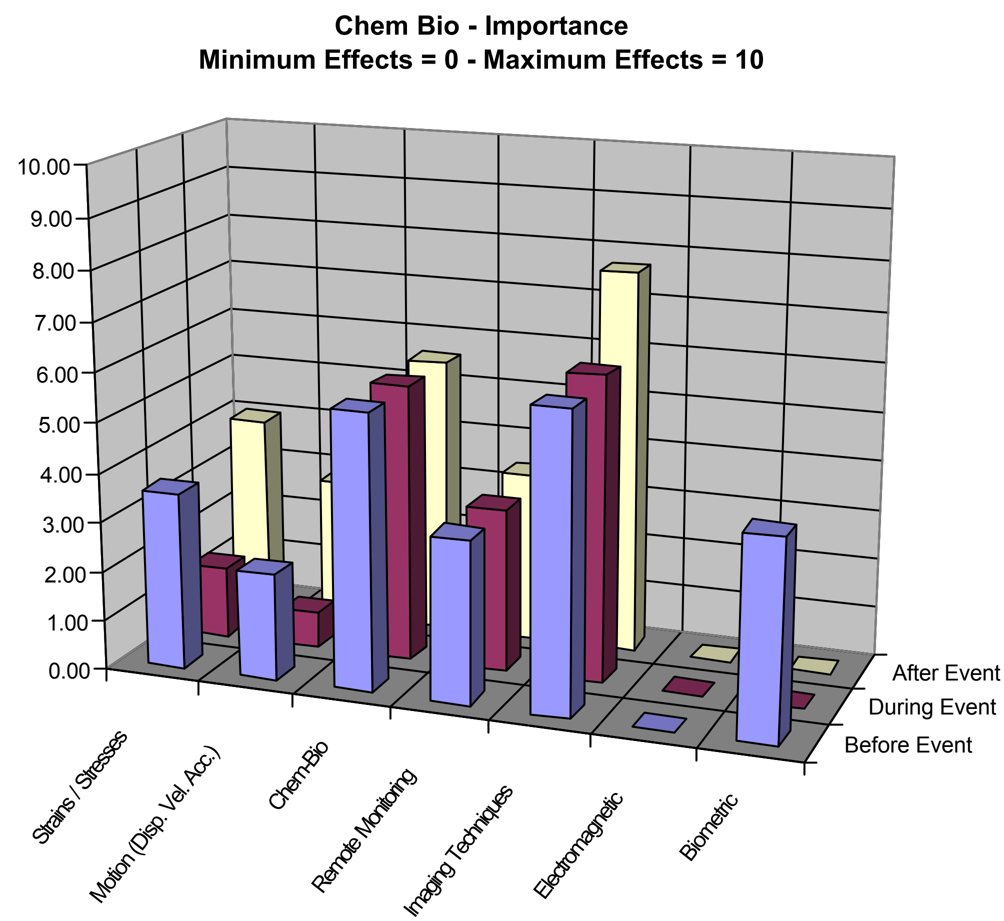

Figure 13 - Scores for Importance of SHM for Chem - Bio Events – Timeline Issues

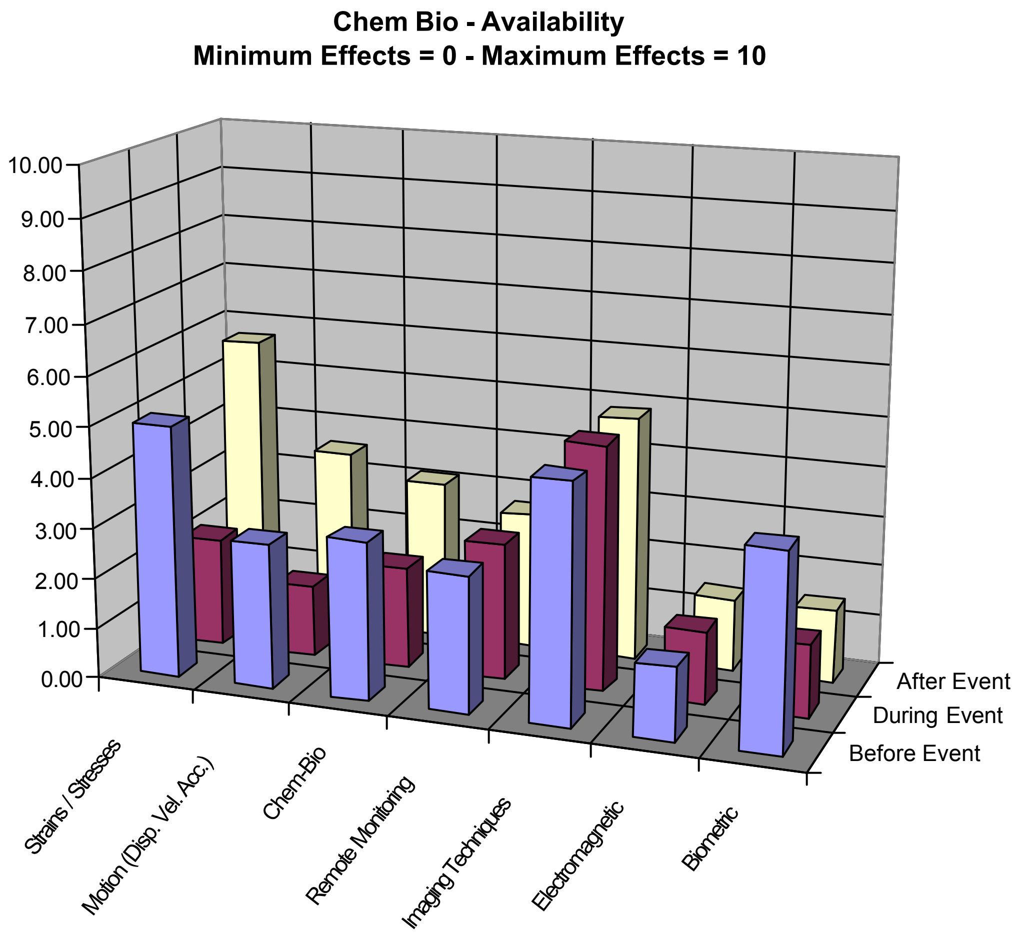

Figure 14 - Scores for Availability of SHM for Chem - Bio Events – Timeline Issues

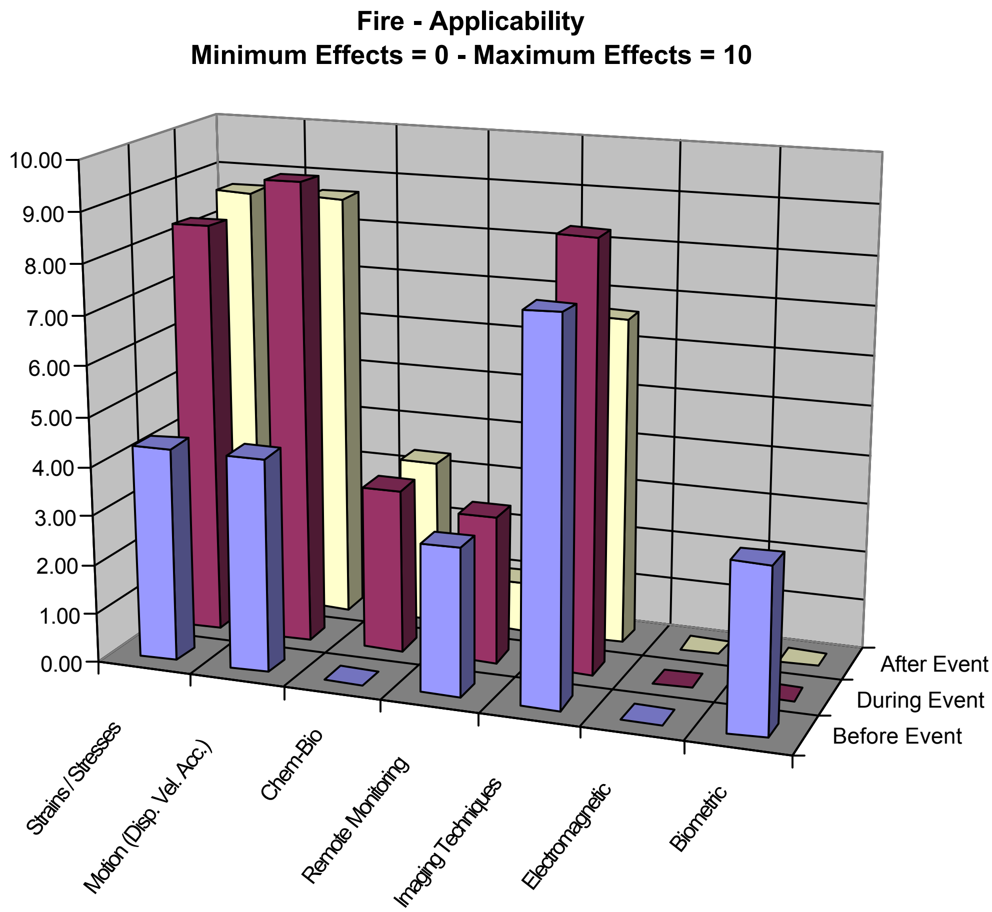

Figure 15 - Scores for Applicability of SHM for Fire Events – Timeline Issues

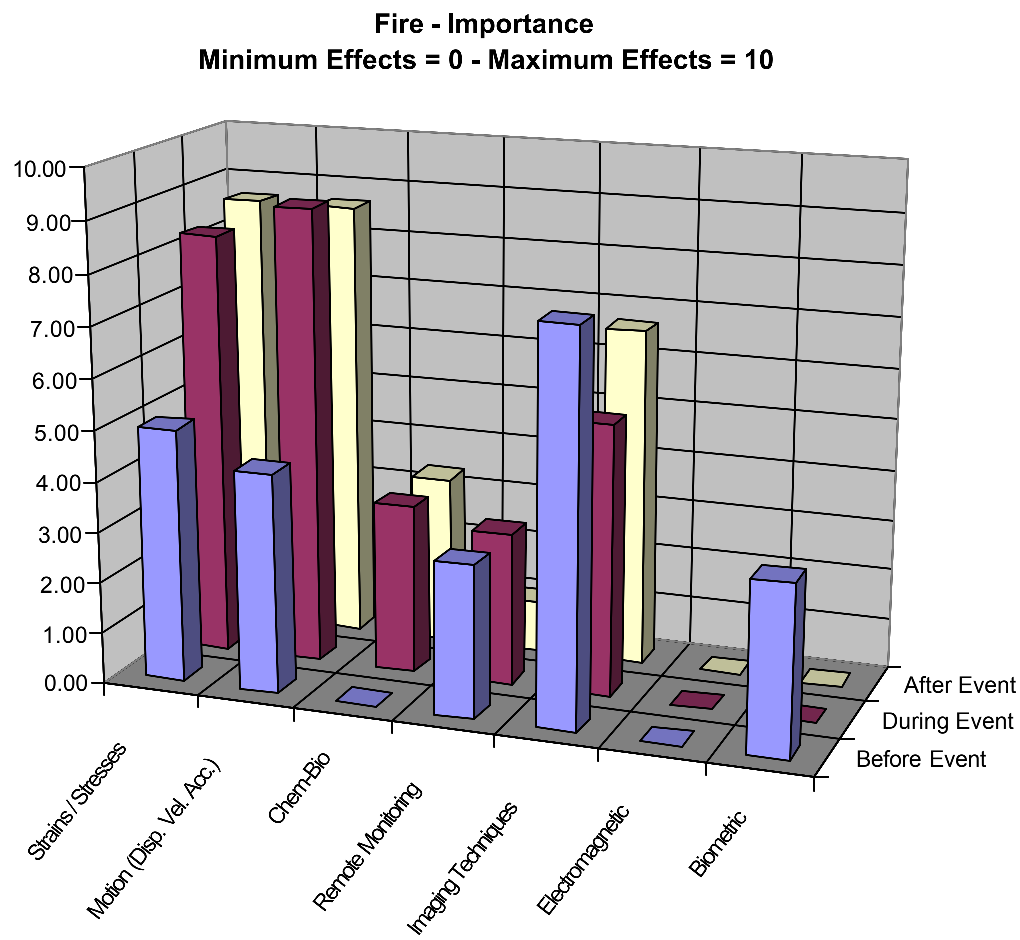

Figure 16 - Scores for Importance of SHM for Fire Events – Timeline Issues

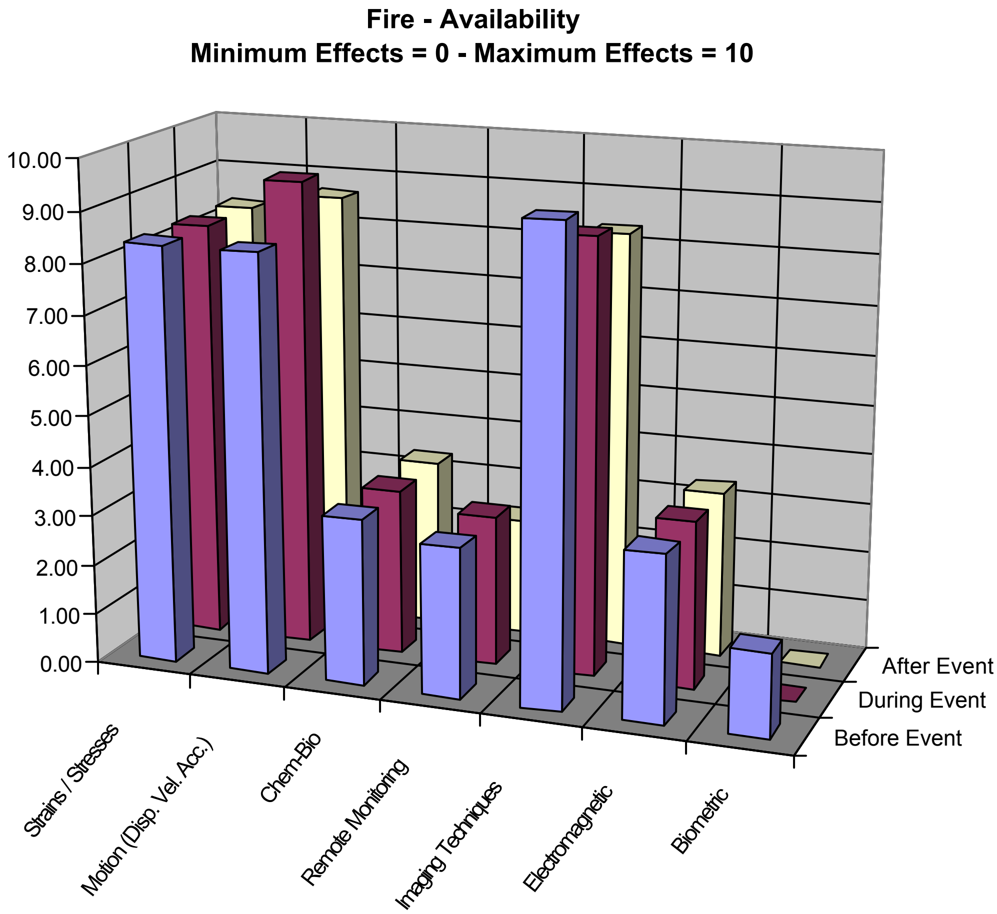

Figure 17 - Scores for Availability of SHM for Fire Events – Timeline Issues

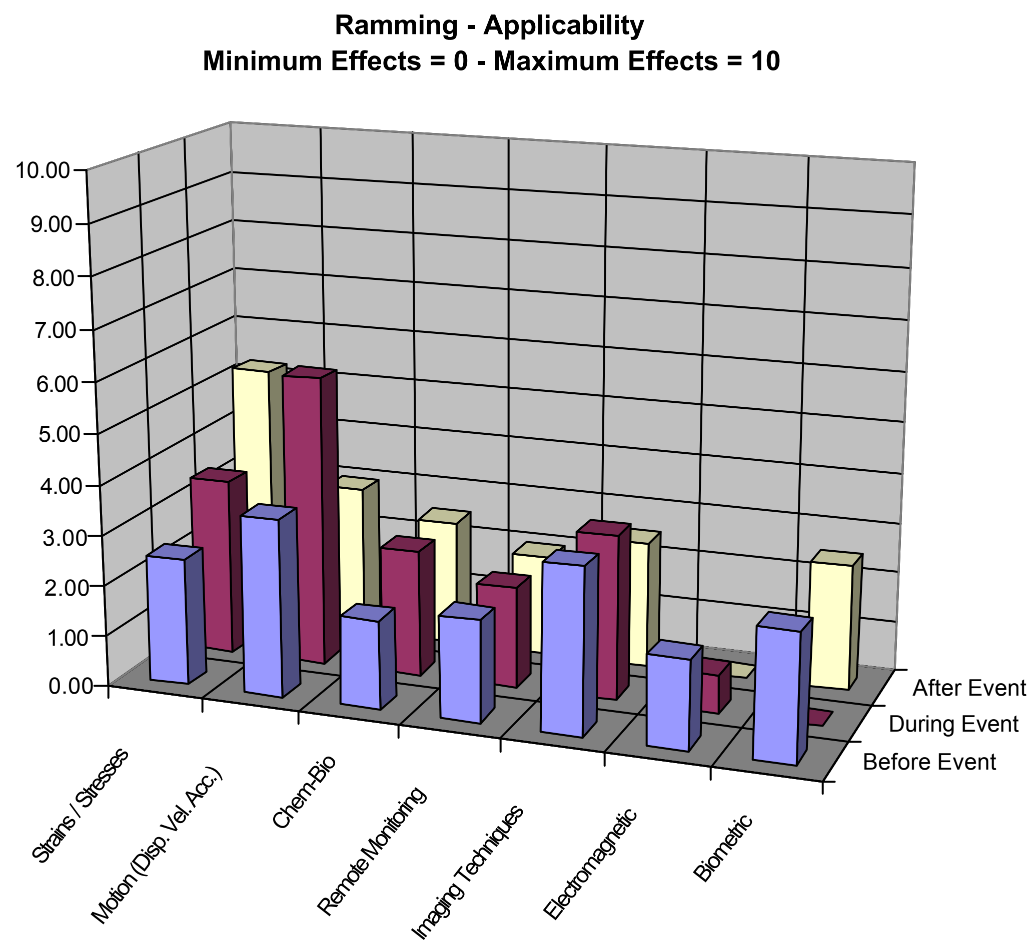

Figure 18 - Scores for Applicability of SHM for Ramming Events – Timeline Issues

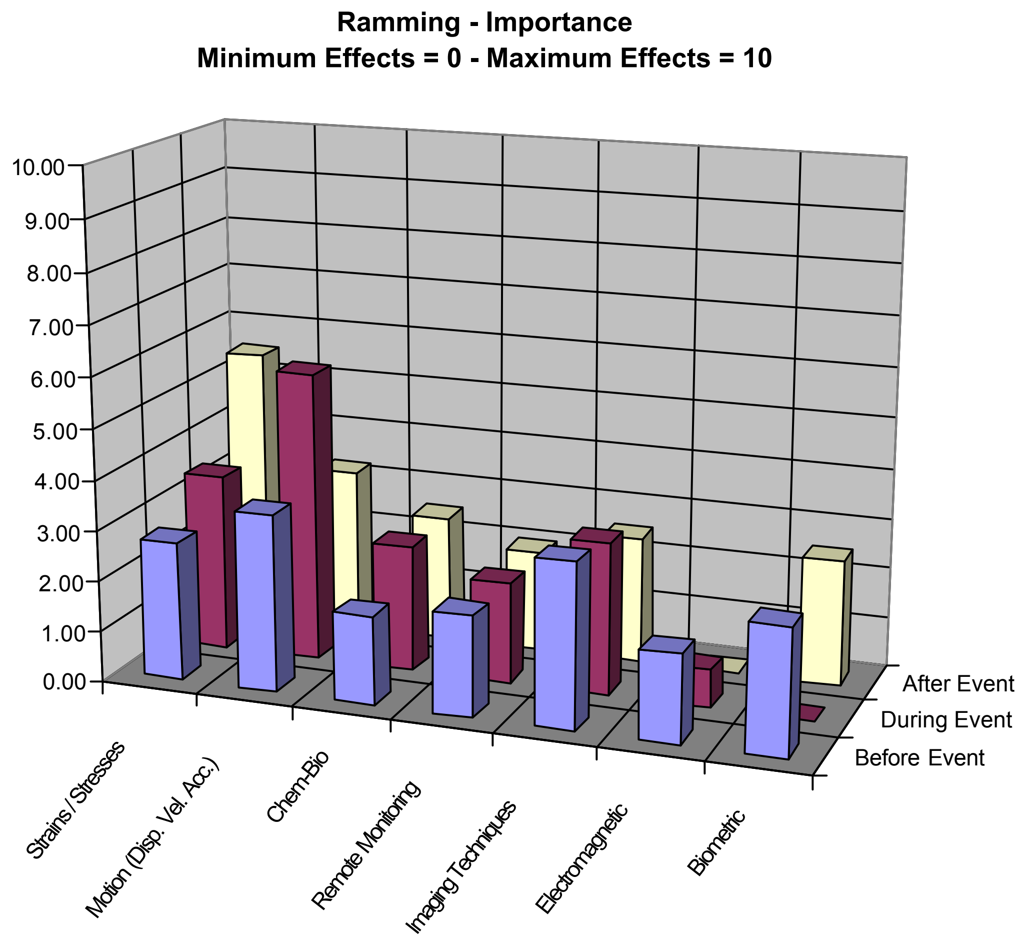

Figure 19 - Scores for Importance of SHM for Ramming Events – Timeline Issues

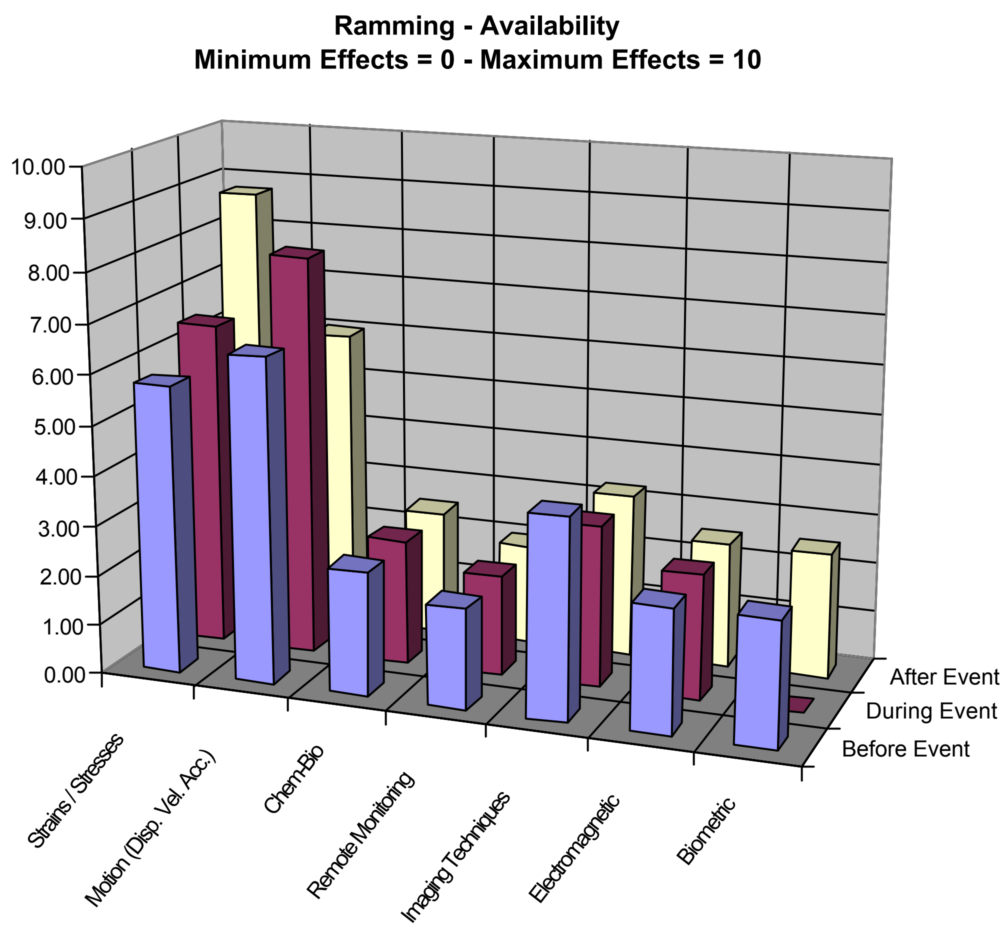

Figure 20 - Scores for Availability of SHM for Ramming Events – Timeline Issues

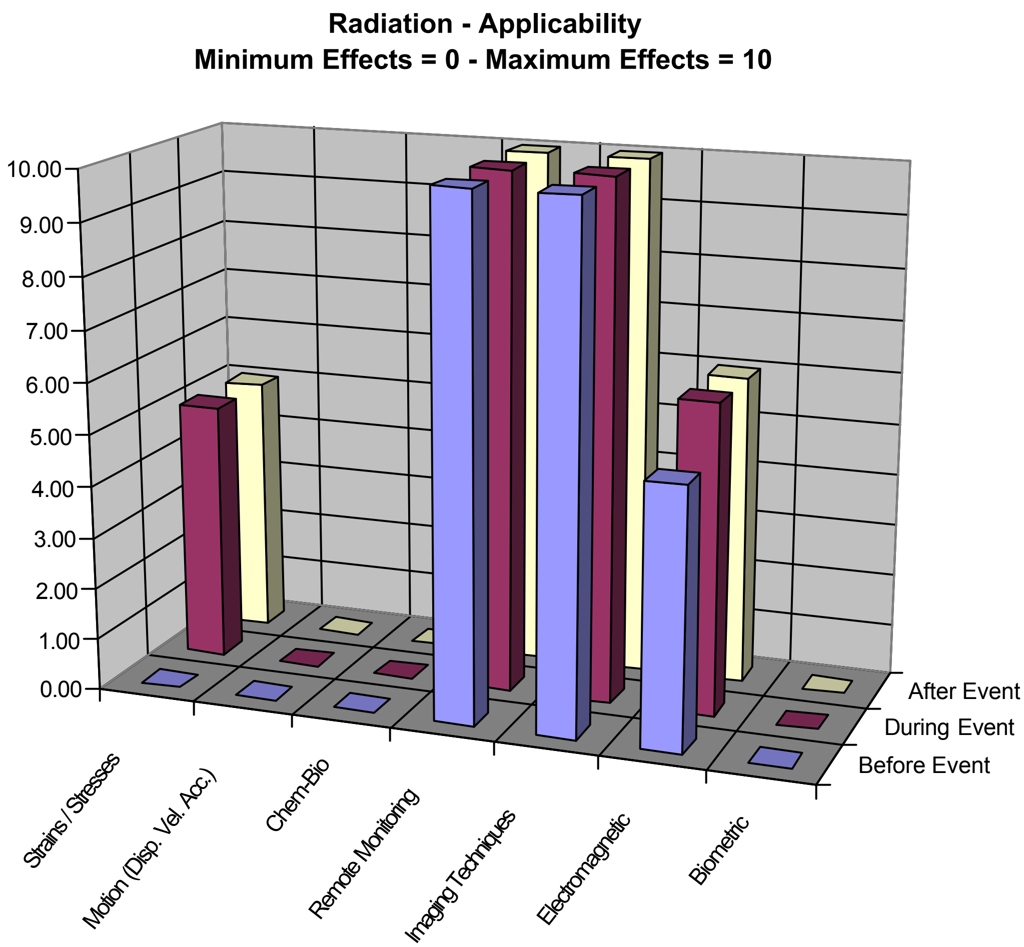

Figure 21 - Scores for Applicability of SHM for Radiation Events – Timeline Issues

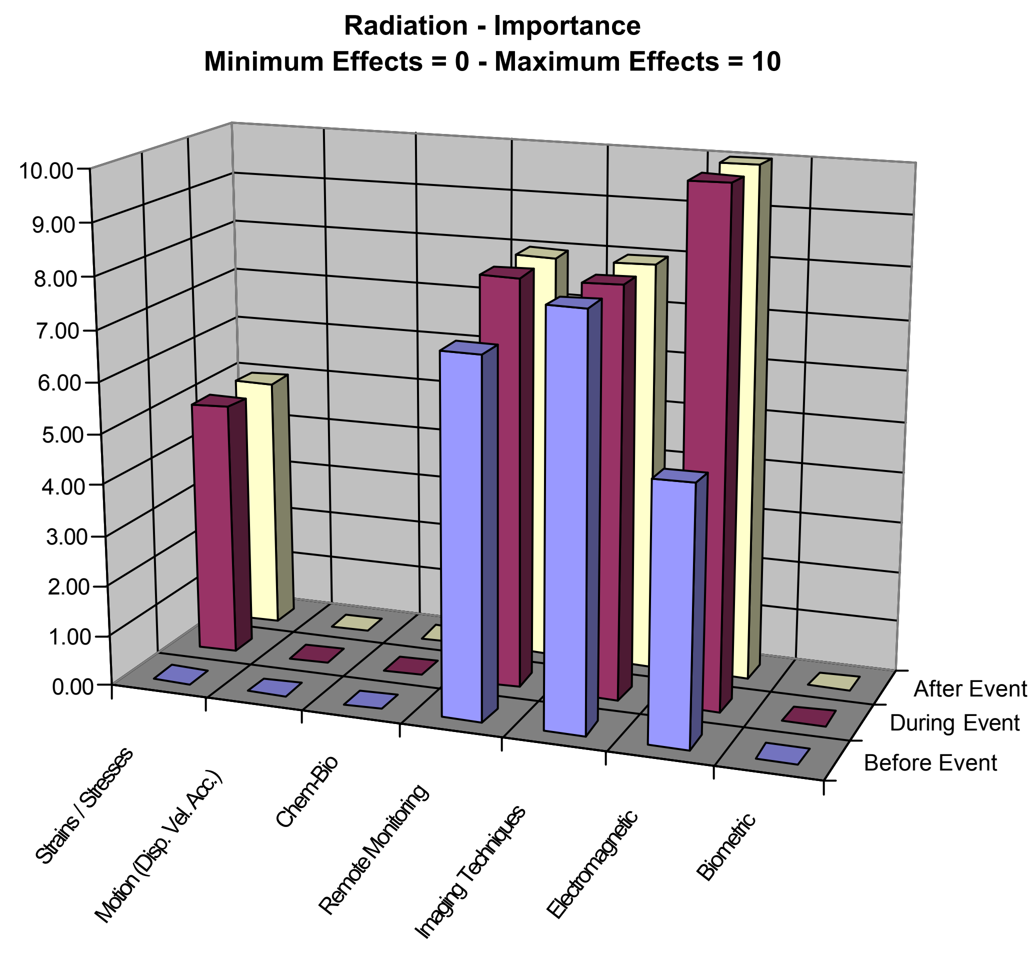

Figure 22 - Scores for Importance of SHM for Radiation Events – Timeline Issues

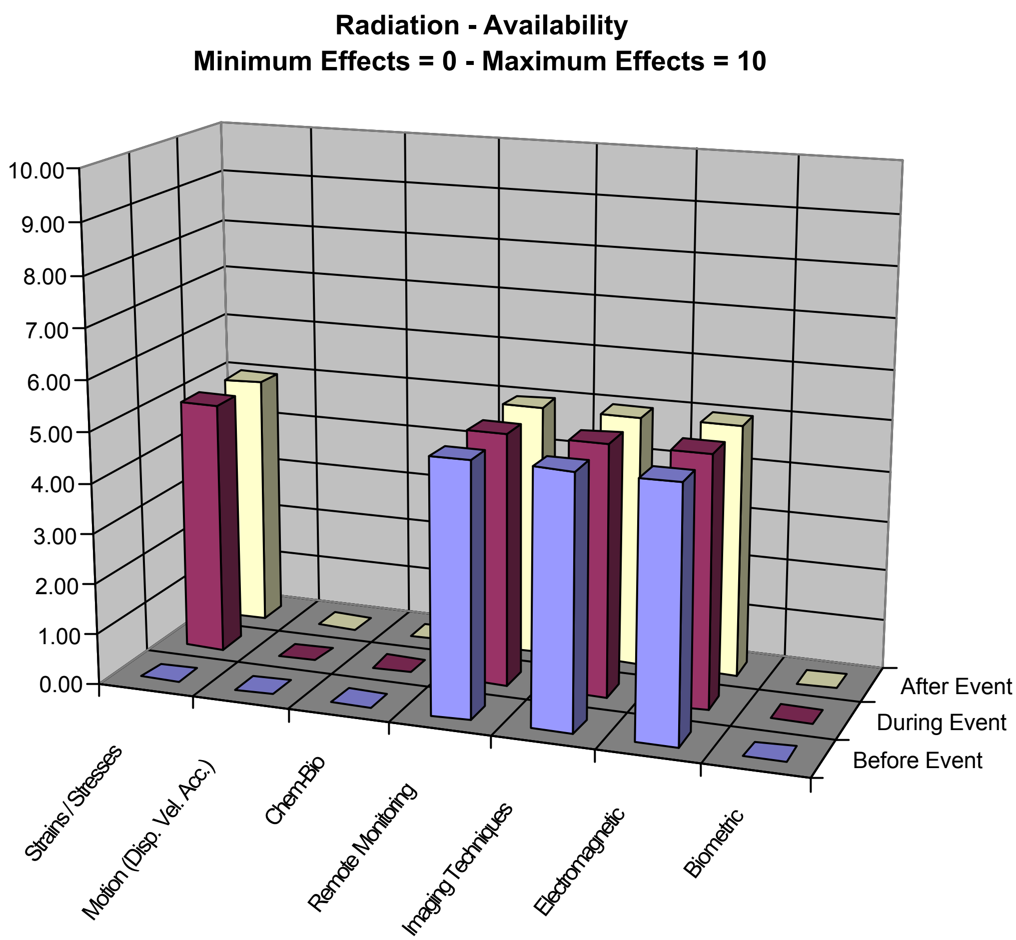

Figure 23 - Scores for Availability of SHM for Radiation Events – Timeline Issues

3.4 Multihazards and Multidisciplines Factors

The concepts of Multihazards and Multidisciplines in infrastructures are emerging as an important concept in analysis, design, and management of bridges. The purpose of this part of the workshop was to assess the role of SHM technologies as a vehicle to improve the interaction between the bridge security field on one hand and other hazards and disciplines on the other hand.

The questions that the attendees were to answer were:

Multihazards:

- **Applicability:** How applicable is the utilization of security-related SHM technologies to the utilization for other hazards?
- **Importance:** How important is the utilization of security-related SHM technologies to the utilization for other hazards?
- **Cost / Benefit:** How high is the cost/benefit of using security-related SHM technologies if utilized for other hazards?

Multidisciplinary:

- **Applicability:** How applicable is the utilization of security-related SHM technologies to the utilization for other disciplines?
- **Importance:** How important is the utilization of security-related SHM technologies to the utilization for other disciplines?
- **Cost / Benefit:** How high is the cost/benefit of using security-related SHM technologies if utilized for other disciplines?

Each attendee was asked to score the answer to those questions with a number between 0 (minimum) and 10 (maximum) using the form shown in Figure 24. The different scores were averaged and tabulated. Table 7, 8 and 9 show all the average scores for Multihazards issue (Appendix IV). Table 10, 11 and 12 show all the average scores for Multidisciplinary issues (Appendix IV).

Figure 25, Figure 26 and Figure 27 show the applicability, importance and cost benefit scores for Multihazards issues. The attendees felt that there are several situations where SHM technologies can be utilized for hazards other than security of bridges. It is also believed that cost/benefit could justify the integrated usage of SHM technologies for several hazards (see Figure 27).

Figure 28, Figure 29, and Figure 30 show the applicability, importance and cost benefit scores for Multidisciplines issues. Unlike Multihazards, the use of SHM technologies across different security-related disciplines seems to be selective and varied. This is also reflected in the cost / benefit (see Figure 30). This indicates careful planning and understanding of the interaction between various disciplines in their use of SHM technologies is needed. With such planning and understanding, the efficient use of SHM technologies can be accomplished.

Multihazards / Multidisciplinary - SHM Technology
Rate: Applicability / Importance / Cost-Benefit: Minimum = 0 – Maximum = 10

		Strains / Stresses	Motion (Disp, Vel, Acc)	Chem-Bio Agents	Remote Monitoring	Imaging Techniques	Electromagnetic	Biometric
Multihazards	**Seismic**							
	Wind							
	Flood - Scour							
	Impact - Traffic							
	Normal Deterioration							
	Corrosion							
Multidisciplinary	**Police**							
	Fire							
	Emergency Management							
	Other Engineering Fields?							
	Other?							
	Other?							

Figure 24 - Form for SHM Technology and Multihazards / Multidisciplinary Issues

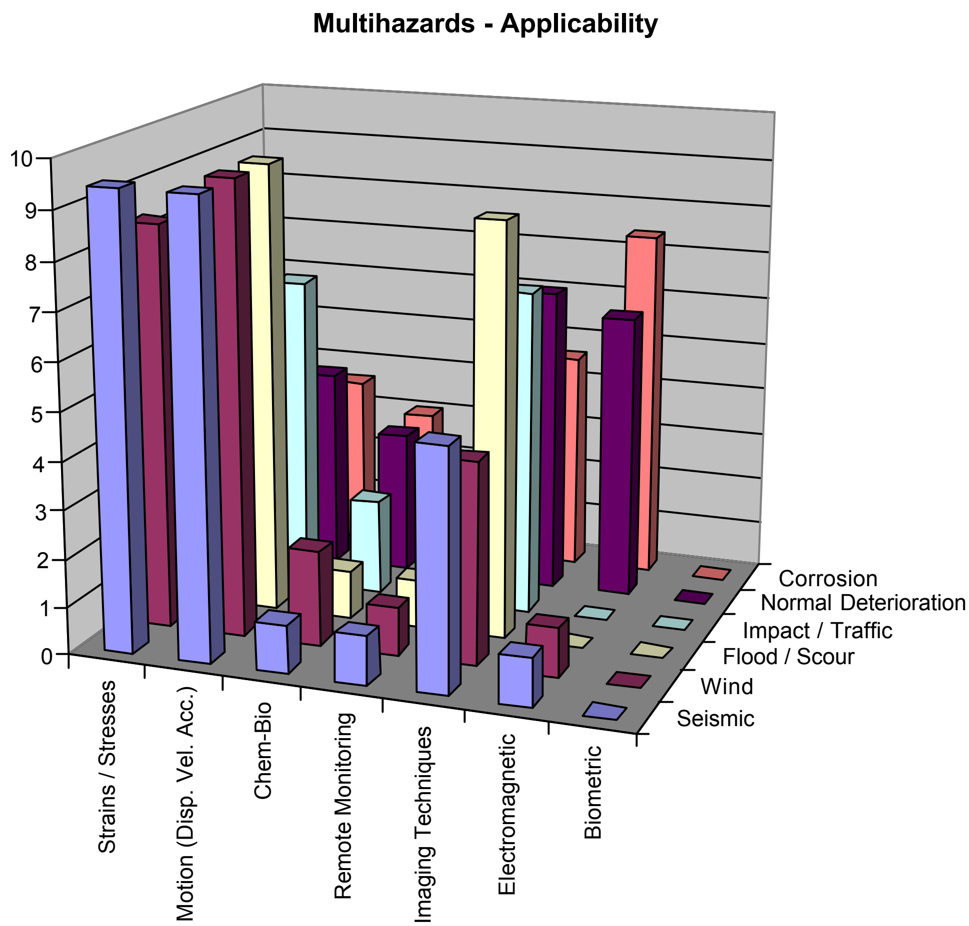

Figure 25 - Scores for Applicability of SHM for Multihazards Issues

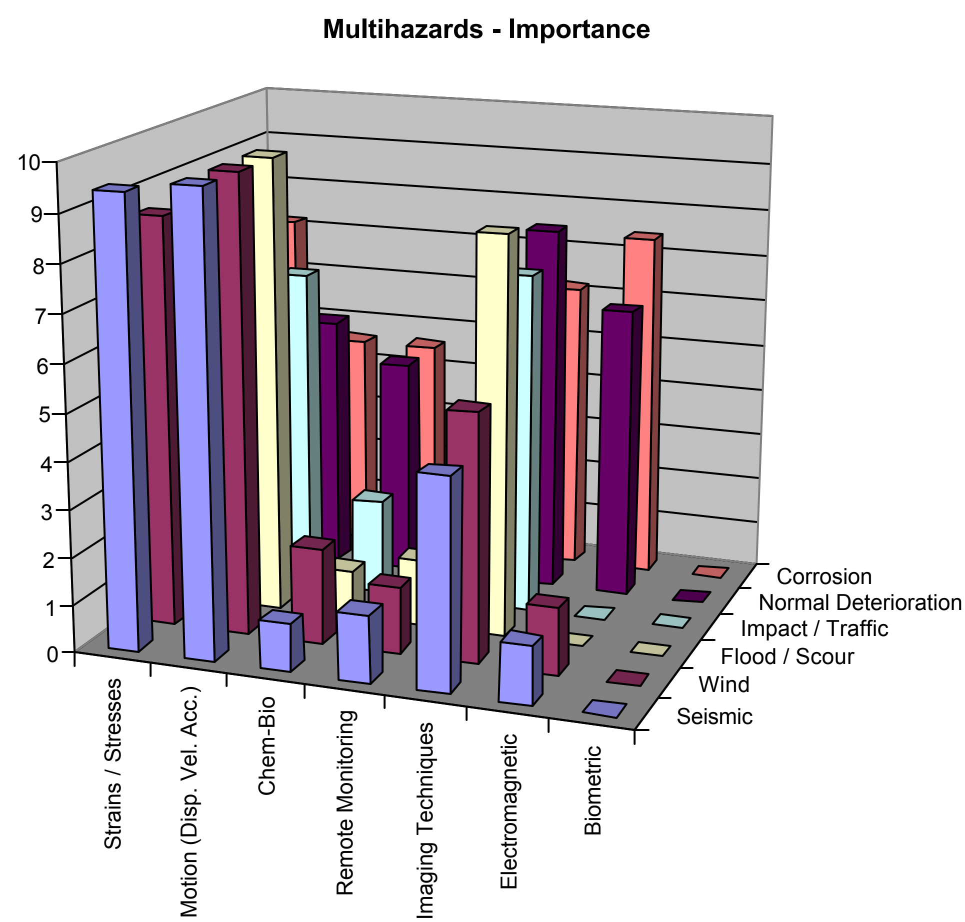

Figure 26 - Scores for Importance of SHM for Multihazards Issues

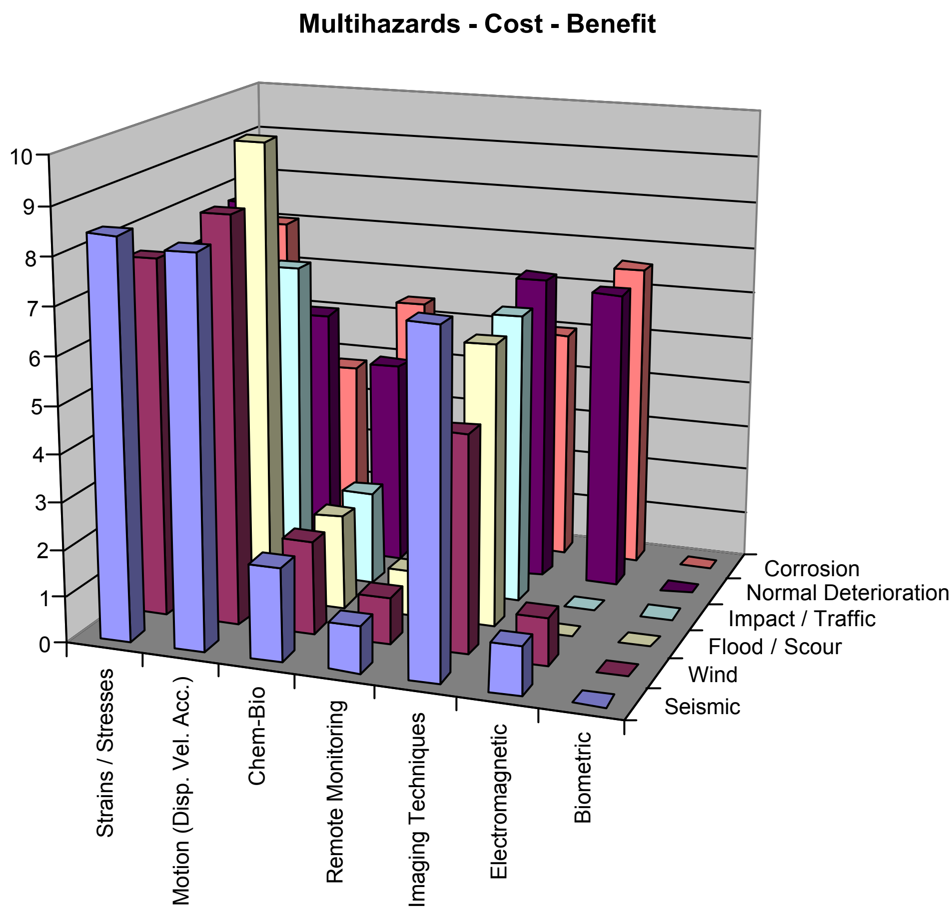

Figure 27 - Scores for Cost-Beneift of SHM for Multihazards Issues

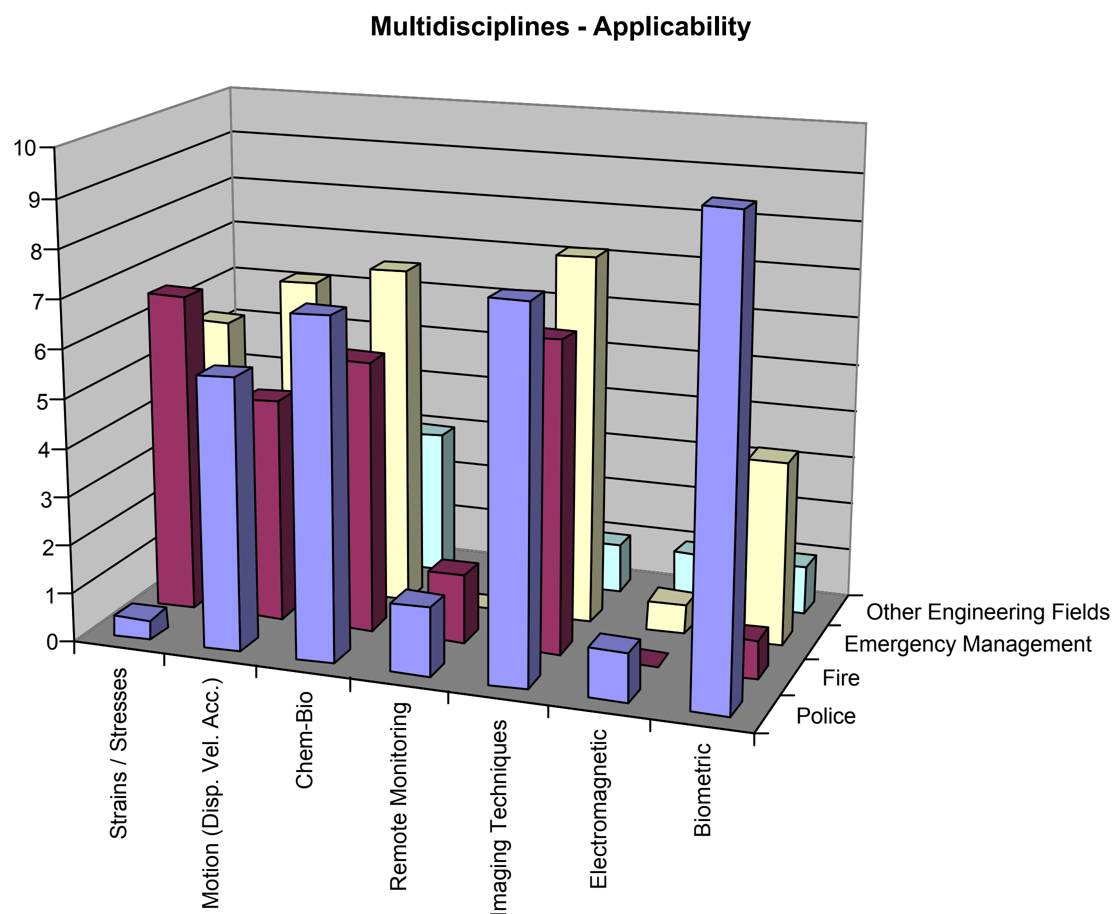

Figure 28 - Scores for Applicability of SHM for Multidisciplinary Issues

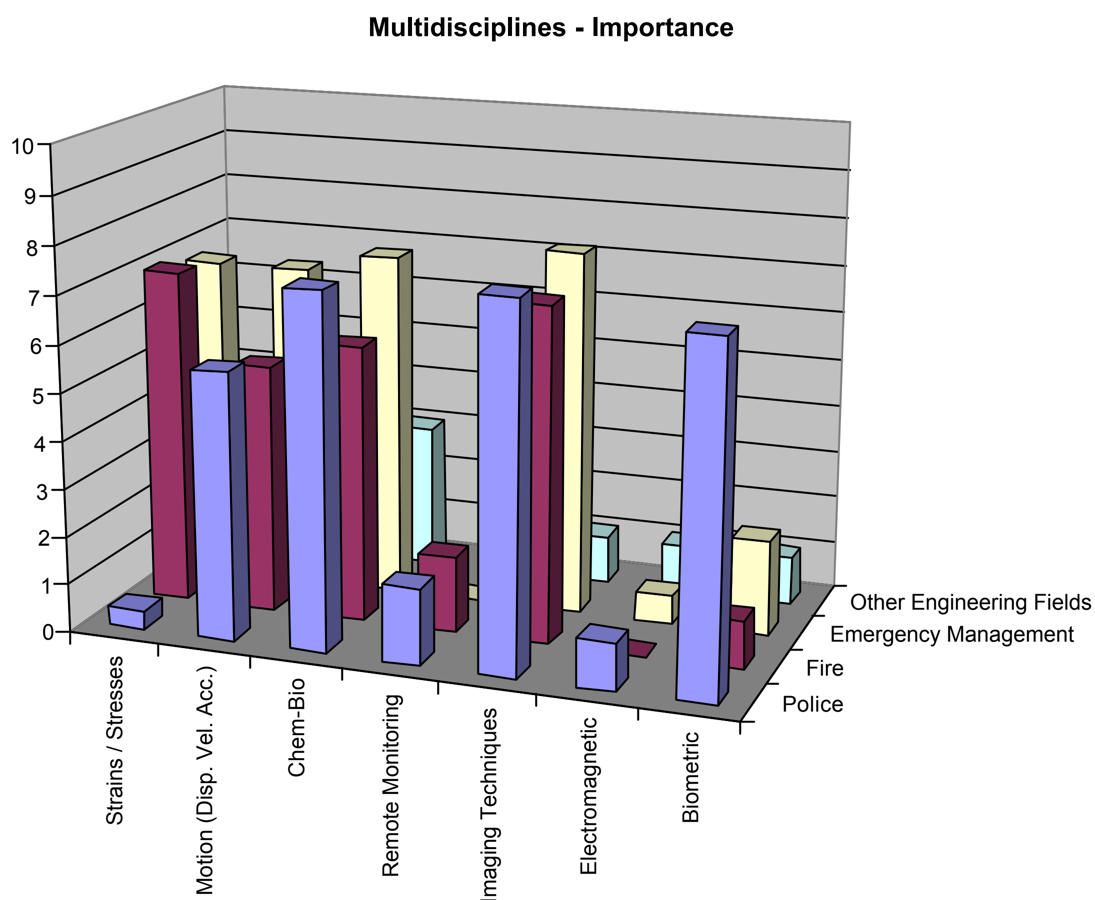

Figure 29 - Scores for Importance of S HM for Multidisciplinary Issues

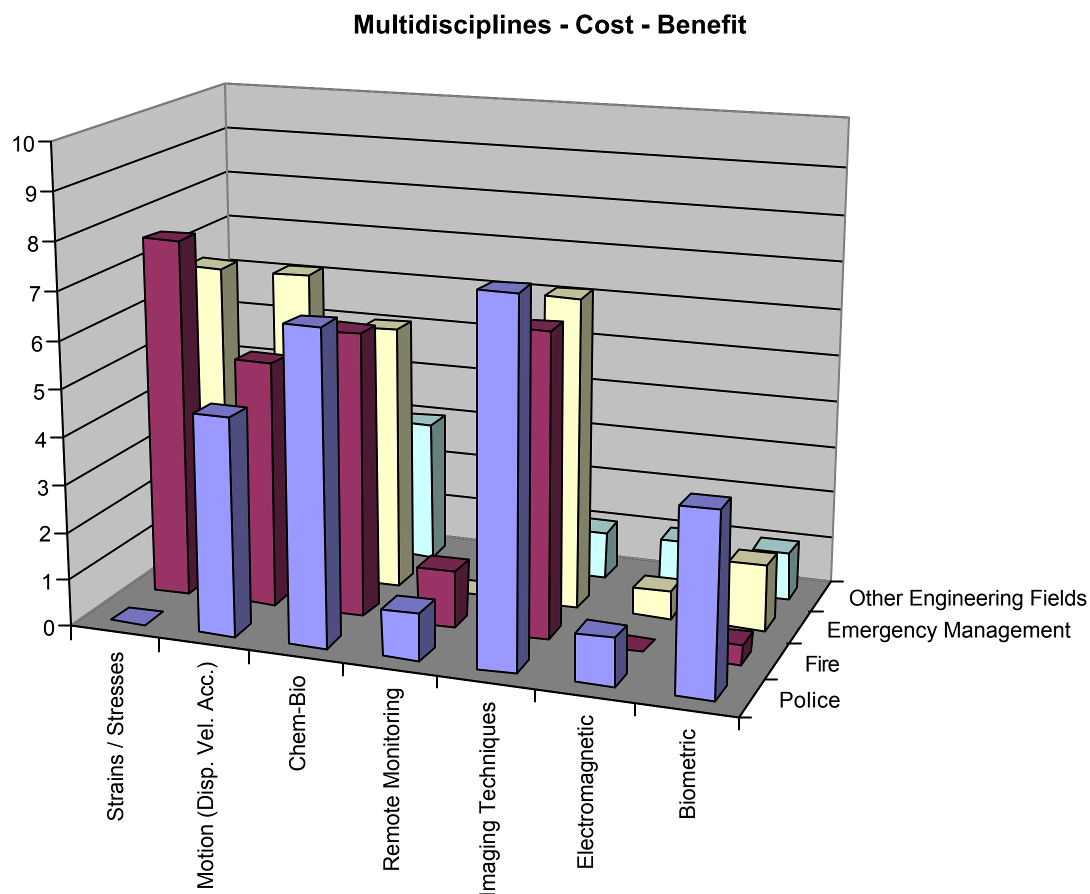

Figure 30 - Scores for Cost-Benefit of SHM for Multidisciplinary Issues

3.5 Current and Future Use of SHM Technologies

This part of the workshop explored the use of SHM technologies as related to several general security-related issues, both at present and in the future. The questions that were given to the attendees for applicability of present use were:

- How applicable is the present utilization of security-related SHM technologies for practice in the bridge community?
- How applicable is the present utilization of security-related SHM technologies for research in the bridge community?
- How applicable is the present utilization of security-related SHM technologies in affecting costs of operations?
- How applicable is the present utilization of security-related SHM technologies in providing benefit (how much security is gained?)?
- How applicable is the present utilization of security-related SHM technologies in affecting perceived value (public's perceived security)?
- How applicable is the present utilization of security-related SHM technologies in affecting actual value (public's actual security)?

Similar sets of questions for current importance, future applicability and future importance were given to the attendees. Each attendee was asked to score the answer to those questions with a number between 0 (minimum) and 10 (maximum) using the form shown in Figure 31. The different scores were averaged and tabulated and shown in Table 13 and 14 in Appendix V.

Figure 32 and Figure 33 show the scores for present and future applicability. Figure 34 and Figure 35 show the scores for present and future importance. It is clear that the attendees felt that the SHM technology usage would increase in both applicability and importance in the future. All branches of SHM technologies are judged to be important and applicable in all fields, albeit to varying degrees. It also seems that the cost is always judged to be of higher importance than the benefit. This is in contradiction with an earlier finding where safety was judged to be more important than cost. Further investigation is warranted on this point. Another interesting scoring is that the perceived value seems to always be more important and applicable than actual value, as judged by the attendees; a finding that needs further investigation.

Current / Future Issues - SHM Technology
Rate: Applicability / Importance: Minimum = 0 – Maximum = 10

		Strains / Stresses	Motion (Disp, Vel, Acc)	Chem-Bio agents	Remote Monitoring	Imaging Techniques	Electromagnetic	Biometric
Current	Practice							
	Research							
	Cost							
	Benefit (how much security?)							
	Value, Perceived							
	Value, Actual							
Future	Practice							
	Research							
	Cost							
	Benefit (how much security?)							
	Value, Perceived							
	Value, Actual							

Figure 31 - Form for SHM Technology and Current/Future Issues

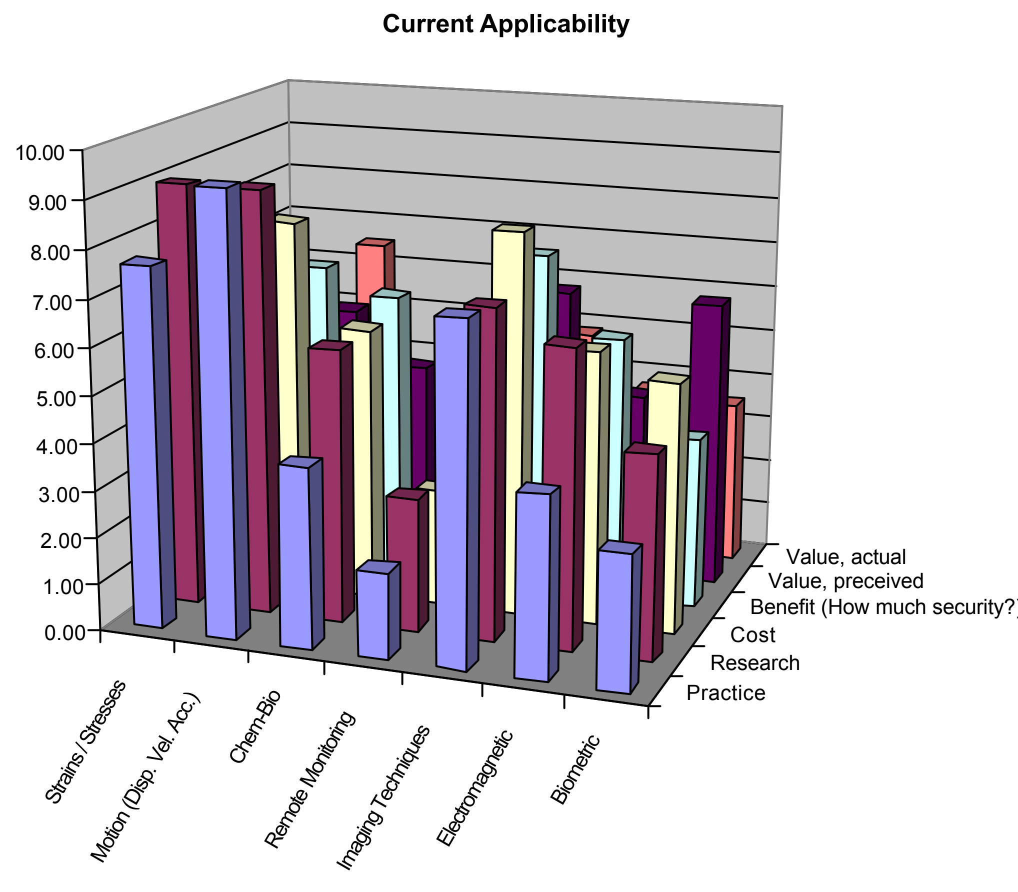

Figure 32 - Scores for Applicability of SHM for Current Issues

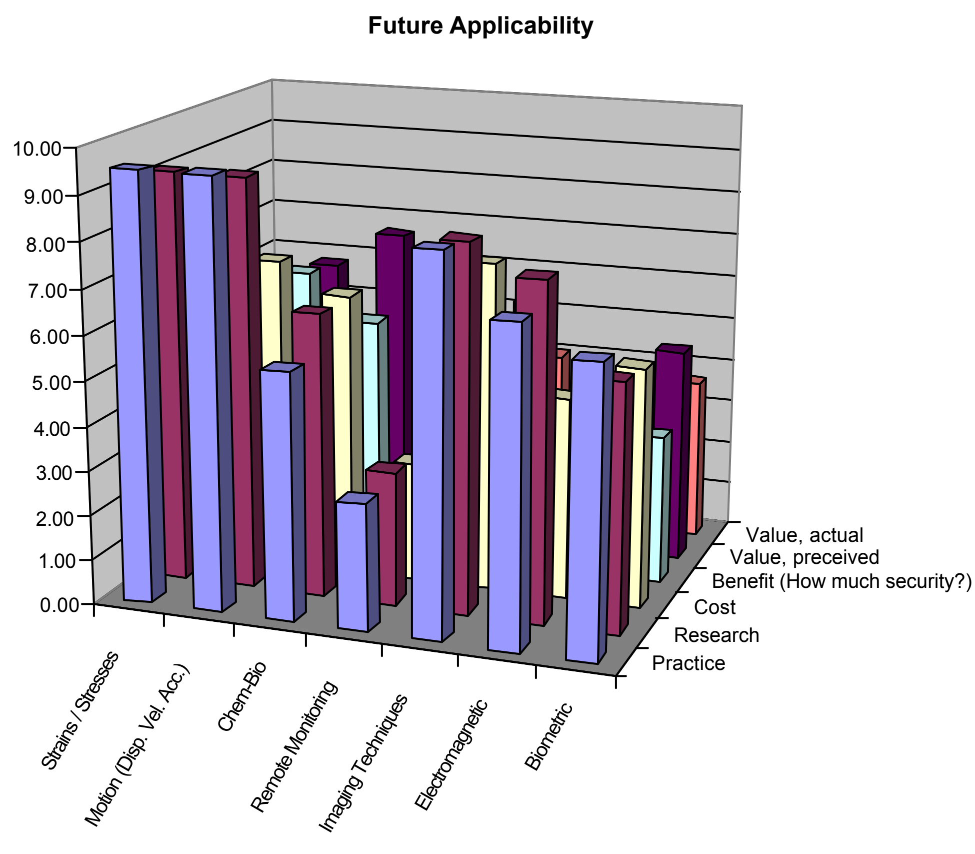

Figure 33 - Scores for Applicability of SHM for Future Issues

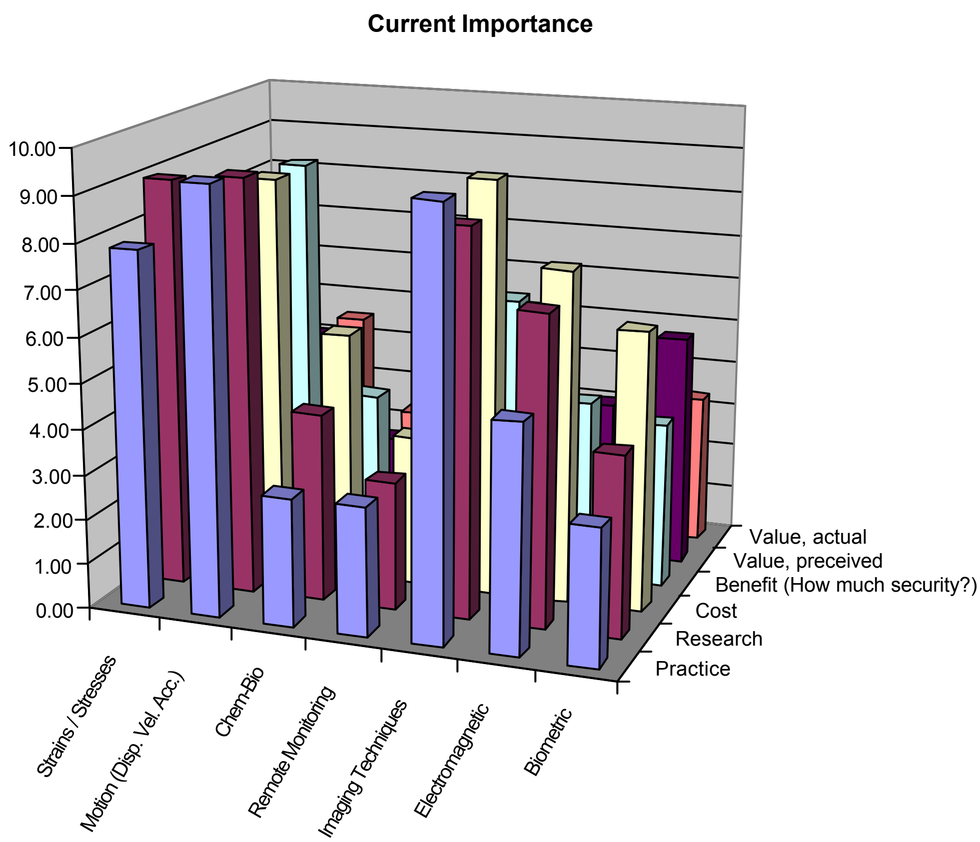

Figure 34 - Scores for Importance of SHM for Current Issues

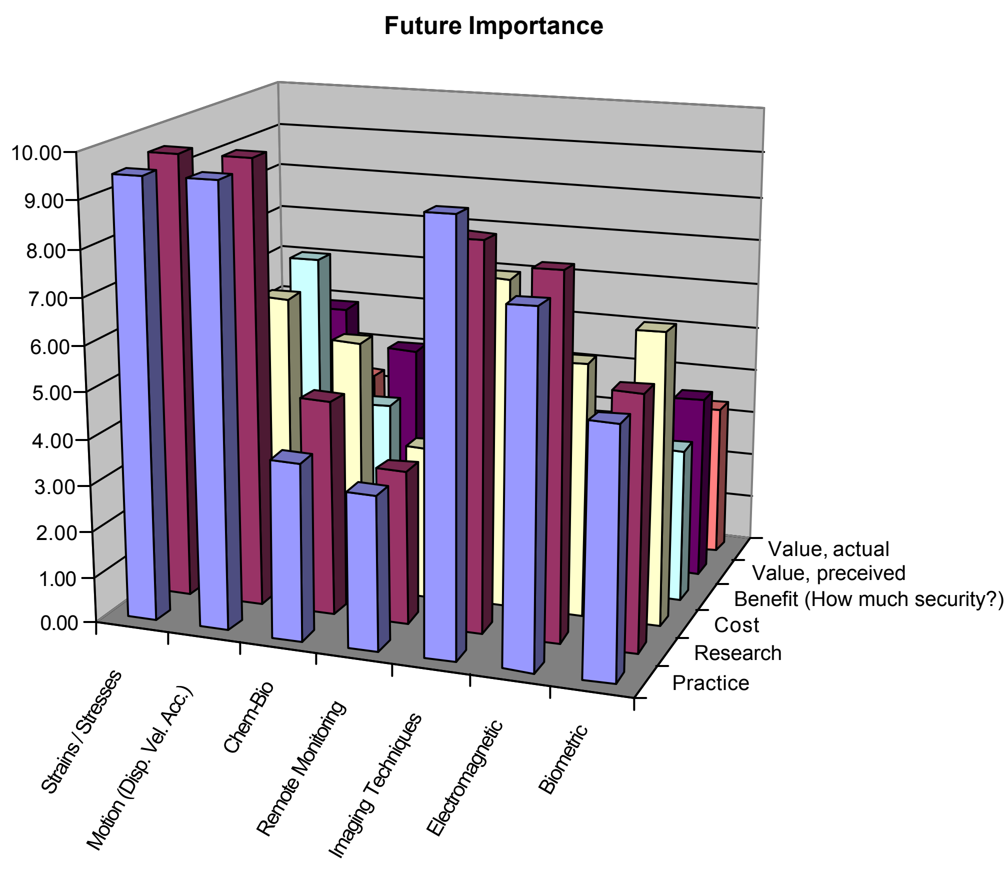

Figure 35 - Scores for Importance of SHM for Future Issues

3.6 Interaction Between Stakeholders

The interaction between stakeholders in the SHM-Bridge security fields are explored in this section of the workshop. The following stakeholders were identified to have interest in the SHM-Bridge Security field.

- Bridge Owners
- Federal Government
- Research Community
- Consultants
- Manufacturers (SHM technologies)
- Security Professionals (Police, Federal Agencies, etc.)

The following three questions were given to the attendees to deliberate and they were asked to score the answer with a number between 0 (minimum) and 10 (maximum) using the form shown in Figure 36.

- How applicable is the interaction between two stakeholders in the security-SHM fields?
- How important is the interaction between two stakeholders in the security-SHM fields?
- How do you rate the current interaction practice between two stakeholders in the security-SHM fields?

The different scores were averaged and shown in Table 15, Table 16 and Table 17 of Appendix VI.

In order to compare applicability, importance and current practice, the averages of Table 15, Table 16, and Table 17 were averaged. The overall averages for the three metrics are shown in Figure 37. As expected, the attendees seemed to agree that interactions are both applicable and important. Not surprisingly, attendees also seemed to feel that the current interaction practice between the stakeholders has room for improvement.

The rows of each of the tables (Table 15, Table 16 and Table 17) were averaged to further study the data in these tables. These averages indicate the state of interaction between each stakeholder with all other stakeholders (see Figure 38.) Even though the applicability and importance of interactions between all stakeholders are apparent, the interaction between owners and the security professionals with other stakeholders seemed more applicable and important than others.

Stakeholders Interaction

Please enter comments in appropriate cells, use additional sheets if needed

Due to the symmetry of the matrix, only upper triangle is needed

	Owners	Federal Government	Research / Academic	Consultants	Manufacturers	Physical Security
Owners	N.A.					
Federal Government		N.A.				
Research / Academic			N.A.			
Consultants				N.A.		
Manufacturers					N.A.	
Physical Security						N.A.

Figure 36 - Form for SHM Technology and Stakeholders Interaction

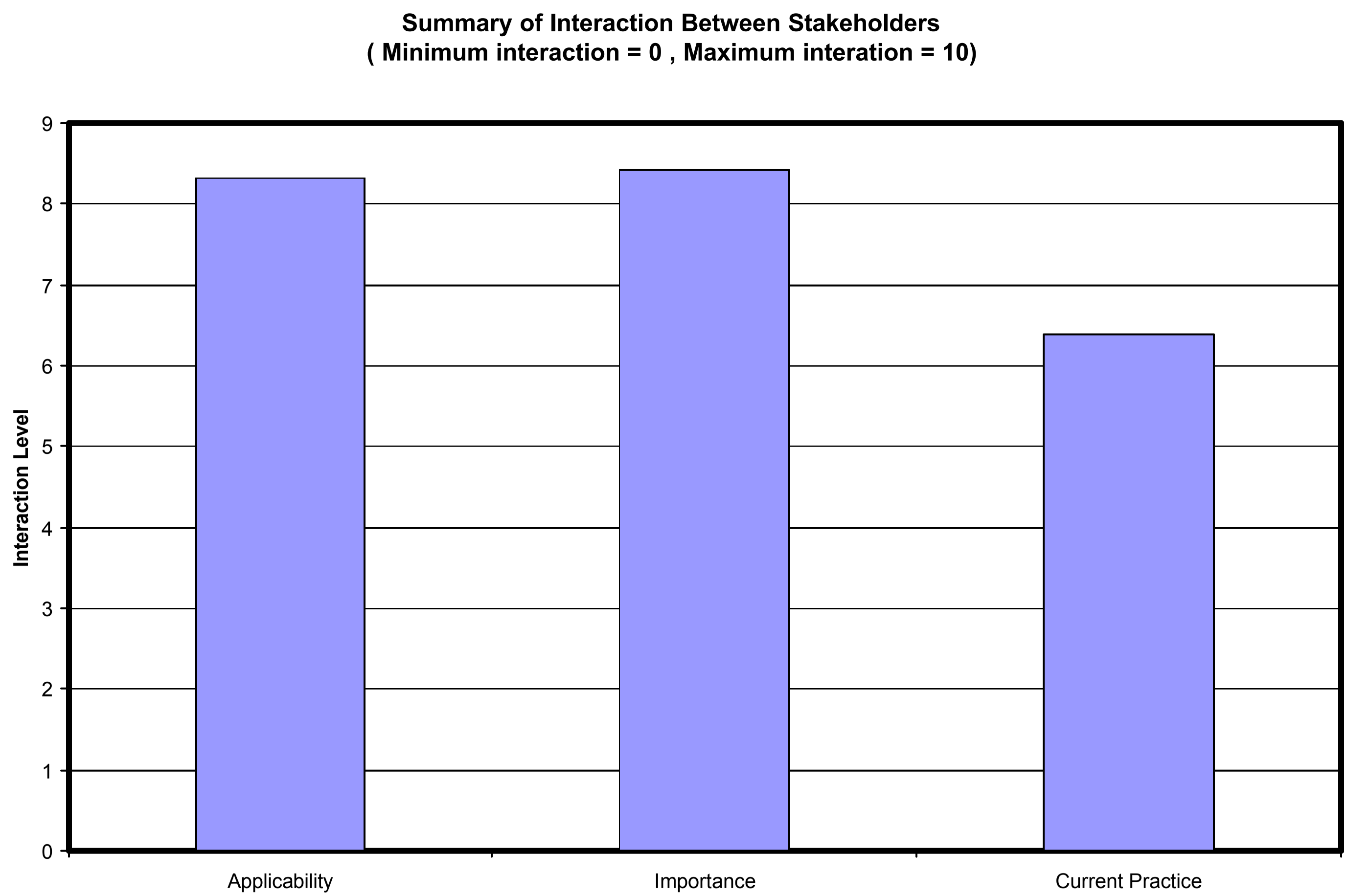

Figure 37 - Scores for Interaction Between Stakeholders: SHM and Bridge Security Issues (Overall)

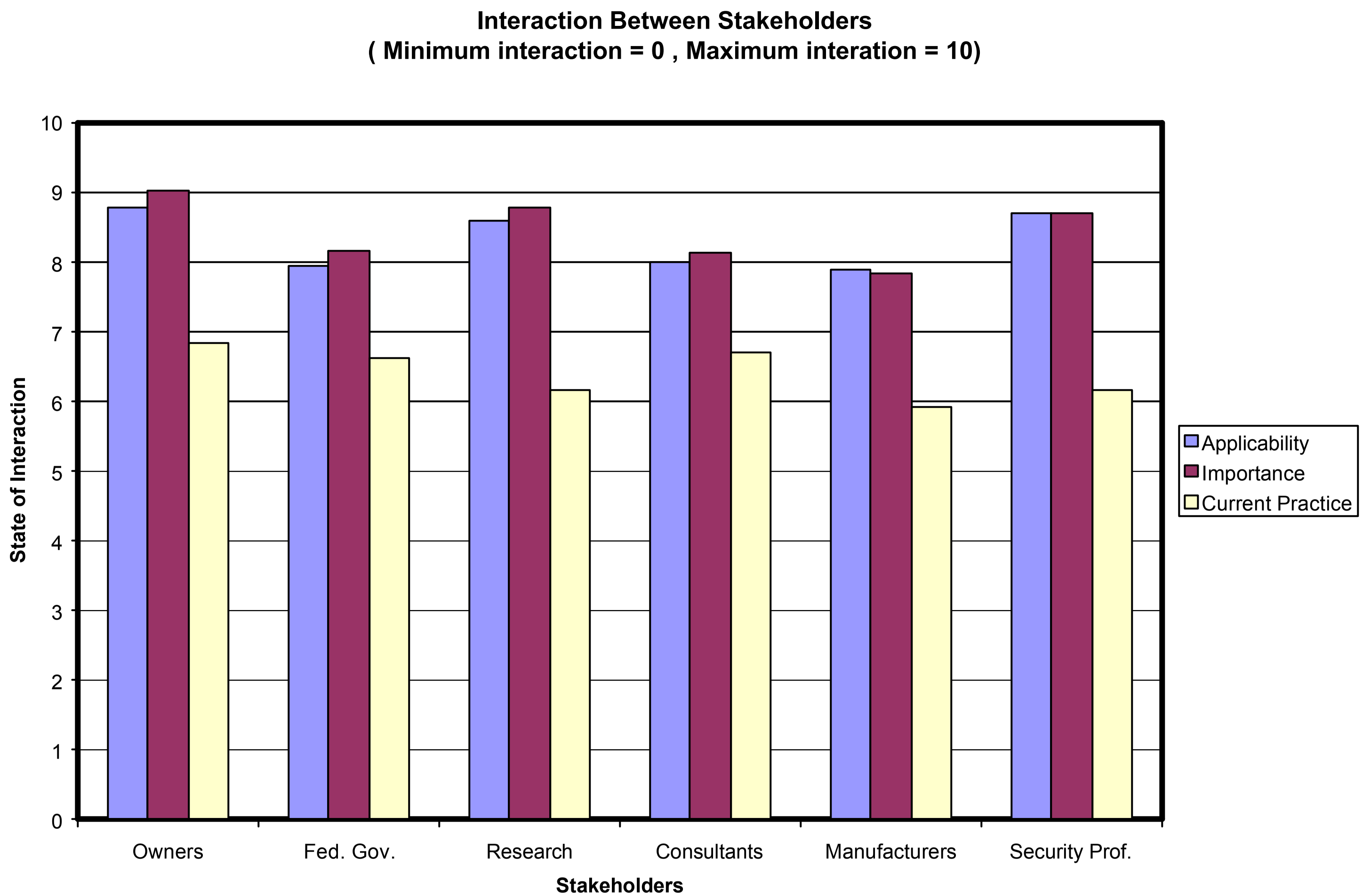

Figure 38 - Scores for Interaction Between Stakeholders: SHM and Bridge Security Issues (Detailed)

4 SOME COMMENTS FROM ATTENDEES

At the end of the workshop, all attendees were asked to comment on SHM and bridge security. In particular, each attendee was asked to mention three lessons learned during the deliberations of the workshop and to present three specific suggestions for the future in the area of SHM and bridge security.

A summary of those lessons learned and future suggestions is presented below. For privacy reasons, the names of the attendees are not given.

Attendee # 1

We are still trying to do Technology Transfer. We should not try to force-fit. We are making headway and we have a ways to go.

Take multi-disciplinary approach from the beginning. Involve law enforcement and others from the beginning.

Engineers should change their culture - from black and white to gray areas.

SHM and security overlap. Try to get multiple hits and try to get more benefits from security work.

Don't lose sight of practicality. Have the end product in your sights.

Opportunities in sensor technologies can be used for after events, where event may not just be the security threat. Transportation is still the key for recovery operations and hence be knowledgeable of various scenarios such as primary and secondary threats.

Attendee # 2

It is nice to see other peoples' views.

We still have a long way to go.

Keep an open mind on new technologies. If something does not work, be open minded, and evaluate in the future as needed.

You may not need complex models always. Explore other Structural Identification options from other fields and apply them to Civil Engineering issues. Civil Engineers should not be afraid of exploring other options.

Attendee # 3

Liked the format of matrix nature except for remote monitoring column, which is an enhancement of other columns.

What does the term "redundancy" mean? It is great and needed always, but if it is not used in redundant network, it is useless.

Prefer bridges which do not need monitoring. As an owner, I rather reduce risk.

Security threat is another hazard. SHM is an optimization of two contradictory demands. SHM should also lead to bridges which do not need monitoring (and does not require monitoring always).

This reminds me of the seismic monitoring project and the monies that went into it. Unless same effort is done on this, not much progress will happen.

Attendee # 4

It is nice to see all stakeholders and interpretation.

Continuous monitoring is not always needed.

Many technologies are out there. Need more stakeholders' meetings to get better perspectives.

Sensor network should be tied to decision making process. 100% safety is an unreal objective.

Attendee # 5

For security, visual inspection is still safe and reliable.

Baseline is needed if you want to use other technologies.

System should be economical. Fancy does not mean much.

More number of sensors does not mean much.

Reliability, redundancy, and automation are important.

Attendee # 6

There is a need for screening and prioritization.

Safety vs. security: Security should complement safety measures.

All hazard threat and all hazard mitigation.

Case study and multi-disciplinary approach is needed.

Performance, safety, security, cost-benefits should be looked into seriously.

Attendee # 7

There are still a lot of questions on definitions of SHM and security. Workshop gave a better understanding of various parameters and their use.

SHM Virtual Team is to create a new generation of bridges. We should not think of monitoring as a burden. It should be seen as a method to assess the structure.

Look at smart materials, not just discrete sensors. Security is a small component of SHM.

Long Term Bridge Performance Program is a $75 million program. Hopefully, through this program, FHWA can make an effort similar to the seismic program.

Multi-hazard approach is important. Incorporate smart sensors which address multiple hazards.

Attendee # 8

Different views of the same subject matter. Is familiar with most attendees and, hence, no surprises. SHM has a strong role in security. It depends on definition.

There is a consensus that there is no security without monitoring – can be simple to complex. Challenge here is how we approach it.

Multi-hazard serving multiple uses is important.

Attendee # 9

It was nice to hear the perspective of personnel involved with physical security.

Security vulnerability mitigation value will be realized by engineers when they become aware of real attempts made on infrastructure.

Comparisons of SHM program to seismic program is worth noting.

Security is one another Vulnerability Bridge engineers should be aware of. Multi-hazard approach is important as it helps bottom line.

Interact and involve all other groups as interpretations may be different and hence, differing values.

Framework should come from regulators and owners. Learn from Strategic Highway Research Program (SHRP) and other experiences, and make sure to involve appropriate personnel from the beginning. Program should not guide needs; needs should guide the program.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Important Conclusions

The workshop deliberated many of the issues that involve SHM and bridge security. Many of the observations and the scores by the workshop attendees point to how to improve bridge security by the utilization of SHM technologies. Some of the important observations are:

- A balance between safety, cost and cost/benefit must be reached.
- Event sequencing (before, during and after) in bridge security field can utilize current state of the art in SHM as applied to earthquake hazard.
- Fire, ramming (impact) and radiation hazards must be considered in the bridge security field.
- Multihazards considerations can improve efficiency, i.e., improve safety while reducing costs.
- The need for a multidisciplinary approach to bridge security was highlighted; all stakeholders must be present when planning or designing a bridge security project.
- Perceived value vs. actual value of bridge security projects were judged to be different.
- Even though interaction between different stakeholders in the SHM-Bridge Security fields was judged to be important, the interaction between bridge owners and security professionals was judged more important. It was also judged that the interaction between all stakeholders needs improvement from the current practice.

5.2 Recommendations

Important recommendations of the workshop were:

- A longer workshop with larger attendance would improve and expand the results of the workshop.
- This workshop considered SHM sensing technologies only. Other aspects of SHM, such as structural identification, damage identification and decision-making tools need to be considered. It is believed that these other aspects of SHM can have a large impact on improving bridge security.

APPENDIX I - AGENDA

Workshop on
Structural Health Monitoring and Bridge Security
January 12, 2006
Weidlinger Associates Offices
375 Hudson Street, New York City, NY 10014

AGENDA

8:30AM	Continental Breakfast
9:00AM	Introduction and Welcome **(Daddazio)**
9:15AM	Workshop Organization and Logistics (**Ettouney)**
9:20AM	3-Slide presentations from all workshop attendees indicating their interests, involvements, plans, experiences, etc., of the subject matter **(All will participate, 3-4 minutes each)**
10:00AM	Breakaway Session I: Building the Matrix: Components of Bridge Security and Components of SHM **(owners and managers)**
10:00AM	Breakaway Session II: Building the Matrix: Components of Bridge Security and Components of SHM **(technical, research, consultants)**
11:00AM	Breakaway Session III: Additional Matrix Dimensions: Event Timelines and Stakeholders Interactions **(owners and managers)**
11:00AM	Breakaway Session IV: Additional Matrix Dimensions: Event Timelines and Stakeholders Interactions **(technical, research, consultants)**
12:00PM	Lunch
1:00PM	Breakaway Session V: Prior, Current and Future Efforts/Needs; Cost-Benefits, Prioritizations of Matrix Entries **(assembly mixed subgroup I)**
1:00PM	Breakaway Session VI: Prior, Current and Future Efforts/Needs; Cost-Benefits, Prioritizations of Matrix Entries **(assembly mixed subgroup II)**
2:30PM	Break
2:45PM	Review of Results, Round Table Discussions, Individual Pass-through for Prioritizations/Future Efforts **(all)**
3:45PM	Final Comments (**Ettouney**)
4:00PM	Adjourn

APPENDIX II - BRIDGE COMPONENTS: SCORES

Table 1 – Applicability Scores for SHM Technologies and Bridge Components

APPLICABILITY								
Component		Strains / Stresses	Motion (Disp, Vel, Acc)	Chem-Bio Agents	Remote Monitoring	Imaging Techniques	Electro-magnetic	Biometric
Hardening	Superstructure	8.5	9.125	0.125	0	4.625	5.75	1.875
	Substructure	8	9.125	0.625	0	5	2	2.625
	Utilities	6.5	8	1.25	0	5.5	8.25	2.625
	Foundations	6.75	8.25	0.75	0	3.875	0.5	2
Redundancy	Fire	7.5	7	2.875	6.25	8	0.625	0.125
	Total Collapse	2.875	4.75	0.75	5	7.625	0.25	0.125
	Chem-Bio	0.25	0.25	3.625	6.25	1.125	1	1
Multidisciplinary	Infrastructures	4.25	2.5	3.5	0	1.25	1.625	3.25
Integration	Risk (management and assessment)	9.375	8	3.25	5	6.125	1.25	6.625
	Site Considerations	1.75	1.75	3.125	5	7.125	0.75	7.25
	Physical Security	6.375	8.25	2	5	8.75	2.5	9.75
Guidelines	General	6.875	6.75	4.875	4.75	3.75	3.75	5.125
	Structural	7.125	6.875	1.75	3.5	3.875	3.875	1.25
	Geotechnical	5.875	6.25	0.625	1.375	2.375	1.125	1.875
Management / Owners	Safety	7.375	6	7.125	2.5	6.875	4.125	4.75
	Costs	4.5	3.5	3.375	1	3.375	2.125	3.75

Table 2 – Importance Scores for SHM Technologies and Bridge Components

IMPORTANCE								
Component		**Strains / Stresses**	**Motion (Disp, Vel, Acc)**	**Chem-Bio Agents**	**Remote Monitoring**	**Imaging Techniques**	**Electro-magnetic**	**Biometric**
Hardening	**Superstructure**	8.5	9.125	0.125	0	4.625	5.25	1.875
	Substructure	8.25	9.125	0.625	0	4.875	1.5	2.625
	Utilities	6.375	8.125	1.5	0	5.375	8	2.625
	Foundations	7.375	7.75	0.75	0	5.125	0.5	2
Redundancy	**Fire**	8.375	6.75	2.625	6.25	7.625	0.625	0.125
	Total Collapse	3.5	4.75	0.75	5	7.625	0.25	0.125
	Chem-Bio	0.5	0.25	3.625	6.25	0.5	1	1
Multidisciplinary	**Infrastructures**	4.375	2.375	3.5	0	1.25	1.625	3.25
Integration	**Risk (management and assessment)**	9	7.5	3.5	5	6.125	1.25	6.625
	Site Considerations	1.75	1.75	3.125	5	7.125	0.75	7.25
	Physical Security	6.5	8.125	2	5	8.75	2.5	9.125
Guidelines	**General**	6.125	6.5	4.375	4.375	3.75	3.375	5.125
	Structural	7	6.625	1.375	3.5	3.75	4.25	1.25
	Geotechnical	5.625	6	0.625	1.875	2.25	1	1.875
Management / Owners	**Safety**	7.625	6	7	2.25	6	4.125	4.75
	Costs	3.375	2.625	3.375	1	4	1.75	4.25

Table 3 – Availability Scores for SHM Technologies and Bridge Components

AVAILABILITY								
Component		Strains / Stresses	Motion (Disp, Vel, Acc)	Chem-Bio Agents	Remote Monitoring	Imaging Techniques	Electro-magnetic	Biometric
Hardening	Superstructure	9.125	9.375	0	0	3.125	3.5	2.5
	Substructure	9	9.125	0.75	0	3.5	1.5	3.25
	Utilities	9	9.25	0.625	0	4.125	5.25	3.25
	Foundations	6.25	6.125	0.75	0	2.375	0.125	2.5
Redundancy	Fire	7.75	6.75	3.25	6.25	8	0.75	1.5
	Total Collapse	3.625	3.375	0.75	5	8	0.25	1.5
	Chem-Bio	0.125	1.375	3.125	6	0.375	0.625	1
Multidisciplinary	Infrastructures	3.875	3.25	3.125	0	1.875	1.75	2.875
Integration	Risk (management and assessment)	9.125	8.125	2.125	3.125	4.75	1.375	5.75
	Site Considerations	3.125	2.625	2.625	3.5	4.75	0.5	5.75
	Physical Security	7.75	7.625	1.625	2.875	5.625	2.125	5.875
Guidelines	General	5.375	5	2.625	1.875	2.375	2.625	4.125
	Structural	5.875	5.375	0.75	1.875	3.75	2.5	2.25
	Geotechnical	4.875	4.25	0.75	0.875	2.625	1.5	2.5
Management / Owners	Safety	6.25	5.125	5.25	1.875	4	2.5	3.25
	Costs	3.625	2.625	2.625	0.875	2.75	2	4.125

APPENDIX III - SEQUENCE OF EVENTS: SCORES

Table 4 - Scores for Applicability of SHM for Different Events – Timeline Issues

Hazard	Timing	Strains / Stresses	Motion (Disp. Vel. Acc.)	Chem-Bio	Remote Monitoring	Imaging Techniques	Electromagnetic	Biometric
Bomb Blast	Before Event	4.43	5.43	4.29	4.00	7.14	0.00	5.29
	During Event	5.57	7.71	1.00	3.86	5.57	1.00	1.43
	After Event	8.43	7.86	4.71	3.71	6.71	3.57	0.00
Chem-Bio	Before Event	3.14	1.86	4.86	3.14	5.57	0.00	4.14
	During Event	1.43	0.43	5.57	3.29	5.29	0.00	0.00
	After Event	4.14	2.14	5.57	3.43	7.71	0.00	0.00
Fire	Before Event	4.33	4.33	0.00	3.00	7.67	0.00	3.33
	During Event	8.33	9.33	3.33	3.00	8.67	0.00	0.00
	After Event	8.67	8.67	3.33	1.00	6.67	0.00	0.00
Radiation	Before Event	0.00	0.00	0.00	10.00	10.00	5.00	0.00
	During Event	5.00	0.00	0.00	10.00	10.00	6.00	0.00
	After Event	5.00	0.00	0.00	10.00	10.00	6.00	0.00
Ramming	Before Event	2.50	3.50	1.75	2.00	3.25	1.75	2.50
	During Event	3.50	5.75	2.50	2.00	3.25	0.75	0.00
	After Event	5.25	3.00	2.50	2.00	2.50	0.00	2.50

Table 5 - Scores for Importance of SHM for Different Events – Timeline Issues

Hazard	Timing	Strains / Stresses	Motion (Disp. Vel. Acc.)	Chem-Bio	Remote Monitoring	Imaging Techniques	Electromagnetic	Biometric
Bomb Blast	Before Event	4.43	5.29	4.29	4.00	7.71	0.00	5.14
	During Event	6.00	8.00	1.43	3.86	5.43	1.43	1.43
	After Event	8.43	7.71	5.14	3.71	6.71	3.71	0.00
Chem-Bio	Before Event	3.57	2.14	5.57	3.29	6.00	0.00	4.00
	During Event	1.43	0.71	5.57	3.29	6.14	0.00	0.00
	After Event	4.00	2.86	5.57	3.43	7.71	0.00	0.00
Fire	Before Event	5.00	4.33	0.00	3.00	7.67	0.00	3.33
	During Event	8.33	9.00	3.33	3.00	5.33	0.00	0.00
	After Event	8.67	8.67	3.33	1.00	6.67	0.00	0.00
Radiation	Before Event	0.00	0.00	0.00	7.00	8.00	5.00	0.00
	During Event	5.00	0.00	0.00	8.00	8.00	10.00	0.00
	After Event	5.00	0.00	0.00	8.00	8.00	10.00	0.00
Ramming	Before Event	2.75	3.50	1.75	2.00	3.25	1.75	2.50
	During Event	3.50	5.75	2.50	2.00	3.00	0.75	0.00
	After Event	5.50	3.25	2.50	2.00	2.50	0.00	2.50

Table 6 - Scores for Availability of SHM for Different Events – Timeline Issues

Hazard	Timing	Strains / Stresses	Motion (Disp. Vel. Acc.)	Chem-Bio	Remote Monitoring	Imaging Techniques	Electromagnetic	Biometric
Bomb Blast	Before Event	7.43	8.43	2.43	3.71	6.14	1.43	4.86
	During Event	6.86	7.43	1.71	3.43	5.00	1.43	2.14
	After Event	7.29	7.86	3.86	3.43	6.57	2.86	1.43
Chem-Bio	Before Event	5.00	2.86	3.14	2.71	4.71	1.43	3.86
	During Event	2.14	1.43	2.00	2.71	4.86	1.43	1.43
	After Event	5.71	3.57	3.14	2.71	4.86	1.43	1.43
Fire	Before Event	8.33	8.33	3.33	3.00	9.33	3.33	1.67
	During Event	8.33	9.33	3.33	3.00	8.67	3.33	0.00
	After Event	8.33	8.67	3.33	2.33	8.33	3.33	0.00
Radiation	Before Event	0.00	0.00	0.00	5.00	5.00	5.00	0.00
	During Event	5.00	0.00	0.00	5.00	5.00	5.00	0.00
	After Event	5.00	0.00	0.00	5.00	5.00	5.00	0.00
Ramming	Before Event	5.75	6.50	2.50	2.00	4.00	2.50	2.50
	During Event	6.50	8.00	2.50	2.00	3.25	2.50	0.00
	After Event	8.75	6.00	2.50	2.00	3.25	2.50	2.50

APPENDIX IV - MULTIHAZARDS AND MULTIDISCIPLINES: SCORES

Table 7 - Scores for Applicability of SHM for Multihazards Issues

APPLICABILITY							
	Strains/ Stresses	Motion (Disp. Vel. Acc.)	Chem-Bio	Remote Monitoring	Imaging Techniques	Electromagnetic	Biometric
Seismic	9.4	9.4	1	1	5	1	0
Wind	8.4	9.4	2	1	4.2	1	0
Flood / Scour	5.4	9.4	1	1	8.6	0	0
Impact / Traffic	8.2	6.6	2	1	6.8	0	0
Normal Deterioration	6.2	4.2	3	0	6.4	6	0
Corrosion	5.4	3.6	3	0	4.6	7.4	0

Table 8 - Scores for Importance of SHM for Multihazards Issues

IMPORTANCE							
	Strains / Stresses	Motion (Disp. Vel. Acc.)	Chem-Bio	Remote Monitoring	Imaging Techniqes	Electromagnetic	Biometric
Seismic	9.4	9.6	1	1.4	4.4	1.2	0
Wind	8.6	9.6	2	1.4	5.2	1.4	0
Flood / Scour	5.8	9.6	1	1.4	8.4	0	0
Impact / Traffic	8.4	6.8	2	1.4	7.2	0	0
Normal Deterioration	6.8	5.4	4.6	0	7.8	6.2	0
Corrosion	7.2	4.6	4.6	0	6.2	7.4	0

Table 9 - Scores for Cost-Benefit of SHM for Multihazards Issues

COST-BENEFIT							
	Strains / Stresses	**Motion (Disp. Vel. Acc.)**	**Chem-Bio**	**Remote Monitoring**	**Imaging Techniques**	**Electromagnetic**	**Biometric**
Seismic	8.4	8.2	2	1	7.2	1	0
Wind	7.6	8.6	2	1	4.6	1	0
Flood / Scour	6.6	9.8	2	1	6	0	0
Impact / Traffic	7.2	6.8	2	1	6.2	0	0
Normal Deterioration	7.8	5.4	4.4	0	6.6	6.4	0
Corrosion	7	3.8	5.4	0	5	6.6	0

Table 10 - Scores for Applicability of S HM for Multidisciplinary Issues

APPLICABILITY							
	Strains / Stresses	Motion (Disp. Vel. Acc.)	Chem-Bio	Remote Monitoring	Imaging Techniques	Electromagnetic	Biometric
Police	0.4	5.6	7	1.4	7.6	1	9.6
Fire	6.6	4.6	5.6	1.4	6.4	0	0.8
Emergency Management	5.6	6.6	7	0	7.6	0.6	3.8
Other Engineering Fields	3	2	3	0	1	1	1

Table 11 - Scores for Importance of SHM for Multidisciplinary Issues

IMPORTANCE							
	Strains / Stresses	Motion (Disp. Vel. Acc.)	Chem-Bio	Remote Monitoring	Imaging Techniques	Electromagnetic	Biometric
Police	0.4	5.6	7.4	1.6	7.6	1	7.2
Fire	7	5.2	5.8	1.6	7	0	1
Emergency Management	6.8	6.8	7.2	0	7.6	0.6	2
Other Engineering Fields	3	2	3	0	1	1	1

Table 12 - Scores for Cost-Benefit of SHM for Multidisciplinary Issues

COST-BENEFIT							
	Strains / Stresses	**Motion (Disp. Vel. Acc.)**	**Chem-Bio**	**Remote Monitoring**	**Imaging Techniques**	**Electromagnetic**	**Biometric**
Police	0	4.6	6.6	1	7.6	1	3.8
Fire	7.6	5.2	6	1.2	6.4	0	0.4
Emergency Management	6.6	6.6	5.6	0	6.6	0.6	1.4
Other Engineering Fields	3	2	3	0	1	1	1

APPENDIX V - PRESENT AND FUTURE USAGE: SCORES

Table 13 - Scores for Applicability of SHM for Current and Future Issues

APPLICABILITY								
		Strains / Stresses	Motion (Disp. Vel. Acc.)	Chem-Bio	Remote Monitoring	Imaging Techniques	Electromagnetic	Biometric
Current	**Practice**	7.67	9.33	3.83	1.83	7.17	3.83	2.83
	Research	9.00	9.00	5.83	2.83	7.00	6.33	4.33
	Cost	7.83	8.00	5.83	2.50	8.17	5.83	5.33
	Benefit (How much security?)	5.83	6.67	6.17	2.33	7.33	5.67	3.67
	Value, perceived	4.67	5.33	4.17	2.83	6.17	4.00	6.17
	Value, actual	5.50	6.50	3.00	1.67	4.83	3.67	3.50
Future	**Practice**	9.50	9.50	5.50	2.83	8.33	7.00	6.33
	Research	9.17	9.17	6.33	3.00	8.17	7.50	5.50
	Cost	6.17	7.00	6.33	2.67	7.33	4.50	5.33
	Benefit (How much security?)	5.50	6.33	5.33	2.67	5.33	3.83	3.33
	Value, perceived	5.50	6.17	7.00	2.33	5.67	3.83	4.83
	Value, actual	5.00	4.17	4.33	2.00	4.00	2.67	3.67

Table 14 - Scores for Importance of SHM for Current and Future Issues

IMPORTANCE								
		Strains / Stresses	Motion (Disp. Vel. Acc.)	Chem-Bio	Remote Monitoring	Imaging Techniques	Electromagnetic	Biometric
Current	**Practice**	7.83	9.33	2.83	2.83	9.33	5.00	3.00
	Research	9.00	9.17	4.17	2.83	8.50	6.83	4.00
	Cost	8.50	8.83	5.50	3.33	9.17	7.33	6.17
	Benefit (How much security?)	8.00	8.83	3.67	2.83	6.17	4.00	3.67
	Value, perceived	3.83	4.50	2.17	1.67	5.00	3.50	5.17
	Value, actual	4.33	4.50	2.33	0.83	3.83	3.00	3.33
Future	**Practice**	9.50	9.50	3.83	3.33	9.17	7.50	5.33
	Research	9.67	9.67	4.67	3.33	8.33	7.83	5.50
	Cost	6.50	6.33	5.50	3.33	7.17	5.50	6.33
	Benefit (How much security?)	6.00	6.83	3.67	3.00	5.83	3.83	3.33
	Value, perceived	4.67	5.33	4.50	1.17	4.50	3.17	4.00
	Value, actual	3.50	3.33	3.50	1.17	2.83	1.83	3.33

APPENDIX VI -STAKEHOLDERS INTERACTION

Table 15 - Scores for Interaction between Stakeholders: SHM and Bridge Security Issues: Applicability

APPLICABILITY						
	Owners	**Fed. Gov.**	**Research**	**Consultants**	**Manufacturers**	**Security Prof.**
Owners	NA	8.75	8.88	8.63	8.38	9.25
Fed. Gov.	8.75	NA	9.38	7.00	6.13	8.50
Research	8.88	9.38	NA	7.88	8.75	8.13
Consultants	8.63	7	7.88	NA	7.50	9.00
Manufacturers	8.38	6.13	8.75	7.5	NA	8.63
Security Prof.	9.25	8.5	8.13	9	8.63	NA

Table 16 - Scores for Interaction between Stakeholders: SHM and Bridge Security Issues: Importance

IMPORTANCE						
	Owners	**Fed. Gov.**	**Research**	**Consultants**	**Manufacturers**	**Security Prof.**
Owners	NA	9.00	9.38	8.88	8.13	9.75
Fed. Gov.	9	NA	9.50	7.25	6.25	8.75
Research	9.38	9.5	NA	8.00	9.00	8.00
Consultants	8.88	7.25	8	NA	7.63	8.88
Manufacturers	8.13	6.25	9	7.63	NA	8.13
Security Prof.	9.75	8.75	8	8.88	8.13	NA

Table 17 - Scores for Interaction between Stakeholders: SHM and Bridge Security Issues: Current Practice

CURRENT PRACTICE						
	Owners	**Fed. Gov.**	**Research**	**Consultants**	**Manufacturers**	**Security Prof.**
Owners	NA	8.00	5.75	8.88	5.00	6.50
Fed. Gov.	8	NA	7.75	6.50	5.13	5.75
Research	5.75	7.75	NA	5.38	7.13	4.75
Consultants	8.88	6.5	5.38	NA	5.63	7.13
Manufacturers	5	5.13	7.13	5.63	NA	6.75
Security Prof.	6.5	5.75	4.75	7.13	6.75	NA