A COMPREHENSIVE SURVEY OF EMERGING TECHNOLOGY FOR NEW YORK METROPOLITAN AREA

Technical Memorandum 5: Assessment of Shortlisted Technologies

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1 Summary

In task 2, a comprehensive, initial list of emerging technologies to improve transportation systems was prepared. In task 3, the technologies identified in task 2 were screened based on preliminary criteria that include: a) relevance to NYMTC, and b) subjective estimate of economic and technical feasibility. Two internet accessible surveys were created for the purpose of obtaining input from the Regional Transportation Plan committee members. An important result from the first survey is the ranking of the different policy sub-categories. The second survey, feasibility assessment questionnaire included both technical and economic feasibility. The rankings for the sub-categories and the economic and technical feasibility of the technologies obtained in task 3 were taken as input in task 4 to determine the shortlist of emerging technologies that could plausibly be used. Based on the ranking of the technologies and the project team's reality-checks, five technologies each in Congestion Reduction and Management, Safety and Security, and Energy and Environment category policy areas were short-listed.

In Task 5, the focus of this report, technologies in each of the broad categories – congestion reduction and management, safety and security, energy and environment – are ranked using the weights obtained from pair wise comparison process. Input is obtained from several experts to assist in the assessment process. Assessment is based on two criteria including the contribution of each technology towards the listed goals and the likely acceptance/growth of the technology in the NY metropolitan region.

The report describes the survey questionnaire used to obtain the expert input for the ranking process and the method used to derive the weights based on the expert input. The detailed results of the survey questionnaire and the ranking of the different shortlisted technologies are presented. These rankings will finally assist us in predicting the trends of different transportation technology for the NY metropolitan area.

2 Shortlist of Technologies

Task 5 assessed the shortlisted technologies by the consultants with input from several experts. A brief summary of the work conducted in previous tasks is: In task 2, a comprehensive, initial list of emerging technologies to improve transportation systems was prepared. In task 3, the technologies identified in task 2 were screened based on preliminary criteria that include: a) relevance to NYMTC, and b) subjective estimate of economic and technical feasibility. Two internet accessible surveys were created for the purpose of obtaining input from the Regional Transportation Plan (RTP) committee members. An important result from the first survey is the ranking of the different policy sub-categories. The second survey, feasibility assessment questionnaire included both technical and economic feasibility. The rankings for the sub-categories and the economic and technical feasibility of the technologies obtained in task 3 were taken as input in task 4 to determine the shortlist of emerging technologies that could plausibly be explored for implementation in the NY metropolitan area.

The methodology for short-listing technologies was based on a ranking procedure using the input obtained from RTP committee members and experts in earlier tasks. A weighted sum method was used to obtain the rankings of the technologies. Since the focus on technologies have always been toward meeting the three broad goals of NYMTC, i.e., congestion reduction and management, safety and security, and energy and environmental impact mitigation, three separate shortlists for each of these broad goals was prepared.

Based on the ranking of the technologies and the project team’s reality-checks, five technologies each in Congestion Reduction and Management, Safety and Security, and Energy and Environment category policy areas were short-listed.

The shortlisted technologies include:

Congestion Reduction and Management

Geographic Positioning Systems and Personal Travel Assistants
Adaptive Ramp Metering
Smart Cards and RFID
Personalized Rapid Transit
Collaborative Technologies

Safety and Security

Vehicle-to-vehicle and Vehicle-to-Infrastructure Communication (DSRC, RFID, VANETs)
Machine Vision
MEMS and Nanosensors
Automated Vehicles
Biometric Identification

Energy and Environment

Natural Gas and Propane
Biogas
Bio-diesel and Ethanol
Electric-driven and Hybrid vehicles
Hydrogen Fuel

3 Assessment of Technologies

In Task 5, the focus of this report, technologies in each of the broad categories – congestion reduction and management, safety and security, energy and environment – are assessed using the weights obtained from pair wise comparison process described in section 3.1. Input is obtained from several experts to assist in the assessment process. Assessment is based on two criteria including the contribution of each technology towards the listed goals and the likely acceptance/growth of the technology in the NY metropolitan region.

Below we present the methodology adopted to obtain the rankings. We then describe the survey questionnaire used to obtain input from the different experts.

3.1 Weights from Ratio Comparisons

Given a set of m alternatives, each having a weight of w_i, the ratio comparison between two alternatives i and k, is given as w_i / w_k. That is alternative i is w_i / w_k times better than alternative k. However, it is often difficult to obtain the weights of the alternatives directly.

The inverse problem, which is the focus here, deals with obtaining the ratio comparison of two alternatives at a time. Having thus obtained the ratio comparison of each pair of alternatives, we obtain the ratio comparison matrix, **A**. The weights are subsequently obtained using the methodologies described below. Matrix **A** is a reciprocal matrix, i.e. the ratio comparison between alternative i and k is a_{ik} and the ratio between k and i is $1/ a_{ik}$. Consequently the diagonal elements of matrix **A** are 1.

The eigen decomposition theorem states that any square matrix can be decomposed into eigenvalues and eigenvectors[1]. It can be shown[2] that if **W** is the vector of weights, and n is the eigenvalue of matrix **A**, then:

$$\mathbf{A}\,\mathbf{W} = n\,\mathbf{W}$$

The above holds only if the ratio comparisons are perfect, i.e. $a_{ik} = w_i / w_k$. However if the ratio comparisons are not perfect, one has to find the eigenvector that corresponds to the maximum eigenvalue n_{max}.

$$\mathbf{A}\,\mathbf{W} = n_{max}\,\mathbf{W} \text{ where, } n_{max} > n.$$

This approach to finding the weights is referred to as the eigenvalue approach. However, the approach is accepted as consistent only when the ratio:

$$\text{CI} = (n_{max} – n) / (n - 1)$$

is 10% or less.

A second method to obtain the weights from an imperfect ratio comparison matrix is by determining the weight vector **W** that provides the least error deviation. This can be obtained by solving for w_i's in the optimization problem below:

[1] http://mathworld.wolfram.com/Eigenvector.html
[2] Evangelos Triantaphyllou, Multi-Criteria Decision Making Methods: A Comparative Study, Kluwer Academic Publishers, 2000.

$$\text{Minimize} \quad \sum_{i=1}^{n}\sum_{k=i}^{n}\left(a_{ij} - \frac{w_i}{w_j}\right)^2$$

$$\text{s.t.} \quad \sum_{i=1}^{n} w_i = 1 \quad \text{and} \quad w_i > 0 \text{ for } i = 1, 2, \dots n.$$

3.2 Survey Questionnaire

In order to obtain ratio comparison values a survey questionnaire was developed. Experts were requested to complete the questionnaire online. The questionnaire was divided into five sections. Two sections each related to congestion reduction and management, and safety and security technologies, and one section dealing with energy and environment technologies. The first section in each of the technology categories included questions on pair wise comparison (Figure 1) of the technologies with respect to the effectiveness of the technology towards meeting the broad category goal. The remaining two sections obtained input on the degree of likely penetration of the technology (Figure 2) and the likelihood of implementation of less developed in the future (Figure 3).

Section 1. Assume all of the above technologies are in place and are performing to their best potential. How do you rate the technologies with respect to their impact on congestion reduction? In the table below, each row represents a separate pair-wise comparison. First choose which of the two technologies is better and then tell us how much better you consider it to be: 1-Equally, 3-Moderately, 5-Strongly, 7-Very strongly, and 9-Absolutely. The even numbers in between suggest intermediate importance values.

Technology 1	**Technology 2**	**Equally**		**Moderately**		**Strongly**		**Very Strongly**		**Absolutely**
		1	2	3	4	5	6	7	8	9
○ Personal Rapid Transit	○ Collaborative Technologies	○	○	○	○	○	○	○	○	○
○ GPS and Personal Travel Assistant	○ Adaptive Ramp Metering	○	○	○	○	○	○	○	○	○
○ Personal Rapid Transit	○ Adaptive Ramp Metering	○	○	○	○	○	○	○	○	○
○ GPS and Personal Travel Assistant	○ Smartcards and RFID	○	○	○	○	○	○	○	○	○
○ Personal Rapid Transit	○ Smartcards and RFID	○	○	○	○	○	○	○	○	○

Fig 1. Survey: Pair wise comparison of technologies

Section 2. In the following questions, we are interested in your opinion on the likely degree of penetration (% of individuals using the technology) for these technologies.

Geographic Positioning Systems and Personal Travel Assistants	
	Likely degree of penetration
Next 10 years	%
Next 20 years	%
Smart Cards and RFID	
Next 10 years	%
Next 20 years	%
Collaborative Technologies	
Next 10 years	%
Next 20 years	%

Fig 2. Survey: Likely degree of penetration of technology

	Highly Unlikely -4	-3	**Unlikely** -2	-1	**Neither** 0	1	**Likely** 2	3	**Highly Likely** 4
What is the likelihood of a Personal Rapid Transit being implemented in a major metropolitan region in the next 20 years?	○	○	○	○	○	○	○	○	○
What is the likelihood of Webinars and Video Conferencing becoming the preferred method of conducting business meetings in the next 20 years?	○	○	○	○	○	○	○	○	○

Fig 3. Survey: Likelihood of implementation of less developed technology

The ratio comparisons provided the input to determine the weights used for ranking the technologies in terms of their effectiveness towards contributing to the major goal. The complete questionnaire may be accessed at: http://transp.rpi.edu/~gita/assess.htm

4 Results

The survey questionnaire was completed by 22 respondents including seven university professors, nine practitioners (including private industry), and six government/DOT officials. Four respondents were New York residents while three respondents were international experts. The response rate for the survey was approximately 30 percent.

The main results from the responses are presented below. The actual response for the ratio comparison questions are presented in the Appendix. We have used the minimization of sum of squares of error methodology to estimate the weights since the CI index when applying the eigenvalue method was consistently over 10% in most of the cases.

4.1 Congestion Reduction and Management Technologies

The five congestion reduction and management technologies compared and their weights are presented in Figure 4 and the table below. The respondents compared the technologies pairwise. The criterion for comparison was the technologies "impact on congestion reduction". On the overall, GPS and Personal Travel Assistant was ranked the most effective (average weight of 0.27), followed by Smartcards and RFID (0.24), Collaborative technologies (0.22), adaptive ramp metering (0.21), and personal rapid transit (0.07). The last column in Table 1 lists the coefficient of variation (COV). COV is the normalized measure of dispersion of a value. While standard deviation provides an absolute measure, the COV given by the ratio of standard deviation to the mean provides a normalized measure that provides additional insight into the degree of dispersion relative to the mean value. Personal rapid transit was consistently ranked the least effective (COV = 0.44). The maximum spread (COV = 0.66) was observed for adaptive ramp metering which also had the highest maximum individual weight; this is perhaps indicating a mixed-response from the experts in terms of the actual effectiveness of adaptive ramp metering. Adaptive ramp metering success and failure are significantly dependent on the particular location and traffic characteristics of the transport network. The number one rank for GPS and personal travel assistants is also in keeping with recent trends of increasing patronage of such devices by travelers. However, no single technology has emerged as a clear winner; this is according to the expectation that several varied technologies all have an interdependent role to play towards reducing congestion.

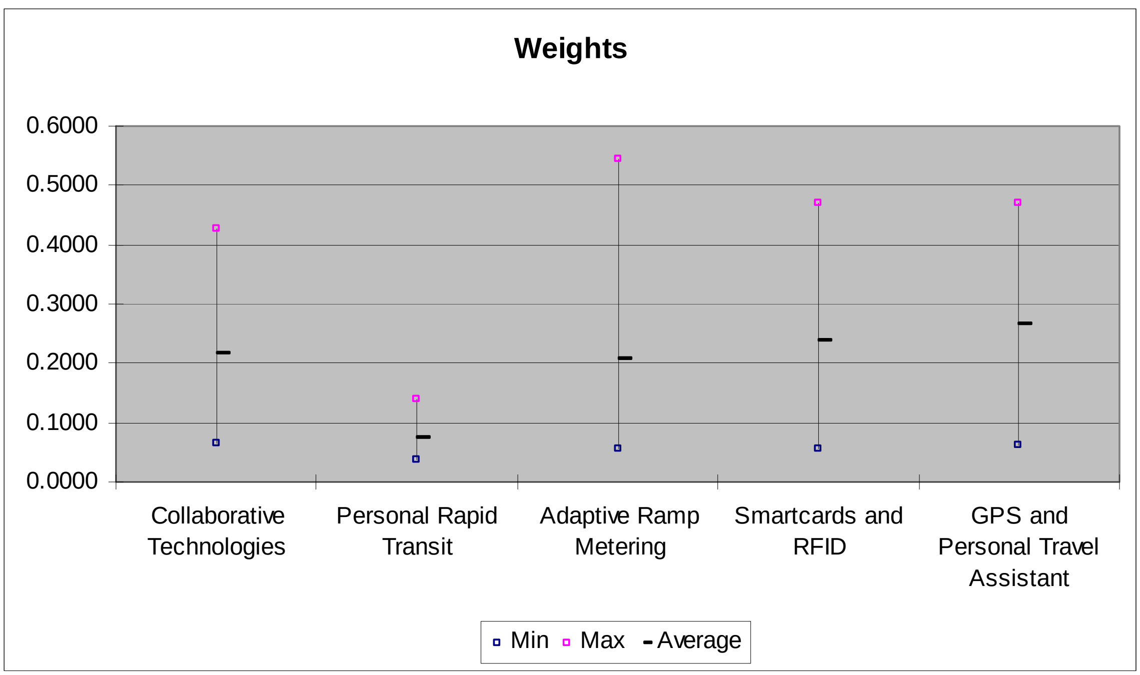

Fig 4. Weights of Congestion Reduction and Management Technologies

Table 1. Weights of CRM Technologies

	Min	Max	Average	Std Dev	C.O.V
Collaborative Technologies	0.0657	0.4254	0.2163	0.11	0.52
Personal Rapid Transit	0.0379	0.1404	0.0730	0.03	0.44
Adaptive Ramp Metering	0.0545	0.5429	0.2061	0.14	0.66
Smartcards and RFID	0.0549	0.4688	0.2391	0.13	0.56
GPS and Personal Travel Assistant	0.0632	0.4712	0.2655	0.13	0.47

The second part of the survey queried experts on the likelihood of implementation of the different technologies. Personal rapid transit was widely perceived as an "unlikely" technology even in the next 20 years. On the other hand, the experts collectively regard webinars and video conferencing as the "likely to highly likely" method for business meeting in 20 years.

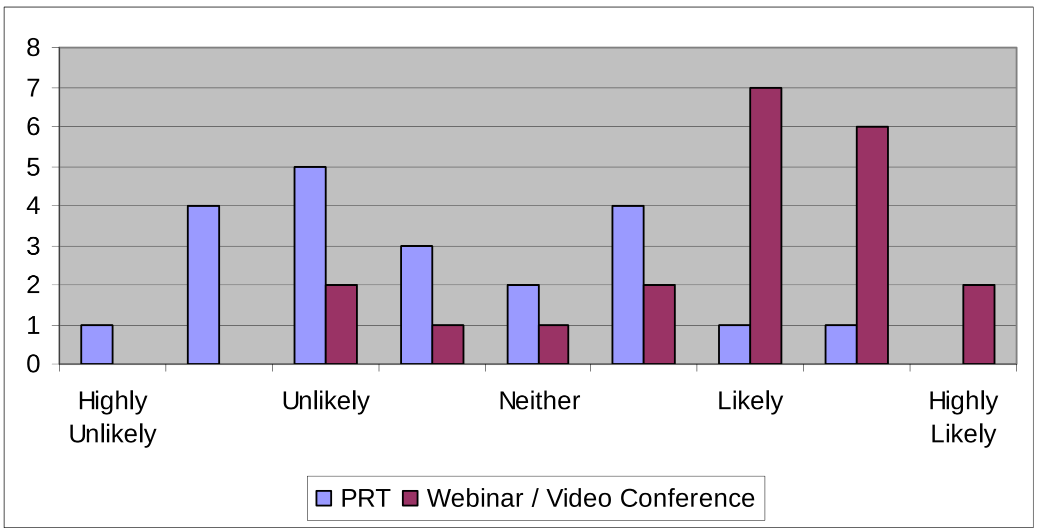

Fig 5. Likelihood of implementation

Table 2. Likely degree of penetration (% of individuals using the technology)

	Min	Max	Average
GPS and Personal Travel Assistants			
10 years later	20%	95%	56.6%
20 years later	50%	100%	80.6%
Smartcards and RFID			
10 years later	5%	99%	53.7%
20 years later	10%	100%	76.1%
Collaborative Technologies			
10 years later	10%	95%	52.1%
20 years later	20%	99%	71.5%
% of Work Trips replaced by Collaborative Technologies			
10 years later	2%	50%	18.7%
20 years later	3%	60%	30.1%

In terms of the degree of penetration, GPS and personal travel assistants are likely to be used by 56.6% and 80.6% percent of individuals after 10 and 20 years respectively. Smartcards and RFID as well as Collaborative technologies are also likely to be widely used with over 70% estimated on average after 20 years. Given their potential to impact congestion, such high penetration could significantly help mitigate congestion over the next two decades. A related question on the percentage of work trips that are likely to be replaced by collaborative technologies, the average response was over 30% after 20 years. On the overall, the shortlisted technologies appear to be highly favored by the experts in terms of their potential to reduce congestion.

Overall general comments from experts:
“These technologies can not work by themselves solely. For example, technologies for traveler information such as GPS have to be combined with better system management technologies such as adaptive ramp metering. Otherwise, the technologies may do harm. I strongly believe in the emergence of tolling schemes, whatever the technology to implement them - SmartCards, license plate recognition etc.”

“The next generation of system user is technology savvy and is already immersed in collaborative technology. Technologies like Adaptive ramp metering and PRT are, to some extent, management technologies, as opposed to enabling technologies. GPS, RFID, and collaborative technologies provide more information and more options to individuals for transportation and other services and will be more fully integrated into other aspects of their lives. PRT and Adaptive Ramp Metering are specialized technologies that address transportation issues alone. They may be important in specific situation but will not enjoy the broadbased adoption that these other technologies already experience.”

4.2 Safety and Security Technologies

The weights obtained from the minimization of error methodology for safety and security technologies are shown in Figure 6 and Table 3. The comparison was restricted to only the three technologies listed since automated vehicles were considered to be a superset of these three technologies. Also, biometric identification was treated as security technology and was not included in the comparison below. The overall response rating for the question “which technology is likely to improve safety to a greater extent?” yielded the greatest average weight for Vehicle-to-Vehicle and Vehicle-to-Infrastructure communication technology, followed by MEMS and Nanosensors, followed by Machine Vision. Given the significant spread in the weights of all three technologies (COV > 0.6) it is likely that a mixture of all three technologies could evolve into the future indicating no single technology will dominate the other.

Table 3. Weights of Safety and Security Technologies

	min	max	ave	Std Dev	C.O.V
Machine Vision	0.0769	0.7596	0.2722	0.18	0.66
V2V and V2I Communication	0.0882	0.7636	0.3977	0.24	0.59
MEMS and Nanosensors	0.0738	0.7769	0.3302	0.21	0.63

In terms of the degree of penetration (Table 4), MEMS devices had the greatest degree of penetration (34.3% after 10 years and 61.7% after 20 years). Over half-the-vehicles are likely to be equipped with V2V and V2I capabilities 20 years hence. Further, over a third of the vehicles 20 years hence are likely to be automated vehicles. Such high degree of penetration can have significant impacts towards improving road safety.

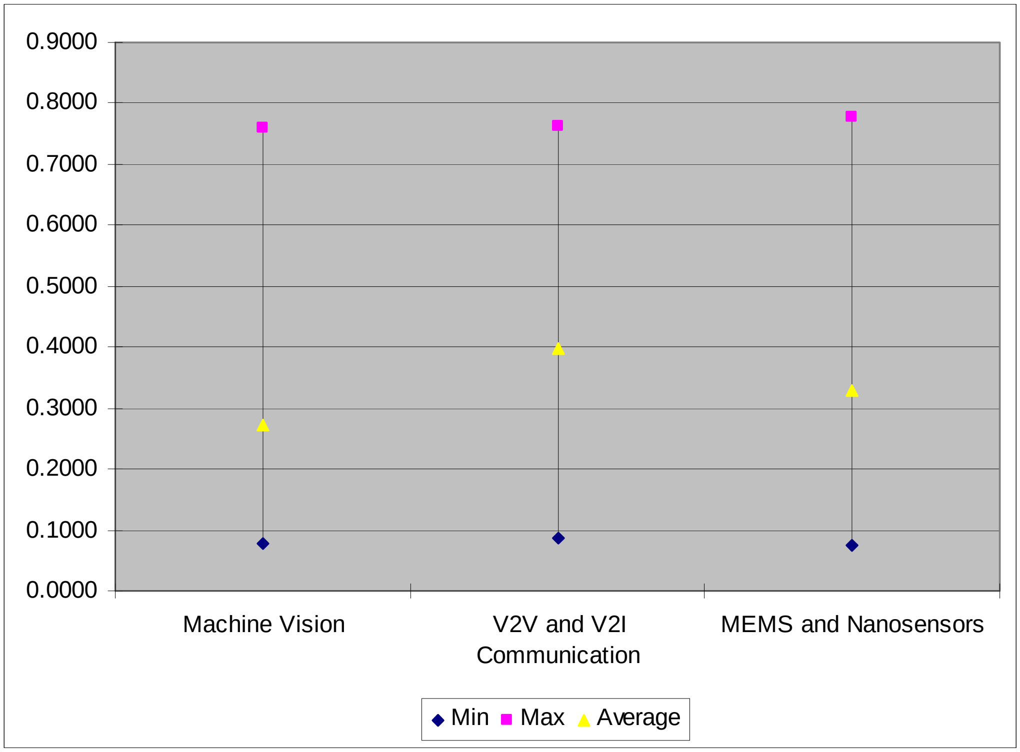

Fig 6. Weights of Safety and Security Technologies

Table 4. Likely degree of penetration (% of individuals using the technology)

	Min	Max	Average
MEMS			
10 years later	5%	90%	34.3%
20 years later	15%	19%	61.7%
Machine Vision			
10 years later	5%	60%	21.6%
20 years later	5%	80%	42.3%
Automated Vehicles			
10 years later	0%	70%	20.7%
20 years later	0%	90%	37.3%
V2V and V2I communication			
10 years later	0%	66%	26.4%
20 years later	5%	90%	51.4%

In terms of the likelihood of implementing biometric identification for fare payment as a security measure, the overall average response remained neutral. However, 55% of respondents indicated a positive likelihood of such a technology being implemented.

Overall general comments from experts:
"I suspect that safety and security technologies will continue to expand as regulatory agencies and OEM identify high payoff technologies that will become standard in new vehicles - perhaps beginning with commercial vehicles. V2V and V2I communications may become standard as well since they can be passive technologies and serve as a mesh network for communicating in sparsely populated areas and in "urban canyons" where line-of-sight communications may be difficult. Biometrics may become popular for convenience and security reasons. Automated vehicles and machine vision will be possible but may be either limited to specific applications e.g., major freeways or specific technologies e.g., detecting obstacles and warning drivers - but may not be widely deployed."

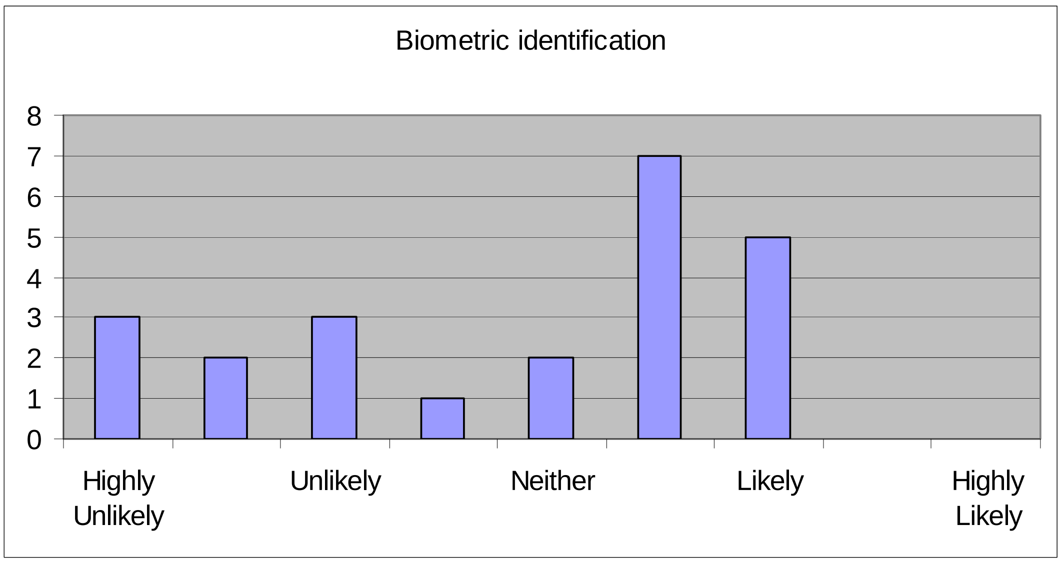

Fig 7. Likelihood of Biometric Technologies for fare payment (Security measure)

4.3 Energy and Environment Technologies

The energy and environment technology weights are presented in Figure 8 and Table 4. The question posed to the experts was:

"A key determinant of future energy sources is the set of policies adopted by governments and corporations involved in energy production. In terms of these policy decisions over the next 20 years which fuel types are more likely to be developed and promoted?"

As expected, electric and hybrid fuel vehicles are collectively (COV = 0.27) ranked the highest (weight = 0.44). Unlike the previous two categories, electric and hybrid vehicles appear to be significantly more important than the next important fuel technology: Natural Gas and Propane (0.18). Surprisingly, Biodiesel and Ethanol has a lower weight than Natural Gas and Propane – perhaps indicative of growing concerns regarding food security. Hydrogen fuel (ranked 4th) has a high coefficient of variation (COV = 1.15) – this is perhaps because of the limited success of the so far. At the same time, the immense promise of hydrogen as a transportation fuel must have triggered few of the respondents to rank it highly.

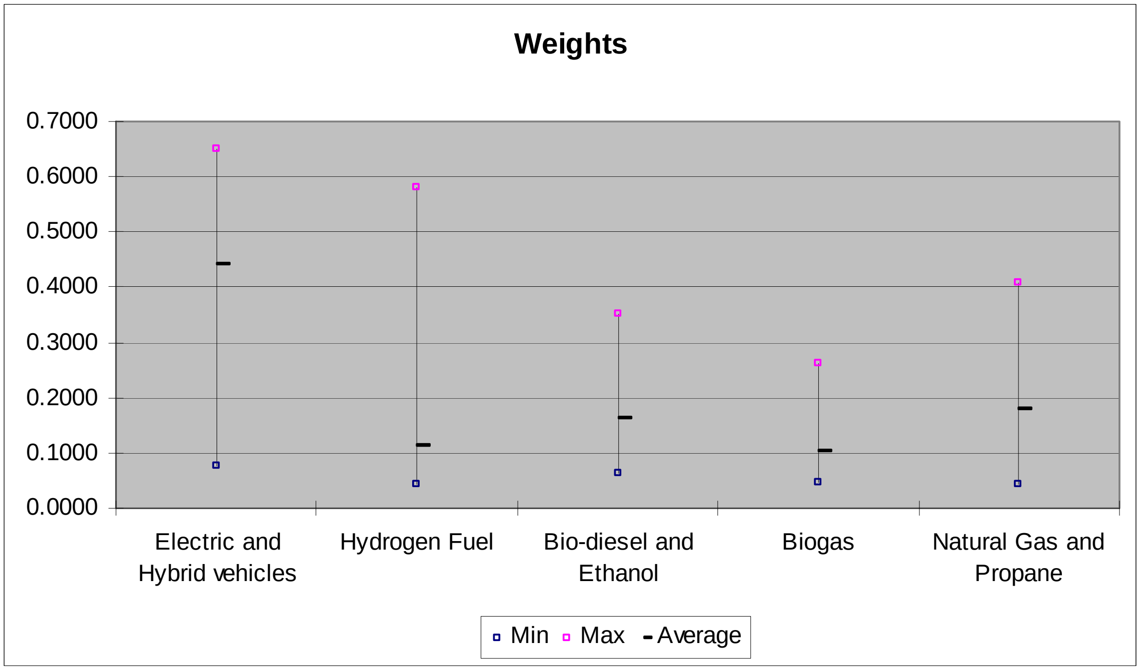

Fig 8. Weights of Energy and Environment Technologies

Table 4. Weights of Energy and Environment Technologies

	Min	Max	Average	Std Dev	C.O.V
Electric and Hybrid vehicles	0.0771	0.6511	0.4429	0.12	0.27
Hydrogen Fuel	0.0417	0.5810	0.1116	0.13	1.15
Bio-diesel and Ethanol	0.0616	0.3533	0.1623	0.09	0.58
Biogas	0.0475	0.2606	0.1025	0.05	0.50
Natural Gas and Propane	0.0424	0.4071	0.1807	0.12	0.65

Overall general comments from experts:
"A variety of fuels would give us resilience. Different fuels will likely be promoted for Different vehicles and applications - auto versus bus and train for example."

"I see electric and hybrid-electric vehicles as potentially more popular assuming appropriate storage technologies batteries and related infrastructure can be developed. The advantage of electric-hybrid vehicles is that the fuel used to generate the electric power can be changed in response to markets and other constraints without changing the vehicle or the support infrastructure. As long as electrical power is delivered to the user, the vehicle can operate, regardless of the energy source used to generate the power. The trade-offs, of course deal with the generation, transmission, and distribution of electrical power versus the production and distribution of alternative fuels and associated infrastructure. Bio-diesel and ethanol has already been integrated into the infrastructure and many vehicles are dual fuel capable so we will likely see increased use of these fuels unless we see this infringing on production of food crops to the point that regulatory intervention results."

5 Appendix: Ratio Comparison Matrices and Weights

CONGESTION REDUCTION AND MANAGEMENT TECHNOLOGIES

1 = Collaborative Technologies
2 = Personal Rapid Transit
3 = Adaptive Ramp Metering
4 = Smartcards and RFID
5 = GPS and Personal Travel Assistant

Expert 1		1	2	3	4	5	Weights
	1	1.00	6.00	6.00	0.33	0.17	0.24
	2	0.17	1.00	0.17	0.13	0.14	0.04
	3	0.17	6.00	1.00	0.14	0.20	0.05
	4	3.00	8.00	7.00	1.00	0.17	0.34
	5	6.00	7.00	5.00	6.00	1.00	0.33

Expert 2		1	2	3	4	5	
	1	1.00	5.00	5.00	4.00	4.00	0.36
	2	0.20	1.00	0.14	0.20	0.50	0.07
	3	0.20	7.00	1.00	0.33	0.13	0.06
	4	0.25	5.00	3.00	1.00	0.33	0.18
	5	0.25	2.00	8.00	3.00	1.00	0.33

Expert 3		1	2	3	4	5	
	1	1.00	6.00	3.00	3.00	2.00	0.34
	2	0.17	1.00	0.20	0.25	0.25	0.05
	3	0.33	5.00	1.00	4.00	3.00	0.30
	4	0.33	4.00	0.25	1.00	0.33	0.10
	5	0.50	4.00	0.33	3.00	1.00	0.20

Expert 4		1	2	3	4	5	
	1	1.00	5.00	3.00	4.00	0.17	0.26
	2	0.20	1.00	0.25	0.14	0.17	0.06
	3	0.33	4.00	1.00	3.00	0.20	0.12
	4	0.25	7.00	0.33	1.00	0.17	0.09
	5	6.00	6.00	5.00	6.00	1.00	0.47

Expert 5		1	2	3	4	5	
	1	1.00	7.00	0.20	0.33	0.17	0.08
	2	0.14	1.00	0.14	0.14	0.13	0.04

	3	5.00	7.00	1.00	1.00	1.00	0.29
	4	3.00	7.00	1.00	1.00	6.00	0.28
	5	6.00	8.00	1.00	0.17	1.00	0.31

Expert 6		1	2	3	4	5	
	1	1.00	0.20	0.25	1.00	0.50	0.09
	2	5.00	1.00	0.20	0.20	0.20	0.06
	3	4.00	5.00	1.00	2.00	1.00	0.33
	4	1.00	5.00	0.50	1.00	1.00	0.24
	5	2.00	5.00	1.00	1.00	1.00	0.27

Expert 7		1	2	3	4	5	
	1	1.00	0.33	1.00	0.50	0.50	0.13
	2	3.00	1.00	0.33	0.25	0.50	0.10
	3	1.00	3.00	1.00	0.50	1.00	0.21
	4	2.00	4.00	2.00	1.00	3.00	0.38
	5	2.00	2.00	1.00	0.33	1.00	0.18

Expert 8		1	2	3	4	5	
	1	1.00	3.00	2.00	0.25	3.00	0.17
	2	0.33	1.00	0.20	0.14	0.33	0.06
	3	0.50	5.00	1.00	0.20	5.00	0.24
	4	4.00	7.00	5.00	1.00	7.00	0.47
	5	0.33	3.00	0.20	0.14	1.00	0.06

Expert 9		1	2	3	4	5	
	1	1.00	5.00	5.00	8.00	6.00	0.38
	2	0.20	1.00	0.20	0.13	0.33	0.06
	3	0.20	5.00	1.00	0.25	0.25	0.09
	4	0.13	8.00	4.00	1.00	7.00	0.41
	5	0.17	3.00	4.00	0.14	1.00	0.07

Expert 10		1	2	3	4	5	
	1	1.00	7.00	0.50	3.00	3.00	0.29
	2	0.14	1.00	0.25	0.14	0.20	0.05
	3	2.00	4.00	1.00	0.50	4.00	0.22
	4	0.33	7.00	2.00	1.00	7.00	0.37
	5	0.33	5.00	0.25	0.14	1.00	0.07

Expert 11		1	2	3	4	5	
	1	1.00	3.00	3.00	0.20	0.33	0.11

	2	0.33	1.00	0.50	0.25	0.50	0.10
	3	0.33	2.00	1.00	0.50	0.25	0.11
	4	5.00	4.00	2.00	1.00	0.33	0.35
	5	3.00	2.00	4.00	3.00	1.00	0.33

Expert 12		1	2	3	4	5	
	1	1.00	0.17	2.00	0.33	0.20	0.07
	2	6.00	1.00	0.14	0.25	0.50	0.14
	3	0.50	7.00	1.00	0.25	0.17	0.08
	4	3.00	4.00	4.00	1.00	0.50	0.30
	5	5.00	2.00	6.00	2.00	1.00	0.41

Expert 13		1	2	3	4	5	
	1	1.00	0.33	0.50	4.00	2.00	0.23
	2	3.00	1.00	0.50	0.20	0.50	0.14
	3	2.00	2.00	1.00	4.00	4.00	0.40
	4	0.25	5.00	0.25	1.00	0.50	0.10
	5	0.50	2.00	0.25	2.00	1.00	0.13

Expert 14		1	2	3	4	5	
	1	1.00	0.25	0.50	2.00	0.50	0.12
	2	4.00	1.00	0.50	0.33	0.33	0.13
	3	2.00	2.00	1.00	2.00	2.00	0.30
	4	0.50	3.00	0.50	1.00	0.50	0.16
	5	2.00	3.00	0.50	2.00	1.00	0.29

Expert 15		1	2	3	4	5	
	1	1.00	4.00	5.00	6.00	0.14	0.27
	2	0.25	1.00	0.17	0.14	0.20	0.06
	3	0.20	6.00	1.00	5.00	0.17	0.21
	4	0.17	7.00	0.20	1.00	0.14	0.05
	5	7.00	5.00	6.00	7.00	1.00	0.41

Expert 16		1	2	3	4	5	
	1	1.00	0.14	0.25	3.00	0.25	0.09
	2	7.00	1.00	0.14	0.13	0.17	0.06
	3	4.00	7.00	1.00	5.00	3.00	0.41
	4	0.33	8.00	0.20	1.00	0.20	0.10
	5	4.00	6.00	0.33	5.00	1.00	0.35

Expert 17		1	2	3	4	5	

	1	1.00	0.25	3.00	3.00	0.33	0.16
	2	4.00	1.00	0.25	0.25	0.25	0.09
	3	0.33	4.00	1.00	0.50	0.33	0.14
	4	0.33	4.00	2.00	1.00	0.33	0.20
	5	3.00	4.00	3.00	3.00	1.00	0.41

Expert 18		1	2	3	4	5	
	1	1.00	7.00	7.00	4.00	7.00	0.43
	2	0.14	1.00	0.25	0.14	0.20	0.05
	3	0.14	4.00	1.00	0.25	0.25	0.06
	4	0.25	7.00	4.00	1.00	0.17	0.25
	5	0.14	5.00	4.00	6.00	1.00	0.21

Expert 19		1	2	3	4	5	
	1	1.00	0.33	0.13	3.00	0.25	0.07
	2	3.00	1.00	0.33	0.13	0.20	0.11
	3	8.00	3.00	1.00	8.00	6.00	0.54
	4	0.33	8.00	0.13	1.00	0.33	0.07
	5	4.00	5.00	0.17	3.00	1.00	0.21

Expert 20		1	2	3	4	5	
	1	1.00	5.00	1.00	1.00	4.00	0.30
	2	0.20	1.00	0.25	0.25	0.20	0.05
	3	1.00	4.00	1.00	1.00	1.00	0.22
	4	1.00	4.00	1.00	1.00	3.00	0.25
	5	0.25	5.00	1.00	0.33	1.00	0.17

Expert 21		1	2	3	4	5	
	1	1.00	7.00	3.00	4.00	1.00	0.33
	2	0.14	1.00	0.25	0.25	0.14	0.05
	3	0.33	4.00	1.00	0.33	0.13	0.07
	4	0.25	4.00	3.00	1.00	0.20	0.11
	5	1.00	7.00	8.00	5.00	1.00	0.44

Expert 22		1	2	3	4	5	
	1	1.00	7.00	5.00	0.17	0.25	0.25
	2	0.14	1.00	0.33	0.13	0.20	0.05
	3	0.20	3.00	1.00	0.13	0.20	0.05
	4	6.00	8.00	8.00	1.00	8.00	0.47
	5	4.00	5.00	5.00	0.13	1.00	0.18

1 = Machine Vision
2 = V2V and V2I
3 = MEMS and Nanosensors

Expert 1	1	2	3	weight
1	1	7	6	0.76
2	0.14	1	0.33	0.10
3	0.17	3	1	0.14

Expert 2	1	2	3	
1	1	0.25	0.25	0.11
2	4	1	3	0.52
3	4	0.33	1	0.37

Expert 3	1	2	3	
1	1	3	2	0.51
2	0.33	1	3	0.31
3	0.5	0.33	1	0.18

Expert 4	1	2	3	
1	1	3	0.25	0.20
2	0.33	1	0.2	0.12
3	4	5	1	0.67

Expert 5	1	2	3	
1	1	4	0.33	0.48
2	0.25	1	1	0.16
3	3	1	1	0.36

Expert 6	1	2	3	
1	1	0.25	3	0.20
2	4	1	5	0.67
3	0.33	0.2	1	0.12

Expert 7	1	2	3	
1	1	0.2	0.25	0.10
2	5	1	1	0.49
3	4	1	1	0.41

Expert 8	1	2	3	
1	1	0.14	5	0.12
2	7	1	5	0.75
3	0.2	0.2	1	0.13

Expert 9	1	2	3	
1	1	2	0.2	0.14

Expert 12	1	2	3	weight
1	1	0.5	3	0.30
2	2	1	0.2	0.14
3	0.33	5	1	0.56

Expert 13	1	2	3	
1	1	3	8	0.40
2	0.33	1	0.14	0.09
3	0.13	7	1	0.51

Expert 14	1	2	3	
1	1	0.5	2	0.29
2	2	1	4	0.57
3	0.5	0.25	1	0.14

Expert 15	1	2	3	
1	1	0.2	6	0.36
2	5	1	7	0.57
3	0.17	0.14	1	0.07

Expert 16	1	2	3	
1	1	0.2	3	0.16
2	5	1	7	0.74
3	0.33	0.14	1	0.10

Expert 17	1	2	3	
1	1	0.17	0.17	0.08
2	6	1	1	0.46
3	6	1	1	0.46

Expert 18	1	2	3	
1	1	6	0.14	0.13
2	0.17	1	0.13	0.09
3	7	8	1	0.78

Expert 19	1	2	3	
1	1	0.14	5	0.12
2	7	1	6	0.76
3	0.2	0.17	1	0.11

Expert 20	1	2	3	
1	1	0.25	0.25	0.11

	2	0.5	1	1	0.26		2	4	1	1	0.44
	3	5	1	1	0.60		3	4	1	1	0.44
Expert 10		1	2	3		Expert 21		1	2	3	
	1	1	5	0.5	0.50		1	1	0.33	0.33	0.15
	2	0.2	1	0.33	0.11		2	3	1	3	0.55
	3	2	3	1	0.39		3	3	0.33	1	0.29
Expert 11		1	2	3		Expert 22		1	2	3	
	1	1	0.33	5	0.41		1	1	1	1	0.33
	2	3	1	5	0.50		2	1	1	1	0.33
	3	0.2	0.2	1	0.09		3	1	1	1	0.33

ENERGY AND ENVIRONMENT

1 = Electric-driven and Hybrid vehicles
2 = Hydrogen Fuel
3 = Bio-diesel and Ethanol
4 = Biogas
5 = Natural Gas and Propane

Expert 1		1	2	3	4	5	Weights
	1	1	7	6	7	2	0.44
	2	0.1429	1	0.25	0.25	0.2	0.06
	3	0.1667	4	1	1	0.1667	0.07
	4	0.1429	4	1	1	0.1667	0.07
	5	0.5	5	6	6	1	0.36
Expert 2		1	2	3	4	5	
	1	1	9	7	7	7	0.60
	2	0.1111	1	0.2	0.2	0.1429	0.05
	3	0.1429	5	1	3	3	0.13
	4	0.1429	5	0.3333	1	0.3333	0.09
	5	0.1429	7	0.3333	3	1	0.13
Expert 3		1	2	3	4	5	
	1	1	4	4	4	3	0.45
	2	0.25	1	3	0.5	0.3333	0.11
	3	0.25	0.3333	1	2	0.5	0.11
	4	0.25	2	0.5	1	0.5	0.11
	5	0.3333	3	2	2	1	0.22
Expert 4		1	2	3	4	5	
	1	1	8	6	7	9	0.39
	2	0.125	1	0.125	0.1429	0.5	0.04
	3	0.1667	8	1	3	8	0.33
	4	0.1429	7	0.3333	1	5	0.20

	5	0.1111	2	0.125	0.2	1	0.04
Expert 5		1	2	3	4	5	
	1	1	7	6	5	5	0.45
	2	0.1429	1	0.3333	0.3333	0.1429	0.05
	3	0.1667	3	1	3	0.25	0.09
	4	0.2	3	0.3333	1	0.3333	0.09
	5	0.2	7	4	3	1	0.32
Expert 6		1	2	3	4	5	
	1	1	4	4	5	2	0.42
	2	0.25	1	0.3333	1	0.5	0.09
	3	0.25	3	1	3	3	0.23
	4	0.2	1	0.3333	1	0.3333	0.08
	5	0.5	2	0.3333	3	1	0.18
Expert 7		1	2	3	4	5	
	1	1	5	5	5	0.25	0.37
	2	0.2	1	0.25	0.25	0.25	0.07
	3	0.2	4	1	4	0.2	0.09
	4	0.2	4	0.25	1	0.2	0.08
	5	4	4	5	5	1	0.39
Expert 8		1	2	3	4	5	
	1	1	9	5	7	9	0.47
	2	0.1111	1	0.1429	0.2	3	0.05
	3	0.2	7	1	5	7	0.33
	4	0.1429	5	0.2	1	7	0.10
	5	0.1111	0.3333	0.1429	0.1429	1	0.05
Expert 9		1	2	3	4	5	
	1	1	9	8	7	1	0.50
	2	0.1111	1	4	6	0.2	0.06
	3	0.125	0.25	1	3	0.2	0.06
	4	0.1429	0.1667	0.3333	1	0.2	0.06
	5	1	5	5	5	1	0.32
Expert 10		1	2	3	4	5	
	1	1	9	8	8	8	0.65
	2	0.1111	1	0.2	0.2	0.3333	0.06
	3	0.125	5	1	2	5	0.11
	4	0.125	5	0.5	1	5	0.10
	5	0.125	3	0.2	0.2	1	0.07
Expert 11		1	2	3	4	5	
	1	1	7	5	5	3	0.49
	2	0.1429	1	0.3333	0.3333	0.25	0.06

	3	0.2	3	1	4	3	0.20
	4	0.2	3	0.25	1	3	0.10
	5	0.3333	4	0.3333	0.3333	1	0.14
Expert 12		1	2	3	4	5	
	1	1	4	3	7	6	0.38
	2	0.25	1	0.3333	8	2	0.25
	3	0.3333	3	1	4	6	0.26
	4	0.1429	0.125	0.25	1	0.5	0.05
	5	0.1667	0.5	0.1667	2	1	0.06
Expert 13		1	2	3	4	5	
	1	1	7	0.1429	8	5	0.52
	2	0.1429	1	0.3333	2	0.5	0.07
	3	7	3	1	0.5	1	0.21
	4	0.125	0.5	2	1	0.5	0.07
	5	0.2	2	1	2	1	0.12
Expert 14		1	2	3	4	5	
	1	1	7	4	5	3	0.51
	2	0.1429	1	0.5	0.5	0.5	0.07
	3	0.25	2	1	2	0.5	0.13
	4	0.2	2	0.5	1	0.5	0.10
	5	0.3333	2	2	2	1	0.18
Expert 15		1	2	3	4	5	
	1	1	7	7	8	8	0.51
	2	0.1429	1	0.25	5	0.2	0.07
	3	0.1429	4	1	6	0.25	0.09
	4	0.125	0.2	0.1667	1	0.1667	0.05
	5	0.125	5	4	6	1	0.27
Expert 16		1	2	3	4	5	
	1	1	0.125	5	0.25	3	0.08
	2	8	1	6	6	5	0.58
	3	0.2	0.1667	1	0.3333	2	0.09
	4	4	0.1667	3	1	3	0.16
	5	0.3333	0.2	0.5	0.3333	1	0.09
Expert 17		1	2	3	4	5	
	1	1	5	5	5	0.2	0.35
	2	0.2	1	0.25	0.3333	0.2	0.07
	3	0.2	4	1	4	0.2	0.10
	4	0.2	3	0.25	1	0.2	0.07
	5	5	5	5	5	1	0.41
Expert 18		1	2	3	4	5	

	1	1	7	3	7	7	0.43
	2	0.1429	1	5	6	6	0.36
	3	0.3333	0.2	1	0.3333	0.2	0.08
	4	0.1429	0.1667	3	1	0.2	0.06
	5	0.1429	0.1667	5	5	1	0.07
Expert 19		1	2	3	4	5	
	1	1	8	6	6	6	0.44
	2	0.125	1	0.1429	0.2	0.1667	0.05
	3	0.1667	7	1	5	6	0.35
	4	0.1667	5	0.2	1	4	0.09
	5	0.1667	6	0.1667	0.25	1	0.07
Expert 20		1	2	3	4	5	
	1	1	6	0.3333	4	3	0.36
	2	0.1667	1	0.25	0.25	0.25	0.06
	3	3	4	1	1	3	0.27
	4	0.25	4	1	1	1	0.17
	5	0.3333	4	0.3333	1	1	0.15
Expert 21		1	2	3	4	5	
	1	1	7	7	7	7	0.62
	2	0.1429	1	0.25	0.3333	0.3333	0.08
	3	0.1429	4	1	4	3	0.13
	4	0.1429	3	0.25	1	3	0.09
	5	0.1429	3	0.3333	0.3333	1	0.08
Expert 22		1	2	3	4	5	
	1	1	4	3	2	1	0.32
	2	0.25	1	0.3333	0.3333	0.3333	0.08
	3	0.3333	3	1	0.3333	0.3333	0.10
	4	0.5	3	3	1	2	0.26
	5	1	3	3	0.5	1	0.24

6 Project Status Report Approvals

Prepared by ________________________________
Principal Investigator

Approved by ________________________________
Project Manager