Development

of

Risk Assessment Matrix

for

NASA Engineering and Safety Center

by

Kelly D. Moses. P. E.

Senior Risk Analyst

Futron Corporation

Roy W. Malone, Jr.

Deputy Director

Safety & Mission Assurance Directorate

NASA Marshall Space Flight Center

Abstract

This paper describes a study, which had as its principal goal the development of a sufficiently detailed 5 x 5 Risk Matrix Scorecard. The purpose of this scorecard is to outline the criteria by which technical issues can be qualitatively and initially prioritized. The tool using this score card has been proposed to be one of the information resources the NASA Engineering and Safety Center (NESC) takes into consideration when making decisions with respect to incoming information on safety concerns across the entire NASA agency. The contents of this paper discuss in detail each element of the risk matrix scorecard, definitions for those elements and the rationale behind the development of those definitions. This scorecard development was performed in parallel with the tailoring of the existing Futron Corporation Integrated Risk Management Application (IRMA) software tool. IRMA was tailored to fit NESC needs for evaluating incoming safety concerns and was renamed NESC Assessment Risk Management Application (NARMA) which is still in developmental phase.

Key Words or Phrases

Risk Assessment, Risk Matrix, Decision, IRMA, Per Opportunity

1.0 Background

The NASA Engineering and Safety Center is an independent organization, chartered in the wake of the Space Shuttle Columbia accident and in response to the observations of the Columbia Accident Investigation Board (CAIB). The objective of the NESC is to ensure the safety and engineering excellence of NASA's programs and institutions. This is to be accomplished by using a diverse mix of talent from across the nation for the following activities: coordinating and conducting robust engineering testing and safety assessments; performing independent testing and analysis; and reviewing programs and institutional issues at all centers including headquarters.

The organization will be proactive in looking for the next problem or issue as well as be one of several collection points for all identified safety related reports, issues, problems and/or concerns for the entire NASA agency. The product of the NESC will be a formal, independent technical assessment of all major NASA programs resulting in written reports, briefings, and/or recommendations. Additionally, the NESC will provide a centralized location for the management of independent engineering assessment by expert personnel and state of the art tools and methods for the purpose of assuring safety.

Areas for independent assessment will be carefully selected and managed with a strong focus on technical merit. Work will be prioritized based on technical risk, the need for independence and the potential for value-added contribution. Methods for this selection and prioritization are ongoing and include the tasks completed during the contract efforts described in this report.

2.0 Risk Matrix Background

Widely accepted and state-of-the-art risk matrix templates are available from several reputable sources including, Defense Acquisition University (DAU)/Defense Systems Management College (DSMC)[1], Software Engineering Institute (SEI)[2], NASA Policy Guidance Document 7120.5B[3] as well as others. The critical step in establishing a meaningful and useful risk management and risk analysis system is tailoring the risk matrix components. This is accomplished by weighing the program's mission, goals and objectives while concurrently considering the organization's degree of risk affinity or aversion. The objective of evaluating the attributes of a risk is to gain a better understanding by determining the expected impact, probability and timeframe of the risk. Risks should be evaluated at a level of analysis that is sufficient to determine the relative importance for effective handling strategies.[2] For NESC purposes, this step will be used in the decision if action will be taken and with respect to who has the responsibility of assessing the issue.

The effort of tailoring a 5 x 5 Risk Matrix Scorecard to NESC needs included developing both quantitative and qualitative attributes and definitions. This will provide a framework for communicating how individual issues will be initially classified and later prioritized by NESC. The 5 x 5 Risk Matrix Scorecard developed for NESC use is shown in Figure 1. The following sections explain in detail how each element of that scorecard was developed.

3.0 Risk Definitions

Following two days of discussions on risk definition, it was agreed that, Fell[4] encompassed the mood toward risk that the NESC currently has adopted:

"Unfortunately, there are no generally accepted definitions of the terms used in risk assessment …… shortly after its formation in 1981, the United States Society for Risk Analysis established a committee to define risk. After 3 or 4 years of work the committee published a list of 14 candidate definitions and reported that it could not reach agreement. They recommended that a single definition of risk not be established but that every one be free to define it as appropriate to his or her own work."

The development of the risk definitions for NESC purposes certainly does not attempt to change this situation; however, it is felt that the various terms apply to the NESC use. The following definitions were proposed:

3.1 Risk

Measure of the potential inability to achieve overall program objectives within defined constraints and has two components: 1) the probability/likelihood of failing to achieve a particular outcome, and 2) the consequence/impact of failing to achieve that outcome[1].

3.2 Consequence

Impact (typically categorized as negative) to program and/or project (loss, injury, disadvantage).

It was felt this definition of consequence was broad enough, combined with the scales developed for the matrix, to communicate NESC preferences. Keeping in

mind, NESC will be receiving risks, problems, concerns, and issues from several sources and various pipelines.

3.3 Likelihood

Ordinal scale: Relative ranking of probability of occurrence. Numerical scale: estimated range of probability an event will occur combined with the uncertainty in the probability assessment.

When developing an NESC likelihood definition, it was important to demonstrate an ordinal scale, to clearly establish preference as well as a numerical scale. There seems to exist two schools of thought regarding how to communicate and assess the likelihood of the issues. One prefers an ordinal scale that represents only priority order and cleanly communicates priority between likelihood categories to those reviewing how issues have already been assessed and placed in the 5 x 5 matrix. The other school of thoughts prefers a numerical scale feeling it is important to those involved in initially assessing the issue. The numerical scale proposed for this effort represents ranges on a lognormal scale. The lognormal scale was proposed in order to allow the communication of events that happen with an occurrence of "one in some "x" order of magnitude. Thus, it was decided the likelihood should incorporate both aspects of what would be communicated in the 5 x 5 Risk Matrix Scorecard. For communicating preferences and guiding others in establishing their subjective likelihood assessments, it was felt examples associated with each likelihood range were necessary. These examples are discussed in Sections 4.4 and 4.5

3.4 Risk Management

An organized, systematic decision-making process that efficiently identifies risks, assesses or analyzes risks, tracks and communicates risk and effectively reduces or eliminates risks to achieve program goals[5].

These definitions appear to embrace the NESC feelings toward risk at this time. It is not inconceivable for these definitions to change or be modified as the NESC matures.

4.0 Likelihood Definitions

A definitions box was developed to accommodate and explain the 5 x 5 Risk Matrix likelihood axis. Four categories of descriptors were chosen for explaining and defining the likelihood bins and associated ranges.

4.1 Level

An ordinal scale from one to five was chosen. This ordinal scale simply represents the degree of probability rank ordered from one to five. Ratio between numbers is not intended to communicate anything other than preference in rank order from one level to the next. The least likely indicator is 1 and the most likely indicator is 5. There should not be any type of mathematical operations performed or associated with this ordinal scale.

4.2 Probability

The narrative probability scale is intended to be a brief descriptor of subject attitudes toward each likelihood descriptor. The range chosen was from “Very Low” to “Very

Likely". Many studies have been conducted on the verbal ranges; however, nearly all of those found were for base ten numerical scales. The verbal likelihood descriptors had to be adopted for not only a lognormal scale, but also for the specific lognormal ranges proposed for NESC in this effort. For each of the ordinal scale categories, there is a corresponding probability description, as is the case for the following two categories.

4.3 Narrative Description and Numerical Ranges

The narrative field approaches a better descriptor, and is another step in the maturity and tailoring of the likelihood definitions box. Numerical ranges on a lognormal scale are incorporated into this category. The two schools of thought are now both satisfied: there is both an ordinal scale and a numerical scale.

4.4 Example

A perspective introduced during the NESC Risk 5 x 5 Matrix development is that of describing likelihood using numerical probabilities that reflect the occurrence of an event on a per opportunity basis. The paradigm of 'per opportunity' appears to be unique (with respect to a risk matrix development) to the NESC Risk Matrix. An example of this can be given as fatal crashes per passenger airplane departure or fatal crashes per automobile trip. This communicates, once the opportunity actuates (the departure in this case) there is either failure or not (failure, being described as death, injury, failure to meet an objective, goal or mission).

It is important to note, the categories do not contain equal ranges. The numerical ranges for each level were proposed for NESC prior to any research on failures per operational

opportunity were conducted. It was discovered the ranges clearly represented distinct classes of events, which will be described in more detail later in this report.

In addition to the narrative example, it was perceived that listing an event example for each range to which a layperson could comprehend would help those assessing the issues develop a better frame of reference. This is intended to facilitate the reduction of the uncertainty in subjective assessments of likelihood for this 5 x 5 matrix.

4.5 Communicating Definitions within Matrix

The following categories are distinguished by Level and Probability descriptors that correspond to the input parameters in the likelihood box on the 5 x 5 Risk Matrix Scorecard. Examples that fall into each category are represented in Table 1.

4.5.1 Level 1 Probability Very Low

Narrative: Likelihood of occurrence is estimated to be less than 0.000001 (10^{-6}) per operational opportunity.

Example: Fatal crashes per passenger airplane opportunity[6].

Brief Explanation: Air travel is by far one of the safest activities in which our society participates daily. It is a very mature technology in which we do not tolerate frequent failure. When failures do occur, we invest extensive resources to prevent future failures.

4.5.2 Level 2 Probability Low

Narrative: Unlikely but possible to occur. Likelihood of occurrence is estimated to be

between 0.000001 and 0.001 (10^{-6} and 10^{-3}) per operational opportunity.

Example: Fatalities per passenger vehicle trip[7, 8].

Brief Explanation: This category represents nearly all risks that are accepted by society as being acceptable to a layperson.

Assumptions: In order to calculate a 'per opportunity' value, it was assumed a passenger vehicle trip was approximately 70 miles on average; a passenger bus trip was approximately 70 miles on average. These average miles per trip are for demonstration purposes only. It was felt, these average values were reasonable; however there was not any evidence available to the authors at the time of the writing of this paper verifying the average passenger vehicle trip, or the average passenger bus trip.

4.5.3 Level 3 Probability Moderate

Narrative: Likely to occur some time in the life of the item event. Likelihood of occurrence is estimated to be between 0.001 and 0.01 (10^{-3} and 10^{-2}) per operational opportunity.

Example: Fatalities per motorcycle trip[9].

Brief Explanation: This category represents events that our society appears to be divided on with respect to whether or not it is an acceptable risk. Many individuals make a conscious choice to avoid this activity; whereas some still accept the risk.

Assumptions: In order to calculate a 'per opportunity' value, it was assumed a motorcycle trip was approximately 50 miles. Again, the value of miles per motorcycle trip is for demonstrational purposes only, but believed to be reasonable.

It should be noted; motorcycle trips are hover at the dividing line between level 2 and level 3, depending on the assumed average miles per trip. If the assumed trip is approximately 20 miles, motorcycle trips would be classified as level 2.

4.5.4 Level 4 Probability High

Narrative: Expected to occur some time in the life of the item. Likelihood of occurrence is estimated to be between 0.01 and 0.10 (10^{-2} and 10^{-1}) per operational opportunity.

Example: US ELV Launches (1998 – 2001) and open-heart surgeries[10, 11, 12].

Brief Explanation: Events in this category are still considered risky by society as a whole. The example provided, Expendable Launch Vehicles, does not involve human death. Or, if they do indeed involve human death, it is an accepted risk a person makes a clear and conscious choice for personal and/or health related issues.

4.5.5 Level 5 Probability Very Likely

Narrative: Likely to occur often. Likelihood of occurrence is estimated to be greater than 0.10 (10^{-1}) per operational opportunity

Example: Mortality (death) during, or as a result of, brain surgery[12, 13, 14, 15].

Brief Explanation: It was discovered that real life examples in this category and probability range typically fall into three subcategories:

1. Stupid stunts: Society as a whole does not accept death or injury rates in this category and we have evolved in such a way as to avoid such activity, unless it is out of sheer stupidity. Darwin Award Winners.
2. Lesser of the Two Evils. There are instances where we will accept high failure

rates when options in this category are the only options available. Very risky surgeries are in this category.

3. Easily/Cheaply replaceable items or, rarely re-used items. Examples are common things such as paper clips. This category is recommended for further investigation, especially in light of emerging technologies and 'low use' parts and/or systems.

5.0 Consequence Definitions

There was not any research performed in this category; but it is included for completeness. Comments and recommendations on this category are as follows: It is recommended, for consistency between likelihood and consequence values, consequence definitions receive a more in-depth study during future development of the NARMA software. In addition, there is an effort to ensure the color-coding scheme of the 5 x 5 risk matrix properly reflects not only NASA perspective, but NESC perspective as well.

The Consequence Definitions evolved from Table 2 titled "Mishap Severity Categories." The indicators for each category came from legacy information primarily obtained out of a Payload Classification Document. As a result of this information, NESC was quite comfortable with the descriptors in this table. The only value added by Futron was the replacement of "No" in level 1 with "minimal to no". It was discussed and agreed upon "no" referred to the absolute value of zero and "minimal to no" communicated a more reasonable range for level 1 occurrences.

It is to be noted, the descriptors discussed above and reflected in Figure 1 have been greatly abbreviated to accommodate the limited space available on the 5 x 5 Risk Matrix

Scorecard.

5.1 Risk Consequence Scoring Terms

It was felt that additional information might help reduce the amount of subjective assessment as much as possible. At this stage in the development of NARMA, the set of screening questions being developed by NESC in a parallel effort, have not been 'tied' to the risk consequence indicators, but this is something that needs to be done in the future. NESC is only dealing with issues that are considered technical in nature. Cost and Schedule considerations will not be evaluated. The emphasis is on the risk consequence scoring terms selected as described above.

5.1.1 Safety, Health, Environment

In the 5 x 5 matrix scorecard, Safety, Health and Environment (SHE) was selected as a consequence category for this effort because it was reflective of death, injury, or damage to resources.

5.1.2 Mission Success

Mission Success (MS) can be described as avoiding loss of crew (LOC), loss of vehicle (LOV) and/or loss of science mission (LOM). It is imperative that successful missions occur on a regular and frequent basis. There is a range of activities that fall under the umbrella of mission success and include the following: Major Mission Objectives (MMOs), Supplemental Mission Objectives, and costly hardware losses in a monetary sense.

5.1.3 National Significance

NESC is concerned about events that fall into a category that has been titled National Significance (NS). National Significance can also be described as national prestige or visibility. At this critical point in NASA's history, another high visibility failure of any kind is likely to result in public outcry and political fallout. The American public put great pride in the capabilities of NASA to achieve technological advances and feats. Public support is critical to future funding of NASA programs.

5.1.4 Risk Scoring

Currently, the NARMA software scores the risks by multiplying representative values for likelihood by consequence. This is done solely to obtain a draft qualitative prioritized listing of risks and an improved method is under development. Care must be taken with using multiplied values as measures. It must be noted, as an example, a score of "6" can be either 2 x 3 or 3 x 2, depending on the values attributed to each likelihood and consequence level. The first mathematical operation places the risk in the 'green' zone of the matrix and the latter places the risk in the 'yellow' zone. These two zones of the matrix, as described later may be treated quite differently by NESC in how they opt to disposition their risks.

An alternative method is having a numerical value reflective of the ordered pair, likelihood, consequence (L,C) which would communicate more information such as either 2,3 or 3,2 from the previous example.

5.1.5 Matrix Placement

When determining risk consequence between Safety Health and Environment (SHE), Mission Safety (MS) or National Significance (NS), NARMA at the time of this paper uses the highest score represented among the three areas and places that value in the matrix corresponding to the consequence axis as shown in Figure 2.

Future endeavors could involve creating individual placeholders in the matrix for S, M and N, as shown in Figure 3. This method will communicate more of the risk information.

For the likelihood values, only one value can be chosen. If a risk assessor feels there are different likelihood values for the consequences of SHE, MS and/or NS writing a separate risk should be considered. It should be noted that currently NARMA is not capable of correlating or linking risks within the database. This capability has been proposed by both the International Space Station (ISS) program office as well as the Orbital Space Plane (OSP) program office (both of which have implemented tailored versions of IRMA) and is currently being investigated by Futron for a future version of IRMA.

5.2 Risk Matrix and Legend

A 5 x 5 risk matrix was proposed for the NESC purposes. It was decided that a typical 3 x 3 did not provide enough resolution, anything greater than a 5 x 5 was too distracting and anything nonsymmetrical was not logical.

The 5 x 5 matrix has been color coded with red, yellow and green segments for each matrix ‘value’. Currently the matrix color-coding is NOT symmetrical, but is under intense scrutiny. Individual likelihood combined with individual consequence needs to be

evaluated in detail. This is suggested as a future effort.

A legend was developed to explain the color-coding within the 5 x 5 matrix. This color-coding is currently under scrutiny as will be explained in the following sections.

5.2.1 Low

It is proposed, those items color-coded green within the risk matrix be considered as 'low' by the NESC. It is also proposed, an item in this category be accepted by NESC for Board review and it is probable that a referral to another NASA Independent Assessment organization will be made.

5.1.2 Medium

It is proposed, those items color-coded yellow be considered 'medium' by the NESC. It is recommended an item in this category be accepted for NESC Board review. NESC or other NASA Independent Assessment group or organization action is required.

5.1.3 High

It is proposed, those items color-coded red be considered 'high' priority items. An item in this category may immediately be accepted for NESC Board review. It is most probable NESC will perform the follow-on independent assessment.

6.0 Summary and Conclusions

A 5 x 5 Risk Matrix Scorecard has been tailored for NESC purposes and incorporated into the NARMA software application. The NARMA NESC 5 x 5 Risk Matrix scorecard is shown in Figure I and can be accessed through the "Help" menu contained within the

NESC Assessment Risk Management Application (NARMA) which is the NESC database used to assess and prioritize concerns brought to the attention of the NESC.

The selection of tools and methods to achieve the goals and objective of the NESC are maturing and ongoing. The tasks completed 1) directly support the efforts to ensure the independent assessments within NASA will be carefully selected and managed and 2) assist NESC in securing their goals and objective of ensuring the safety and engineering excellence of NASA's programs and institutions. The recommendations made for further development of these tools and processes are critical extensions of the work performed thus far.

Acknowledgements

The National Aeronautics and Space Administration, Langley Research Center, Engineering and Safety Center under Award NNL04AA29T provided funding for this study. Any opinions, findings, or conclusions expressed here are those of the authors and do not necessarily reflect the views of the Administration.

References

1. Risk Management Guide for DoD Acquisition Fourth Edition, February 2001, Department of Defense, Defense Acquisition University, Defense Management Systems College.

2. Dorofee, Audrey J., et. al., *Continuous Risk Management Guidebook*, Software Engineering Institute, Carnegie Mellon University, Pittsburgh, August, 1996.

3. NASA NPR 7120.5B *NASA Program and Project Management Processes and Requirements*, Section 4.2, November 21, 2002.

4. Fell, R. "Landslide Risk Assessment and Allowable Risk," Canadian Geotechnical Journal, 31(2): 261-272. 1994.

5. NASA ISS-JPD (Joint Program Directive)-306 Revision B. Subject: Establishment of the Program Risk Management System (PRMS). September 4, 2001

6. National Transportation Safety Board, AVIATION ACCIDENT STATISTICS http://www.ntsb.gov/aviation/Stats.htm, Table 5. Accidents, Fatalities, and Rates, 1983 through 2002, for U.S. Air Carriers Operating Under 14 CFR 121, Scheduled and Nonscheduled Service (Airlines)

7. U. S. Department of Transportation, Bureau of Transportation Statistics Report – "National Transportation Statistics 2002 BTS02-08" Chapter 2 - Transportation Safety *Table 2-24: Bus Occupant Safety Data* http://www.bts.gov/publications/national_transportation_statistics/2002/excel/table_02_24.xls

8. U. S. Department of Transportation, Bureau of Transportation Statistics Report – "National Transportation Statistics 2002 BTS02-08" Chapter 2 - Transportation Safety *Table 2-18 - Motor Vehicle Fatalities, Vehicle-Miles, and Associated Rates by Highway Functional System* http://www.bts.gov/publications/national_transportation_statistics/2002/excel/table_02_18.xls

9. U. S. Department of Transportation, Bureau of Transportation Statistics Report – "National Transportation Statistics 2002 BTS02-08" Chapter 2 - Transportation Safety *Table 2-22: Motorcycle Rider Safety Data* http://www.bts.gov/publications/national_transportation_statistics/2002/excel/table_02_22.xls

10. SpaceCRG Data on U.S. and Worldwide Launch Vehicle Failures

Worldwide Space Launch Vehicle Failure Rate... By Decade
http://www.spacecrg.com/charts.htm

11. State of New York Department of Health, Commissioner Novello Releases Report on Open Heart Surgery
http://www.health.state.ny.us/nysdoh/commish/2000/hheart.htm

12. John D. Birkmeyer, M.D., Therese A. Stukel, Ph.D., Andrea E. Siewers, M.P.H., Philip P. Goodney, M.D., David E. Wennberg, M.D., M.P.H., and F. Lee Lucas, Ph.D. "Surgeon Volume and Operative Mortality in the United States" The New England Journal of Medicine. Volume 349:2117-2127 Number 22 November 27, 2003 http://content.nejm.org/cgi/content/short/349/22/2117

13. The Society of Thoracic Surgeons
http://www.sts.org/graphics/sts/db/us98/gchart53.gif

14. Polin RS, Shaffrey ME, Bogaev CA, Tisdale N, Germanson T, Bocchicchio B, Jane JA. Department of Neurosurgery, University of Virginia Health Sciences Center, Charlottesville, USA "Decompressive bifrontal craniectomy in the treatment of severe refractory posttraumatic cerebral edema". Neurosurgery. 1997 Jul;41(1):84-92

15. Good Samaritan Hospital's Gamma Knife Center
http://www.goodsam.org/gamma_knife/gamma.html

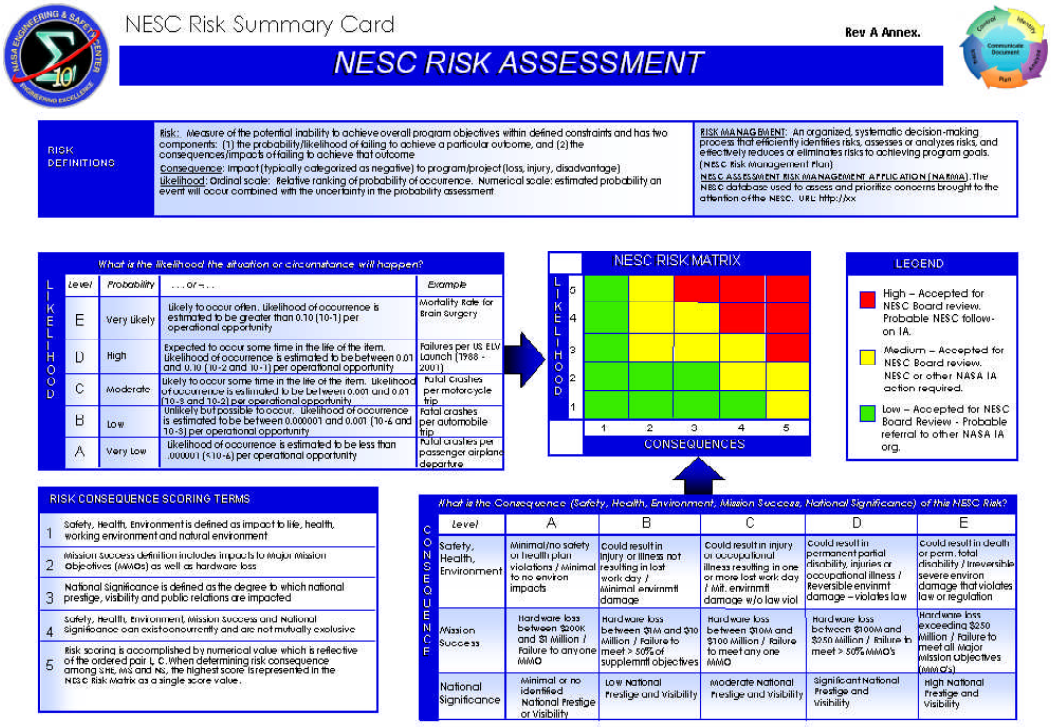

Fig.1. NESC 5 x 5 Risk Matrix Scorecard

Fig. 2. Current NARMA Consequence Scoring

Fig. 3. Proposed NARMA Consequence Scoring

Table I: Likelihood Level Corresponding Event Examples

Event	Likelihood per operational opportunity	Level	Source
Fatal crashes / passenger airline departure	$4.5x10^{-7}$	Level 1	6
Fatalities / Public Bus trip	3.5×10^{-5}	Level 2	7
Fatalities / passenger vehicle trip	$7.5x10^{-5}$	Level 2	8
Fatalities / motorcycle trip (20 mile avg trip)	$6.6x10^{-4}$	Level 2	9
Fatalities / motorcycle trip (50 mile avg trip)	$1.65x10^{-3}$	Level 3	9
Failures of ELV per launch	4.5×10^{-2}	Level 4	10
Mortality Rate Open Heart Surgery	2.2×10^{-2}	Level 4	11
Aortic Replacement Surgery	6.1×10^{-2} to 1.02×10^{-1}	Borderline Level 4/5	12, 13
Mortality Brain Surgery (Craniectomies)	2.2×10^{-1}	Level 5	14,15