Prevention Sequence Mechanisms (PSM) for Near Earth Objects (NEOs) based on a Three Parameter Scheme Based Classification Framework.

by

Rohan Sahani
Bachelor of Engineering in Computer Science and Engineering, Sathyabama Institute of Science and Technology, 2005

Submitted to the Department of Electrical Engineering and Computer Science, and the System Design and Management Program in Partial Fulfillment of the Requirements for the Degrees of

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To my parents and Victoria

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Abstract

There is a significant amount of space debris from previous space endeavors left over by the Russians and the US, leave alone the possibility of collisions with Near Earth Objects (NEOs) like asteroids and comets. Currently, there is no early detection and emergency response system in place. This study will apply the CLIOS (Complex Large Interconnected Open Socio-technical) Process to design and construct novel and unique strategic alternatives for possible detection, defense and tracking systems which are not currently in use. A software application will demonstrate the dynamics of this new classification scheme for Near Earth Objects (NEOs) that would correspond to a set of Prevention Sequence Mechanisms (PSM) which represent a specific sequence of deterrence mechanisms. Potentially dangerous NEOs were classified into various groups that were derived from three different classes based on NEO size, Time-to-Impact (TTI) and chemical composition. For each NEO group, corresponding PSMs were designed. Each PSM illustrates the best possible sequence in which a set of prevention mechanisms (applicable to a specific NEO group of our classification scheme) are to be implemented. A software-package called PDTS 1.0 was designed for tracking and cataloging potentially hazardous NEOs based on the PSM framework and the three-parameter based classification scheme. Through mutual collaboration and segmentation of PSM modules the mitigation effort was optimized. Therefore, in future, if an NEO on collision course with the Earth is detected then the group name of that NEO is found from our classification scheme and the corresponding PSM for that group is implemented to deflect or destroy the NEO.

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Table of Contents

List of Figures and Tables:

Glossary of Terms:

AU	:	Astronomical Unit
DoD	:	Department of Defense
DoE	:	Department of Energy
EPA	:	Environmental Protection Agency
ESA	:	European Space Agency
GDP	:	Gross Domestic Product
IEO	:	Interior Earth Object
IOC	:	Initial Operational Capability
IR	:	Infrared energy band
Isp	:	Specific Impulse
JPL	:	Jet Propulsion Laboratory
KBO	:	Kuiper Belt Objects
K/T	:	Cretaceous-Tertiary
L1	:	First Sun-Earth Lagrange Point
LEO	:	Low-Earth Orbit
LINEAR	:	Lincoln Near Earth Asteroid Research
MPC	:	Minor Planet Center

MPEC	:	Minor Planet Electronic Circulars
MT	:	Mega Ton
MTRDC	:	Mitigation Technology Research and Development Council
NASA	:	National Aeronautics and Space Administration
NCA	:	National Command Authority
NCGIA	:	National Center for Geographic Information and Analysis
NEO	:	Near-Earth Object
PA&E	:	Office of Program Analysis and Evaluation
PDCC	:	Planetary Defense and Coordination Council
PDTS	:	Planetary Defense and Tracking System
PHA	:	Potentially Hazardous Asteroid
PSM	:	Prevention Sequence Mechanisms
SNF	:	Spent Nuclear Fuel
USSTRATCOM	:	United States Strategic Command
USSPACECOM	:	United States Space Command

Chapter 1: Introduction

"Near-Earth Objects (NEOs) are asteroids, comets and large meteoroids whose orbits bring them close (perihelion distance < 1.3 AU) to Earth's orbit because of which they pose a collision danger for our planet (Shiga, 2006)." An Astronomical Unit (AU) is a unit of length nearly equal to the semi-major axis of Earth's orbit around the Sun[1]. The value of one AU is about 93 million miles. The Earth has been struck by NEOs throughout its existence. In the last two decades, with increasing geological and astronomical evidence of asteroid and comet collisions, the threat of an NEO colliding with the Earth has transcended from a problem with "initial laughs" and "giggle factors" to hours of brainstorming and research by several organizations and individuals. The vast expanse of interplanetary space might seem very empty to us, however, in reality, our planet is in a cosmic shooting gallery consisting of asteroids and comets, racing through space at velocities relative to the earth of up to 75 times the speed of sound (Tyson, 1995).

The threat awareness level of NEOs has risen steeply with two large NEO collisions in the last century. One of these collisions was in 1908 when a stony asteroid measuring approximately 50 meters in diameter exploded in the air above the Tunguska River in Siberia, producing an equivalent TNT yield of 15-30 megatons (MT) and leveling over 2,000 square miles of dense forest (Farinella et al., 1983). The results would have been catastrophic if the

[1] Definition of Astronomical Unit in the following webpage: http://en.wikipedia.org/wiki/Astronomical_unit

Tunguska collision had occurred over a populated city. The other significant collision was in July 18, 1994 when Comet Shoemaker-Levy 9 measuring approximately 2 kilometers in diameter collided with Jupiter. This impact created a giant dark spot over 12,000 km across, and was estimated to have released an energy equivalent to 6,000,000 megatons of TNT (McGrath et al., 1995). This megaton equivalent is about 750 times the world's nuclear arsenal.[2]

Apart from these two significant events, there have been several other impacts and near misses that have been recorded. In 1994 a small asteroid missed the earth by only 60,000 miles, and in 1996 comet "Hyakutake" passed within 0.1 astronomical units (AU) of the Earth (James, 1998). On our planet itself, thousand of lives have been claimed by natural disasters like "Hurricane Katrina" and the "2004 Tsunami, and have cost approximately $500 billion for rebuilding and rehabilitation. While the warning time of the tsunami was merely hours, the tragedy of Hurricane Katrina took place in spite of several warnings, years before the event, about the need to update the inadequate levee system surrounding New Orleans. We can learn valuable lessons from these experiences and, in the future, we must have sophisticated and accurate detection, mitigation and emergency response systems in place.

"The general scientific consensus is that the planets grew, in part, from the accumulation of much smaller objects called *planetismals.* The planetismals within Jupiter's orbit are referred to as "asteroids" and those farther out are referred to as "comets" (Weidenschilling, 2000).

[2] Statistical details at the following webpage: http://en.wikipedia.org/wiki/Shoemaker_Levy

Disintegrated fragments of NEOs are called as meteoroids. Meteoroids are referred to as ‘‘meteors’’ while in the atmosphere and ‘‘meteorites’’ when on the ground (Chapman, 2004).” Thus, scientists use the term “meteor showers” for meteoroids that enter the atmosphere and burn up, and use the term “recovered meteorites” when they are found on the ground on the Earth and the Moon.

“Most NEOs originate when collisions in the main asteroid belt eject fragments into the gravitational influence of Jupiter and Saturn. Distribution Asteroids in near-Earth space are categorized as Amor, Apollo, or Aten objects, depending on whether their orbits lie outside that of Earth, overlap that of Earth with periods greater than one year, or overlap that of Earth with periods less than one year, respectively. Comets are classified as short period or long period, depending on whether their orbital periods are less or greater than 200 years. Albedos (as functions of wavelength), reflectance spectra and calculated densities provide information on asteroid and comet compositions and internal structures (Commission on Physical Sciences, 1998).”

As of April 20, 2007, 4669 Near-Earth objects have been discovered (NASA NEO Program Office, 2007). 848 of the NEOs discovered so far have been classified as Potentially Hazardous Asteroids (PHAs) and 709 of the NEOs discovered so far are asteroids with a diameter of approximately one kilometer or larger. It has been predicted that an asteroid “2004 MN4” which is approximately 390m in diameter, will fly past the Earth only 18,600 miles (30,000 km) above the ground. If 2004 MN4 were to collide with the Earth several cities might be destroyed because of its large diameter. Over the years, several U.S. government agencies, international organizations, and representatives of private organizations have been providing a range of possible options for detection and defense against potentially hazardous NEOs. Increased threat-awareness levels of the fact that NEOs can collide with Earth has led to increased support by NASA for systematic surveys of potentially hazardous objects. "The U.S. has implemented the Near Earth Object Program at NASA. Section 321 of the NASA Authorization Act of 2005 (Public Law No. 109-155) is the George E. Brown, Jr. Near-Earth Object Survey Act. The objectives of the George E. Brown, Jr. NEO Survey Program are to detect, track, catalogue, and characterize the physical characteristics of NEOs equal to or larger than 140 meters in diameter with a perihelion distance of less than 1.3 AU, achieving 90 percent completion of the survey within 15 years after enactment of the NASA Authorization Act of 2005. The Act was signed into law by President Bush on December 30, 2005 (NASA NEO Program Office, 2006). "

It is beyond doubt that there are several NEOs which remain undetected in our solar system. It is for this reason that there is a strong need for having an organized Planetary Defense and Tracking System (PDTS) in place to protect against devastating impacts from NEOs. The proposed PDTS detection system in this thesis will have dynamic detection capabilities that should actually increase the lead-time to impact of a potential threat. The longer in advance we know about the threat, the more choices we have. The capabilities and risk-levels of a range of mitigation options are analyzed through the backdrop of the CLIOS (Complex Large Interconnected Open Socio-technical) Process. The CLIOS Process is used select technically feasible and competent solutions (called strategic alternatives) for such a complex problem. This thesis intends to provide an organized way to deal with potentially dangerous NEO threats through a new method of classifying them and having pre-planned mitigation options for different alternatives.

In chapter 2 of this thesis, we analyze the risks and effects of NEOs. The risk is evaluated in terms of expected number of people affected per year as a function of NEO diameter. The effects are calculated in terms of TNT equivalent energy as a function of impactor size. This analysis gives us an indication of the hazard posed by both the discovered and undiscovered NEO population. In chapter 3, we introduce the CLIOS Process to deal with the NEO problem. The various steps in the process are described in detail in this chapter. In chapter 4, we design four specialized tools for the CLIOS Process. One of these tools is applied extensively to the NEO problem in Chapter 6 in three different subsystems.

In Chapters 5 and 6, we apply the CLIOS Process to the NEO problem, and design various strategic alternatives that help us to improve the design and performance of various subsystems. The three parameter based classification scheme is described in Chapter 7. Most of this research in Chapter 7 was done in 2005 and 2006. The work culminated with an invitation in the summer of 2006 to the present the research to the Heinlein Trust. This classification scheme helps us to classify potentially dangerous asteroids and comets into specific NEO groups. We then go on to describe how the classification scheme relates to the Prevention Sequence Mechanisms (PSM) framework. A software application called PDTS 1.0 is used to demonstrate how PSMs are generated for different NEO groups. The different software modules and their specific roles within the PDTS 1.0 System are described in detail in Chapter 7. Based on the information gathered and the ideas generated in previous chapters we make recommendations for dealing with the NEO problem in Chapter 8.

Chapter 2: Risks and Effects of NEOs

Research has now revealed that the Earth is impacted by a significantly large NEO at least once every century. This fact has been overlooked because such an NEO has never hit densely populated areas. Considering that 75% of the Earth is water and merely one to three percent of land is occupied by human beings it is not surprising to see that we overlook this fact. "On millennial time scales, impacts large enough to cause destruction comparable to the greatest known natural disasters may occur (NASA AMES Space Science Division, 1996). "

2.1. Impact magnitude as a function of NEO size

The magnitude of such a large NEO impact can be compared to TNT (Trinitrotoluene) equivalent energy. TNT equivalent is a method of quantifying the energy released in explosions. A gram of TNT releases 980–1100 calories upon explosion[3]. "To define the ton of TNT, this was arbitrarily standardized such that 1000 thermochemical calories is equivalent to one gram of TNT which releases exactly 4184 joules of energy (Taylor, 2001)." The explosive effect of the Hirsohima atomic bomb was equal to about 15 kilotons, which is equivalent to 15 thousand tons of TNT equivalent, and the explosion at Nagasaki equal to about 25 kilotons. The Tunguska explosion was caused by the airburst of an asteroid, and the energy of the blast was estimated to be between 10 and 20 megatons of TNT. If an asteroid around 150 meters in

[3] Definition and data taken from the following webpage: http://en.wikipedia.org/wiki/Megaton

diameter were to impact the ocean, then it would cause a huge Tsunami that would release more than 100 megatons of TNT equivalent energy. Such a huge Tsunami would change most of the coastal lining throughout the world. If any asteroid larger than 1 kilometer in diameter were to impact the Earth then there would be global catastrophic consequences. The K/T (Cretaceous/Tertiary) impact that completely wiped most life on the planet 65 million years ago was estimated to be about 10 kilometers in diameter, about the size of Manhattan. A graphical comparison of the frequency, size and energy yields of the Tunguska and K/T impacts is shown in Figure 1. It should be noted that the frequency of impacts representation on the Y-axis of Figure 1 is a measure of the average time period between expected occurrences.

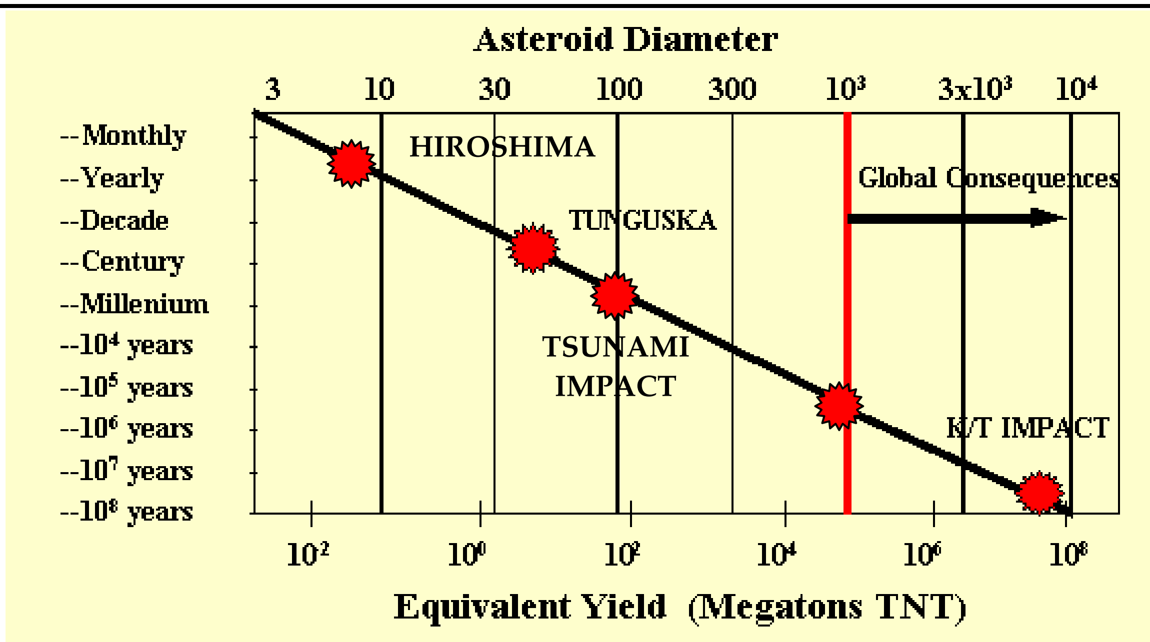

Figure 1: Asteroid Size/TNT Equivalent Energy Versus Frequency. Source: Urias et al. (1996)

Sunlight would be blocked (which would prevent photosynthesis) due to the huge cloud created by a K/T impact. This would cause the extinction of plants, phytoplankton and all organisms dependent on them[4]. This is the soundest theory explaining the disappearance of the dinosaurs from the Earth. The increased iridium concentration (about 100 times more than normal) in the K/T layer fossils also supports the theory, because iridium is found in comparatively large concentrations in asteroids.

2.2. Closest NEO Approaches

While this thesis mainly potentially dangerous NEOs, it is also useful to analyze past Earth impacts to understand future impacts. Figure 2 represents the location of large craters which were formed by impacts prior to 1991. Sea impacts were not included in the Figure because it is hard to distinguish sea impacts from tectonic plate shifts. "However, given the random pattern of the land impacts and the fact that the Earth's surface contains three times as much water, it is likely that the number of sea impacts far outnumbers land impacts (Brown et al. 1994)."

It is useful to know that several NEOs have passed within the Earth-Moon system in the recent past. Many of them were detected only a few days before they flew by the Earth. On March 18, 2004 there was a very close recorded approach of asteroid 2004 FH, which was about 30 meters in diameter. Its closest flyby distance was approximately 43,000 kilometers (one-tenth of the distance to the Moon) above the Earth's surface, and it was detected only three days before its fly-by. Relative to the much larger asteroids, the impact of this 30 meter diameter

[4] Details taken from the following webpage: http://en.wikipedia.org/wiki/Cretaceous-Tertiary_extinction_event

asteroid would not have been too harmful. Needless to say, a larger asteroid would have been discovered much earlier.

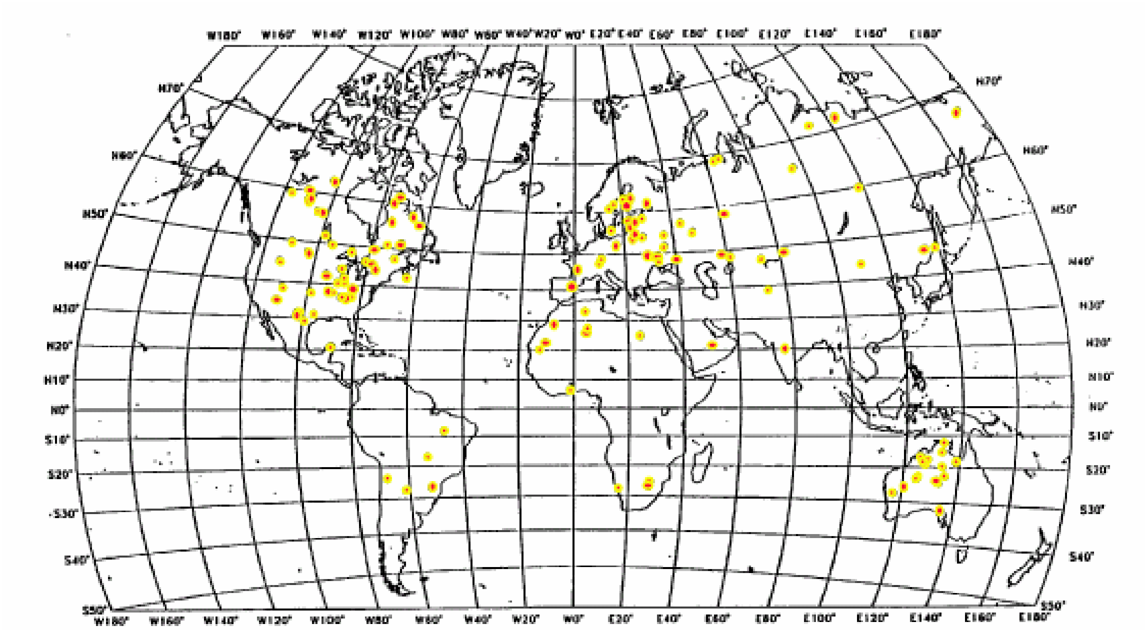

Figure 2: Terrestrial Impact Craters Ranging from 140 to 200 Kilometers in Diameter. Source: Sharpton et al. (1991)

Figure 3 represents the possible sequences of events that could occur after a large-scale impact. Two weeks after the 2004 FH passed earth, another meteoroid, 2004 FU$_{162}$ that was about six meters in diameter set a new record for closest recorded approach by passing only 6,500 km (1/60 of the distance to the Moon) above the Earth's surface. Considering the elementary and inadequate detection systems that we currently have in place, it was not surprising that the meteoroid was detected only hours before its closest approach. We refer to 2004 FU$_{162}$ as a meteoroid because it would have harmlessly disintegrated in the atmosphere if it had been on a collision course with Earth. Usually, a meteoroid larger than 50 meters is referred to as an asteroid.

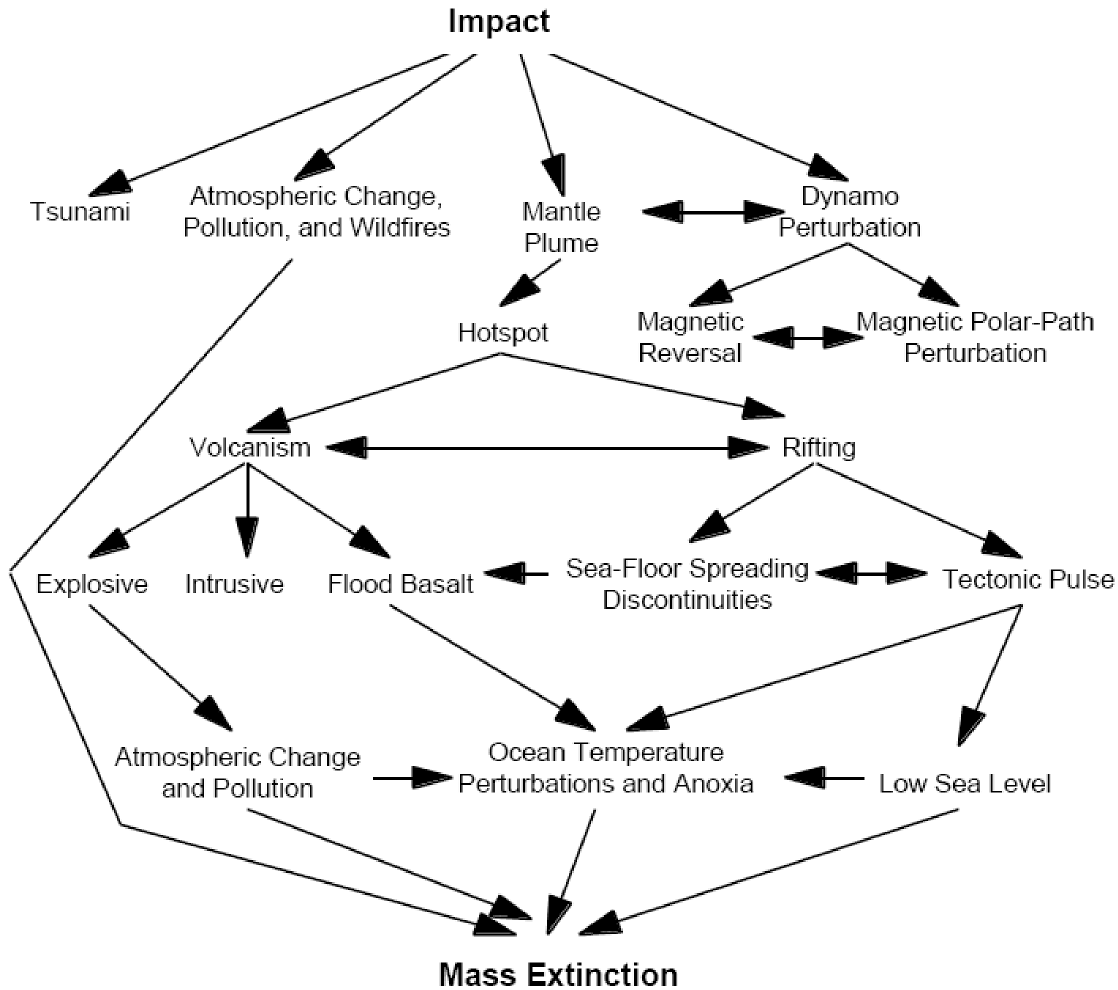

Figure 3: Speculative Flow Diagram Illustrating representing how large-body impacts cause mass extinctions. Source: Sharpton et al. (1990)

Table 1 describes several other NEOs listed in increasing order of nominal geocentric distance. These are the closest known approaches to the earth by NEOs. "In order to qualify for such a listing, the approach must have occurred during an observed apparition, although in some cases the object was not under observation at the time of closest approach (Williams, 2007). "

Table 1: Closest Approaches to the Earth by Asteroids. Source: Williams (2007)

Distance (AU)	Approximate size in terms of diameter (m)	Date of closest approach	Object
0.000086	6	2004 March 31	2004 FU162
0.00033	30	2004 March 18	2004 FH
0.00056	5	2003 September 27	2003 SQ222
0.00072	15	1994 December 9	1994 XM1
0.00099	5	1993 May 20	1993 KA2
0.00114	10	1991 January 18	1991 BA
0.0015	10	2007 April 24	2007 HB15
0.00289	500	2006 July 3	2004 XP14
0.00457	300	1989 March 22	4581 Asclepius
0.00495	300 & 300	1937 October 30	69230 Hermes

On December 10, 2004, asteroid 2004 XP14 flew past the Earth at an approximate distance of 432,308 km. This distance is about 1.1 times the Moon's average distance from the Earth. The size of 2004 XP14 is not precisely known, but one can estimate the size based on optical measurement which is done by relating the value of an object's absolute magnitude (H) with respect to the object's albedo. Through this method the object is estimated to be between 300 to 900 meters in diameter. On March 22, 1989, asteroid 4581 Asclepius flew past the Earth's at an approximate distance of about 700,000 km, and on October 30, 1937 asteroid 69239 Hermes flew past the Earth at an approximate distance of about 730,000 kilometers.

It should be taken into account that NEOs detected in 2007 may have been undetectable only a decade earlier, since the detection technology has improved significantly in the last few years. "In addition, many experts wrongly believe there have been no recorded deaths due to asteroid strikes, acknowledging only that there have been some narrow escapes from small meteorites striking cars and houses (Meteorite House Call, 1993)." Recorded injuries, deaths and destruction (in the past four millennia) from NEO impacts has been shown in Table 2.

Table 2: Injuries and Deaths Caused by ECO Impacts. Source: Lewis (1996)

1420 BC	Israel - Fatal meteorite impact.
588 AD	China - 10 deaths; siege towers destroyed.
1321-68	China – People & animals killed; homes ruined.
1369	Ho-t'ao China - Soldier injured; fire.
02/03/1490	Shansi, China – 10,000 deaths.
09/14/1511	Cremona, Italy – Monk, birds, & sheep killed.

1633-64	Milono, Italy - Monk killed.
1639	China - Tens of deaths; 10 homes destroyed.
1647-54	Indian Ocean - 2 sailors killed aboard a ship.
07/24/1790	France - Farmer killed; home destroyed; cattle killed.
01/16/1825	Oriang, India - Man killed; woman injured.
02/27/1827	Mhow, India - Man injured.
12/11/1836	Macao, Brazil - Oxen killed; homes damaged.
07/14/1847	Braunau, Bohemia – Home struck by 371 lb meteorite.
01/23/1870	Nedagolla, India - Man stunned by meteorite.
06/30/1874	Ming Tung li, China – Cottage crushed, child killed.
01/14/1879	Newtown, Indiana, USA - Man killed in bed.
01/31/1879	Dun-Lepoelier, France - Farmer killed by meteorite.
11/19/1881	Grossliebenthal, Russia – Man injured.
03/11/1897	West Virginia- Walls pierced, horse killed, man injured
09/05/1907	Weng-li, China - Whole family crushed to death.

06/30/1908	Tunguska, Siberia - Fire, 2 people killed.
04/28/1927	Aba, Japan - Girl injured by meteorite.
12/08/1929	Zvezvan, Yugoslavia - Meteorite hit bridal party, 1 killed.
05/16/1946	Santa Ana, Mexico - Houses destroyed, 28 injured.
11/30/1946	Colford, UK - Telephones knocked out, boy injured.
11/28/1954	Sylacauga, Alabama, USA - 4 kg meteorite struck home.
08/14/1992	Mbole, Uganda - 48 stones fell, boy injured

Lewis details 123 cases of deaths, injuries, and property damage due to NEO impacts (over the last two centuries) are described in the book *Rain of Iron and Ice (1996).*

2.3 Size and Frequency distribution

NASA conducted a study in 2003 to determine the feasibility of extending the search for NEOs to smaller limiting diameters. In order to define the various populations of NEOs, NASA included all asteroids with a perihelion q (i.e. the point where an object is nearest the sun in its orbit) of less than 1.3 AU. Figure 4 graphically represents the size-frequency distribution of NEOs that were included in the study. "The currently discovered population of NEOs is estimated to be complete until H reaches about 15 or 16, where H is the absolute magnitude of the object. Shoemaker (1983) was one of the first to estimate the population of NEOs based on the cratering record of lunar maria, which are large, dark, basaltic plains on Earth's Moon that were formed by ancient volcanic eruptions. Many other population estimates have been proposed by various sources. Brown et al. (2002) estimated the population based on infrasound and orbiting infrared sensors that detected bolide entries into the atmosphere (NASA NEO Science Definition Team, 2003)." A bolide is an asteroid or meteor which explodes in the Earth's atmosphere.[5]

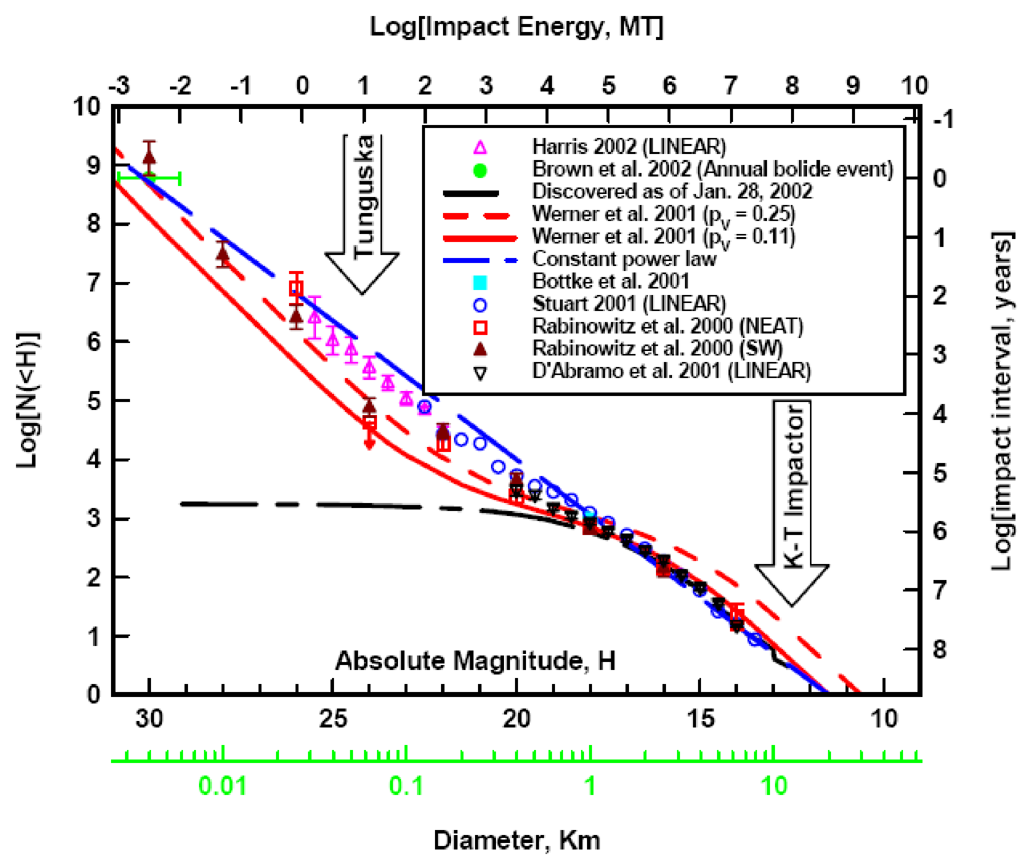

Figure 4: Population of Near Earth Objects. Source: NASA NEO Science Definition Team (2003)

[5] Definition in the following webpage: www.fas.org/spp/military/docops/usaf/2020/app-v.htm

Some other prominent estimates involving straight-line extrapolation were carried out by Rabinowitz et al. (2000), Stuart (2001) and Harris (2002). In the 2003 NASA study, all of the previous estimates described above were combined in order to devise a single straight-line population model. "Thus, the *straight* line in Figure 4 is actually the following function in logarithmic/magnitude units: $\log[N(<H)] = -5.414 +0.4708H$. In units of diameter, taking an equivalence of H = 18.0 to be equal to D = 1 km, the relation is: N(>D) = 1148D-2.354. At first glance, it may seem as though the impact frequencies may be overestimated by this model. However, its values still lie below earlier population estimates of the same time-period (NASA NEO Science Definition Team, 2003)."

2.4 Land Impact Hazard

The hazard from land impacts can be estimated as a function of impactor size. However, in order to measure land impacts we need estimates of blast damage as a function of impactor size. This work was done by Hills and Goda (1993). Figure 5 is a plot of radius of destruction versus the impactor radius. In this analysis hard stone impactors of mean density 3 g/cm3 were taken into account. According to their research it was found that objects lesser than 150 m in diameter do not hit the ground at their original cosmic velocities. Instead, they will explode in an airburst like the 1908 Tunguska explosion. Figure 6, 7 and 8 display the number of people affected per year as a function of diameter for both the discovered and undiscovered (residual) NEOs.

These calculations were done by the NEO Science Definition Team at NASA by using an impact velocity of 20 kilometers/sec. They calculated the fraction of the Earth's surface that was represented by the area of the radius of destruction. The population of the Earth (6×10^9) was multiplied by this fraction in order to estimate the average number of fatalities per event. Based on different impactor size, three different levels of fatalities were calculated: minimum, nominal, and maximum number of fatalities per year. The nominal value according to the NASA team was the product of impact frequency times fatalities per year.

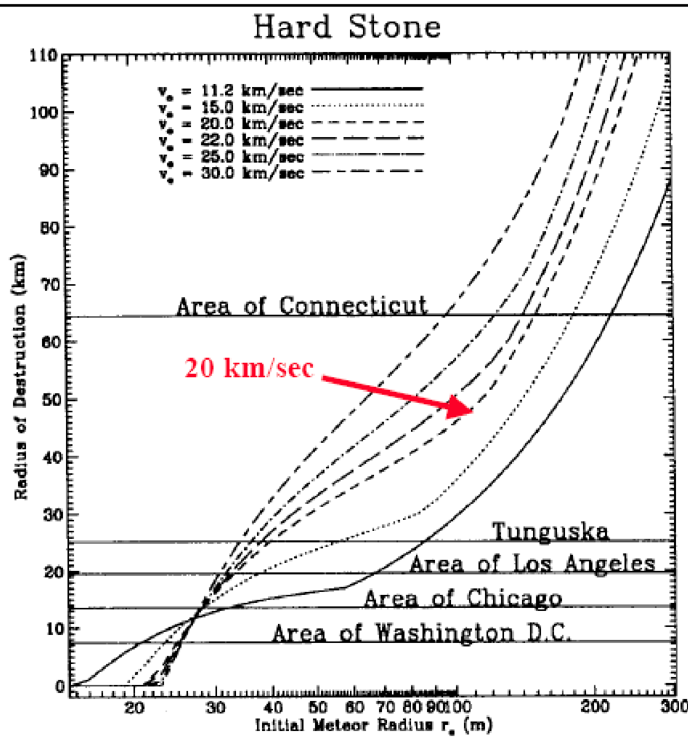

Figure 5: Radius of Destruction versus Impactor Radius. Source: Hills and Goda (1993)

The residual hazard was also calculated to take into account the number of NEOs that were yet to be discovered. "The NEO discovery-incompleteness for the remaining five years at the present level survey was taken into account. It should be noted that the uneven distribution of population on the Earth was ignored in the aforementioned calculations, as well as the fact that 75% of the Earth's surface is water where no one lives (NASA NEO Science Definition Team, 2003)." Therefore, according to this argument there will only be large fatalities in the rare event of an impact in a densely populated area. This characteristic was investigated quantitatively by the NEO Science Definition Team at NASA by obtaining a digital population map of the world from data compiled by the National Center for Geographic Information and Analysis (NCGIA, 2003).

2.5 Tsunami and Environmental Effects Hazard

Research has proved that blast damage from land impacts is similar in nature and scale to blast damage from nuclear explosions. Over the last century, nuclear explosions have been studied extensively; thus, the range of uncertainties of the estimates in Figure 6 is quite small. However, when we estimate the impacts into the sea that cause tsunamis, we will notice that the range of uncertainty is quite large because there is no recorded history to consult to support our analysis and results. However, based on historical fatality rates from earthquake generated tsunamis, one can estimate that actual fatalities are usually only 10% of the number of people within an inundation zone. In calculating the Tsunami damage because of an NEO impact into the sea the NEO Science definition team used work of Chesley and Ward (2003). Chesley and Ward (2003) took into account several model uncertainties to produce an analysis of the risk from impact-generated tsunamis as a function of impactor size. Their work was based on models of wave size, coastal run-up and penetration of Ward and Asphaug (2000), combined with a model of coastal population derived from Small et al. (2000). "Even though they used a single power law model of NEO population like Ward and Asphaug (2000), they were conservative in their estimates about the frequency of impacts. At any given size, their frequency of impacts was less than a factor of five. The frequency adopted corresponded to an expected number of one impact per 500,000 years of an asteroid one kilometer in diameter or larger (NASA NEO Science Definition Team, 2003)."

Some of the model uncertainties that Chesley and Ward took into consideration in their analysis are as follows. "Practical elevation above sea level of any given population settlement was taken into account. Some sites that were prone to diurnal tides and frequent storm waves are under protected areas or inside estuaries. Short wavelength tsunami waves from small imp actors would break upon passing over continental shelves, thus substantially reducing the coastal run-up of impact generated tsunami waves (NASA NEO Science Definition Team, 2003)." Thus, by using the above methodology they assigned lower and upper bounds for these uncertainties to obtain overall limits on the tsunami risk as a function of impactor size. Chesley and Ward found that the highest risk does not come from a Giant Tsunami fast moving tsunami, but from smaller ones that hardly penetrate one kilometer of the land. We explained before in this section of the thesis that only 10% of the people in a given impact area (Tsuanmi impact) are fatally affected. Therefore, in Figure 7 property damage was considered when examining the expected number of fatalities, such that the number of people affected should be taken as a proxy for property damage.

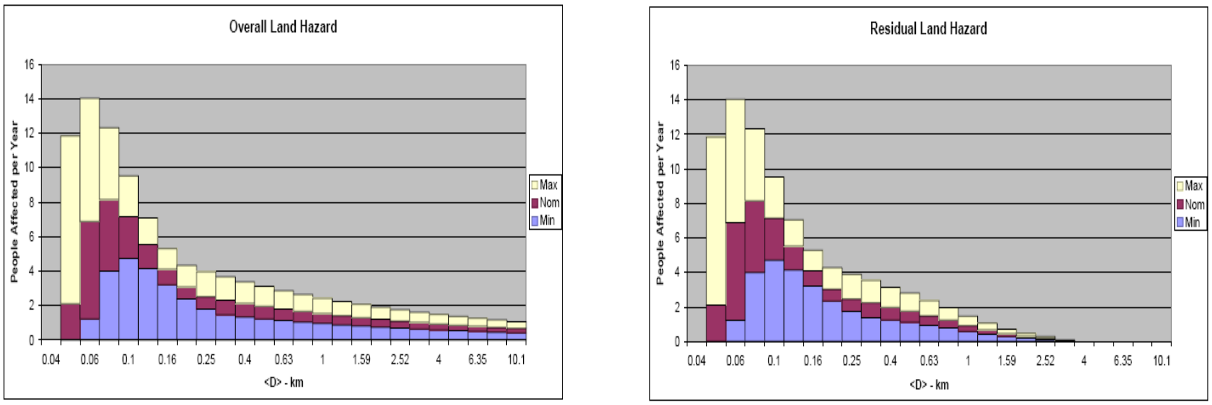

Figure 6: Overall and Residual Land Impact Hazard. Source: NASA NEO Science Definition Team (2003)

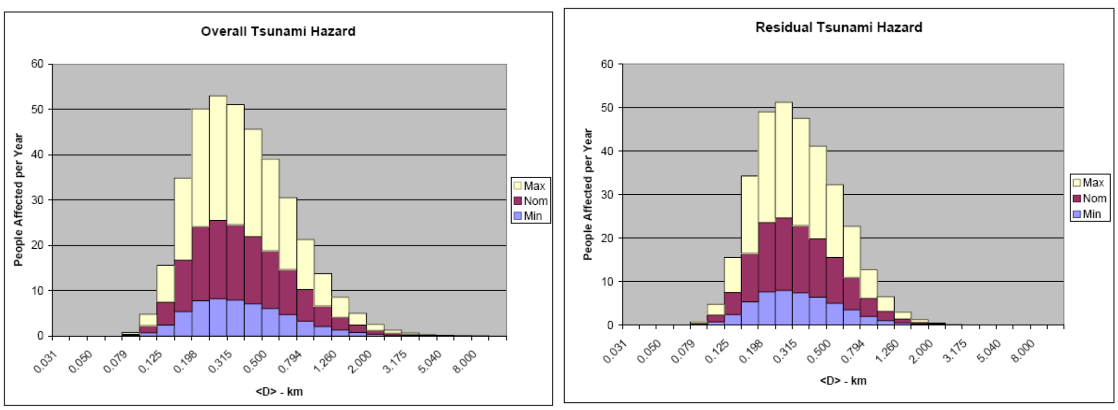

Figure 7: Overall and Residual Tsunami Impact Hazard. Source: NASA NEO Science Definition Team (2003)

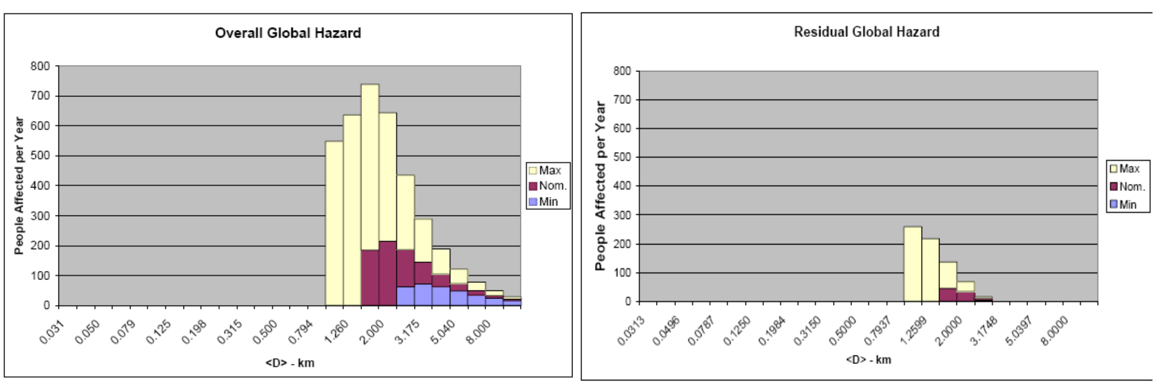

Figure 8: Overall and Residual Risk from Global Environmental Effects of Large Impacts. Source: NASA NEO Science Definition Team (2003)

First, a global environmental consequence can only follow if an NEO larger than one kilometer in diameter were to collide with the Earth. Second, the probability that such a large NEO will remain undiscovered at the present level of survey is quite low. Therefore, there appears to be an inverse relationship between these two uncertainties.

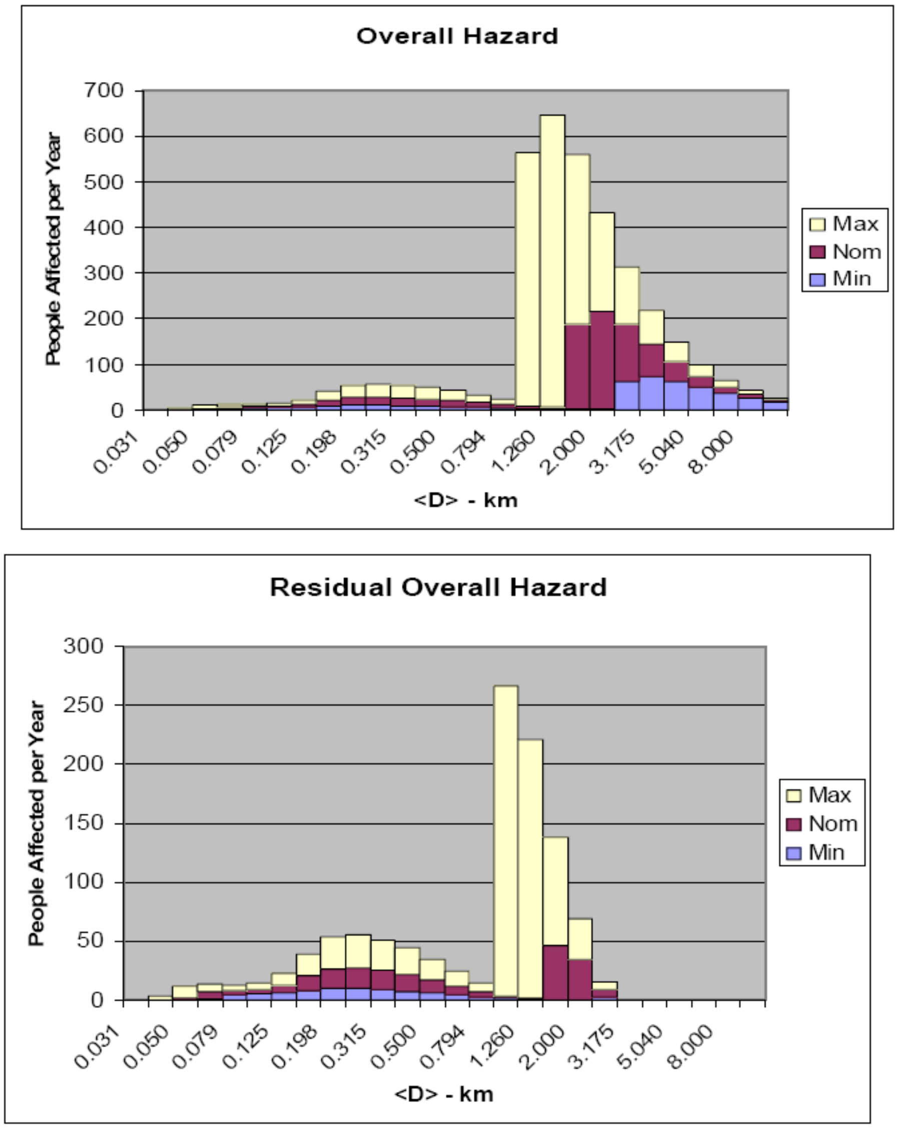

Figure 9: Overall and Residual Hazard after Five More Years of Current Surveys. Source: NASA NEO Science Definition Team (2003)

“The lower limit for the impact-induced energy yield that would spark global environmental effects is estimated to be approximately 105 MT (megatons) by Toon et al. (1997). If we were to gauge the magnitude of an impact in terms of TNT equivalent energy, it is estimated that the lower and higher probable energy yields of such an impact are 105 MT and 108 MT, respectively. The K/T asteroid that wiped out the dinosaurs was estimated to be in the vicinity of 108 MT. Even impacts that are equivalent to 107 MT will place most of the world's population at risk. Any impact in the vicinity of the higher limit would most certainly cause mass extinction of all species on our planet (NASA NEO Science Definition Team, 2003).”

Table 3: Summary of Residual Impact Hazard (NASA NEO Science Definition Team, 2003)

Case	Residual hazard casualties/year	Source		
		Land	Tsunami	Global
Minimum	81	34%	62%	4%
Nominal	293	17%	53%	30%
Maximum	1105	8%	29%	63%

Figure 9 combines all the current and residual risk in all Land, Tsunami and Environmental categories. They have been represented in terms of minimum, nominal and maximum estimates. “Note that although this chart illustrates all three categories in units of *people affected*, the different categories of actually impact *affect* people differently (NASA NEO Science Definition Team, 2003).” The minimum causalities per year from the undiscovered NEO population itself are estimated to be around 81 per year. It is interesting to see from Table 3 that most of the damage is from tsunamis, since they are mobile (rather than localized) in nature and have a cascading effect.

The NEO problem is a socio-technical problem with several complexities. It is difficult to design detection, prevention and emergency response systems because of different priorities for different stakeholders involved in this problem. We definitely need a process that can help us design and implement these systems effectively. The CLIOS Process provides an excellent framework for analyzing Complex, Large Interconnected Open Socio-Technical (CLIOS) systems through an iterative methodology. The CLIOS Process helps us to determine what types of strategic alternatives are ideal for the system, and how to effectively implement those strategic alternatives. It is for this reason that we use the CLIOS Process to evaluate different strategic alternatives for the various subsystems. The various steps of the CLIOS Process are described in Chapter 3.

Chapter 3: Introduction to the CLIOS Process

The CLIOS Process is an iterative process for analyzing Complex, Large Interconnected Open Socio-Technical (CLIOS) Systems. The three stages of the CLIOS Process are the: (i) Representation, (ii) Design, Evaluation and Selection and (iii) Implementation Stage (Dodder, Sussman et al. 2005).

3.1. Understanding and Working through the Process

When applying the CLIOS Process to the Near Earth Object problem, this thesis will focus on the Representation Stage, the objective of which is to "convey the structural relationships between the components of the CLIOS System" (Dodder, McConnell, at al. (2006). CLIOS Systems have a Physical Domain and an Institutional Sphere. The Physical domain has several subsystems which in turn have various components and subcomponents. The institutional sphere is populated by organizations that interact with the various subsystems in the Physical Domain. The concept of having the physical domain nested within the institutional sphere provides a solid platform from which we can start analyzing complex interactions in socio-technical systems. By utilizing quantitative and qualitative methods we can customize the CLIOS Process for the specific problem it is being applied to. Figure 10 represents the nested complexity that exists when there are interactions between the physical domain and the institutional sphere of a CLIOS System.

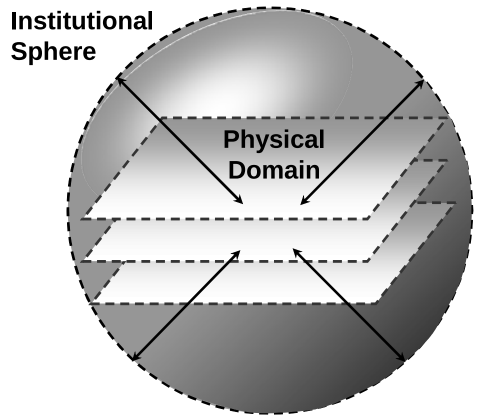

Figure 10: Illustration of Nested Complexity. Source: Dodder, Sussman et al. (2005)

Through the CLIOS Process we can design and implement strategic alternatives which in turn trigger several changes in both the physical domain and the institutional sphere. It is because of this reason that CLIOS Process is different from other system analysis approaches.

3.2. The Basic Structure

The basic structure of the CLIOS Process has twelve steps which are divided into three stages. This is shown in Figure 11. The three stages are: Representation; Design, Evaluation and Selection; and Implementation. In the Representation stage, checklists are prepared for the system. There are three types of checklists which are the: characteristics, opportunities/issues/challenges and system goals checklist. In this stage we also construct the CLIOS System diagrams. Through these checklists, the CLIOS Process user is able to gain key insights on how to approach the design and construction of the system. In the Design, Evaluation and Selection stage, we design strategic alternatives for improving the overall system performance. These strategic alternatives are evaluated and the best ones are selected to form a bundle that is implemented in the Implementation stage (Dodder, McConnell, et al. 2006).

Table 4: Summary of the three Stages. Source: Dodder, Sussman et al. (2005)

Stage	Key Ideas	Outputs
Representation	▪ Understanding and visualizing the structure and behavior ▪ Establishing preliminary goals	System description, issue identification, goal identification, and structural representation
Design, Evaluation, and Selection	▪ Refining goals aimed at improvement of the CLIOS System ▪ Developing bundles of strategic alternatives	Identification of performance measures, identification and design of strategic alternatives, evaluation of bundles of strategic alternatives, and selection of the best performing bundle(s).
Implementation	▪ Implementing bundles of strategic alternatives ▪ Following-through – changing and monitoring the performance of the CLIOS System	Implementation strategy for strategic alternatives in the physical domain and the institutional sphere, actual implementation of alternatives, and post-implementation evaluation.

An overview of the three stages is provided in Table 4. In order to conduct an in-depth analysis, the CLIOS Process provides the user a specific set of questions at different stages of the CLIOS

Process. When these questions are answered, the user gains a deeper understanding of the overall system, which in turn helps the user to design, construct and implement an efficient system. Table 5 lists the sample questions that should be answered at each stage.

Table 5: Sample questions to be answered in each CLIOS Process Stage. Source: Dodder, Sussman et al. (2005)

In Stage One, regarding the representation of the CLIOS System structure, we can ask questions such as the following: ▪ Can we break out the physical domain into relatively independent subsystems? ▪ What are the technical, economic, and social aspects of each subsystem? ▪ What are the main components of each identified subsystem? ▪ How do the physical subsystems relate to the institutional sphere? ▪ What are the main actor groups and who are the key individual actors/organizations on the institutional sphere that impact the physical domain or are affected by it? Also in Stage One, regarding the representation of the behavior of the CLIOS System, we can ask: ▪ What is the degree and nature of the connections between subsystems? ▪ Are the connections weak or strong? ▪ Are there important feedback loops connecting subsystems? ▪ What insights can we gain into emergent behavior?
Turning to the design, evaluation, and selection in Stage Two, we look at both how different strategic alternatives change system performance as well as preferences of different stakeholders.

- How is performance measured for the entire CLIOS System as well as the physical subsystems?
- How do key stakeholders and decisionmakers measure or rank different types of performance?
- What are the tradeoffs among the various dimensions of performance (e.g. cost vs. performance)
- What strategic alternatives can lead to improved performance?
- How can we combine or "bundle" strategic alternatives to improve the system?
- Which bundle is selected for implementation?

Finally, reaching Stage Three, implementation of the CLIOS Process, we can ask the following:

- How do these performance improvements actually get implemented, if at all?
- What compromises have to be made in the name of implementation?
- What actors/organizations on the institutional sphere have an influence on the parts of the system targeted for intervention? How are these actors/organizations related to each other?
- Do the types of policies made by different organizations on the institutional sphere reinforce or counter each other?
- Under the current institutional structure, can organizations manage the system to achieve target levels of performance?

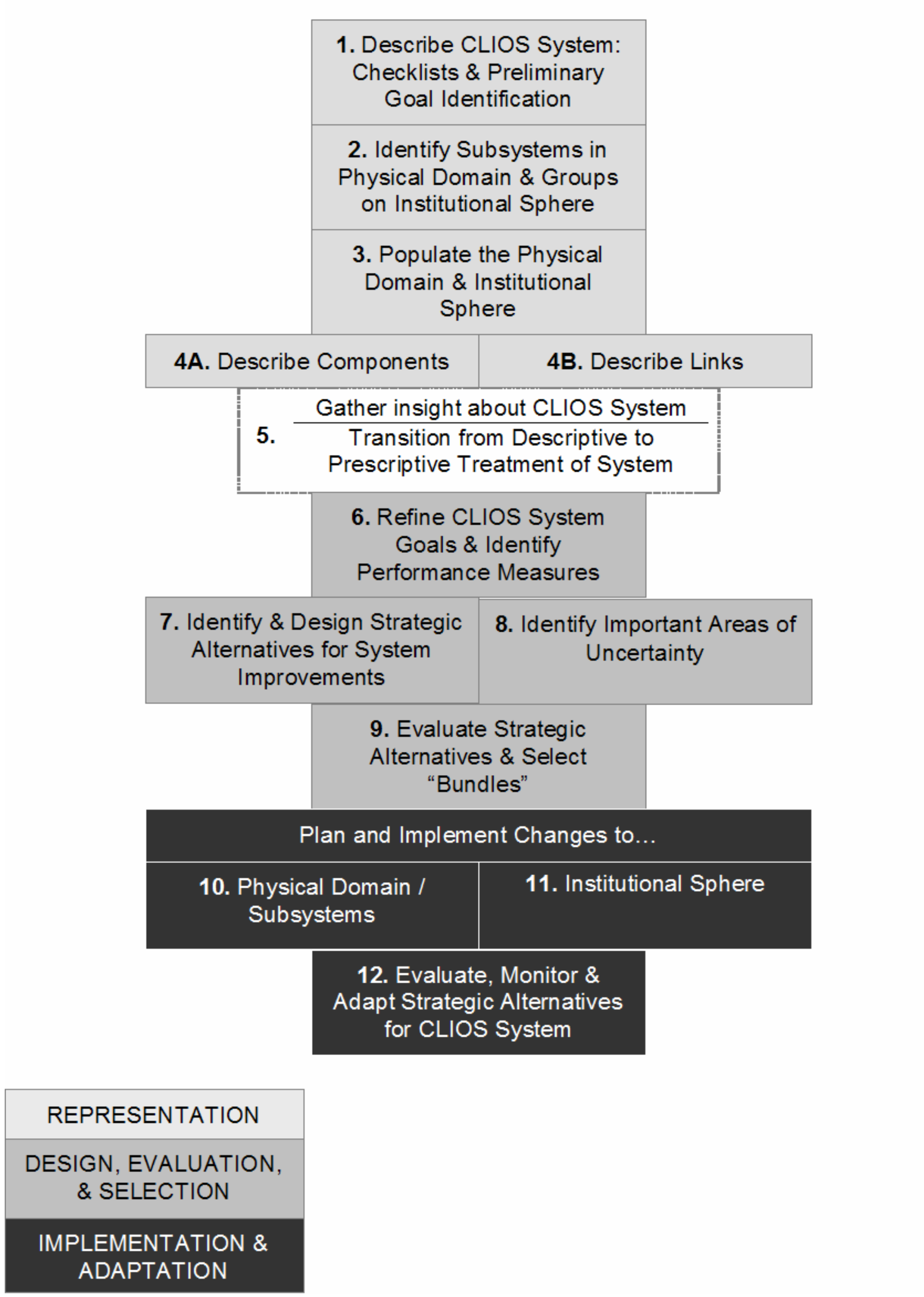

Figure 11: The Twelve Steps of the CLIOS Process. Source: Dodder, Sussman et al. (2005)

The goals and issues identified in the representation stage help the user gain key insights on the system boundaries and entities that play a role within the system. The three stages and twelve steps of the CLIOS Process are shown in Figure 11. The three stages are represented in different colors in order to easily distinguish between them. There are three different checklists that are used in the representation stage (i) Characteristics checklist, (ii) Opportunities, Issues and Challenges checklist (iii) Preliminary System Goals checklist. These checklists are used for the NEO problem, and have been described in Chapter 5. "As one thinks about how to *tinker with* the system, it often becomes clear that one does not fully understand the ways that the whole system will react in response to this *tinkering*, both in the short and long run (Dodder, McConnell, at al., 2006)."

3.3. CLIOS as a Christmas tree

It must be noted that CLIOS is a flexible, iterative and modular process. Various tools and methods of analysis are needed to support the twelve steps and three stages. The CLIOS Process is considered analogous to Christmas tree, where the ornaments on the Christmas tree are the various tools that support the twelve basic steps. "Its overall structure allows for quantitative and qualitative analytical tools (called "models" and "frameworks," respectively) suitable for each stage or step to be "attached" to the CLIOS Process like ornaments that hang on a tree (Osorio-Urzúa, 2007)." The various iterations in the CLIOS process help us to redefine the system boundaries. The new boundaries give us key insights into refining our checklists, goals and priorities. This helps us to select the best strategic alternatives.

In Figure 12, the letter "A" is used to represent a point in the CLIOS Process where iteration can occur. Similarly, we can have iterations in other points B, C, D, E, F and G.

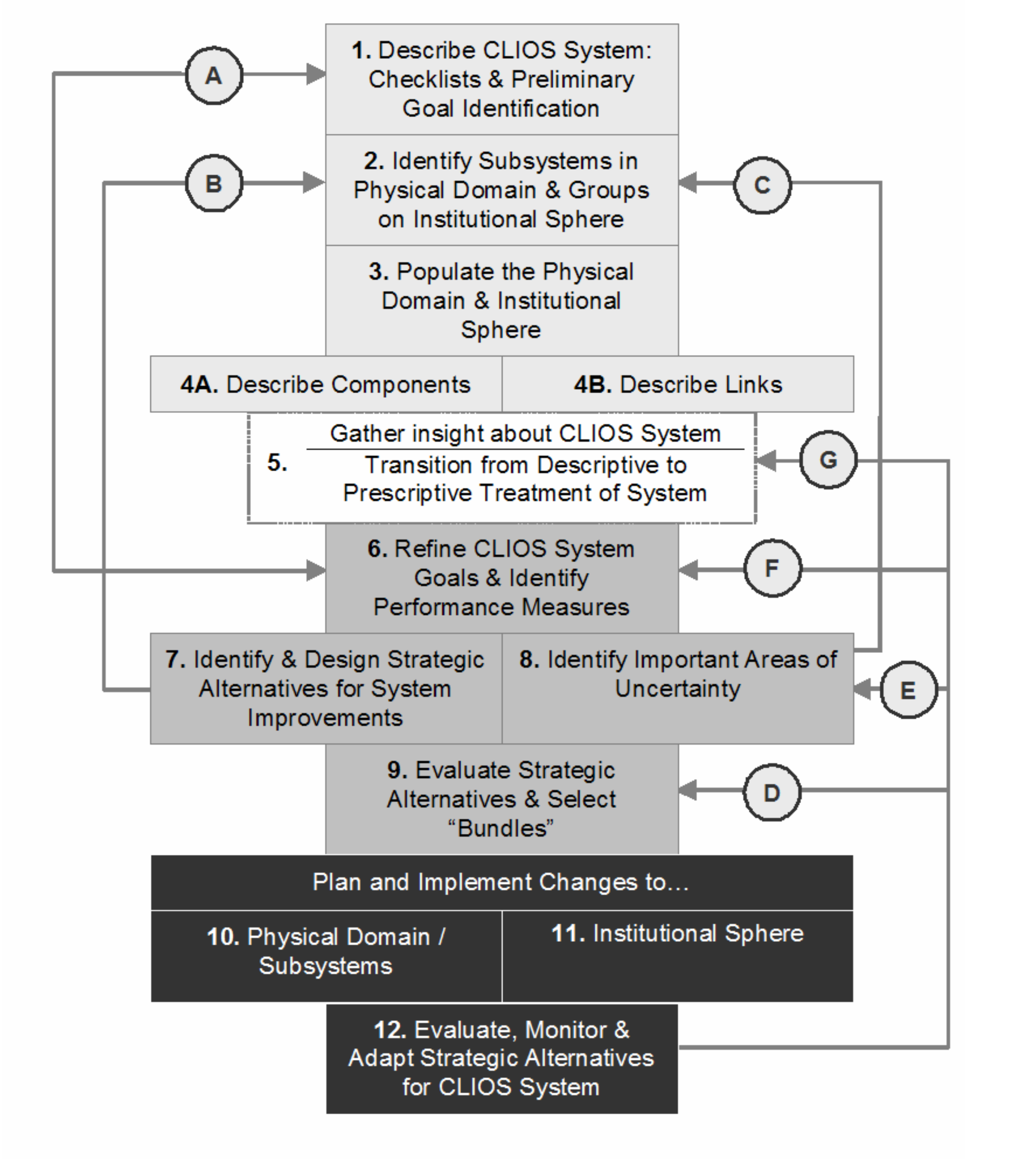

Figure 12: Iteration in the CLIOS Process. Source: Dodder, Sussman et al. (2005)

In step 1 of the CLIOS Process we identify system goals. The iteration in this step is evident from the fact that these goals are analyzed in greater detail in Step 6, when the user refines CLIOS System goals and identifies performance measures. Moreover, additional reviews of the checklists in Step 1 help us to make sure that we have not overlooked key characteristics, opportunities, challenges, issues and goals in the system. It is for this reason that an iteration point "A" is placed before Step 1. "It should be noted that this iteration is bidirectional, such that both Step 1 and Step 6 provide inputs and outputs to one another. This illustrates not only that the CLIOS System is not only iterative, but also there are inter-step feedback loops within the overarching stage-by-stage process (Osorio-Urzúa, 2007)."

3.4 Components and Links within the CLIOS System

Dodder, Sussman et al. (2006) define four types of system and subsystem components: (i) Oval-shaped physical components, (ii) Rectangle-shaped policy levers, which are the elements of the physical domain that are most easily affected by organizations on the institutional sphere, (iii) diamond-shaped common drivers, which are elements of the physical domain, and (iv) gray-rectangle shaped external factors which are freestanding components which influence the system, but are not affected by the system. These shapes have been represented in Figure 13.

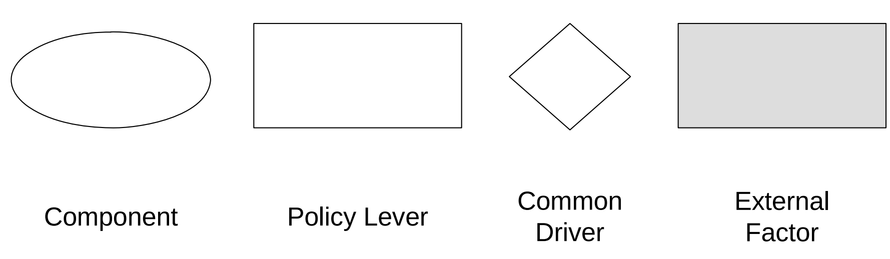

Figure 13: Shapes for Representation of Components in the CLIOS Process. Source: Dodder et al. (2006)

The various types of links between various components of the subsystem are described by Dodder, Sussman et al. (2006) in terms of strength, timing of influence, activity or inactivity, the directionality and magnitude of influence. They have defined the following three classes of links: (i) links among elements of the physical system (Class 1 links), (ii) links between the physical system and institutional sphere (Class 2 links), and (iii) links among components of the institutional sphere (Class 3 links). These links help the user to map exactly the right elements to each other, based on the nature of their relationships.

The Near Earth Object problem can have catastrophic results if not dealt with properly. It is a complex socio-technical problem that generates many conflicting opinions on how to deal with the problem. The nested complexity that is inherent in the subsystems is brought to the forefront by the CLIOS Process. By applying the CLIOS Process to the NEO problem we can analyze the system behavior as a whole by examining its subsystems, components, and relationships among them. It is for this reason that we apply the CLIOS Process to the NEO problem in Chapter 5 and Chapter 6. Before we apply the CLIOS Process to the NEO problem, let us examine in Chapter 4 the four specialized tools we have designed specifically for the CLIOS Process.

Chapter 4: Contributions to Theory

The CLIOS Process has several tools that act as ornaments on a Christmas tree. When we get down to the specifics of a particular system, we will most certainly require specialized tools to address problems in the system. It is for this reason that we have come up with four specialized tools for the CLIOS Process that are described below. The *institution-specific segmentation* tool can be applied to systems where there exists substantial ambiguity in selecting players to populate the institutional sphere. One possible example is a system that doesn't have a clear business-government divide. For Example, the piracy problem in the movie and music industry will require the *institution-specific segmentation* tool to filter players in the institutional sphere because of the fuzzy nature of the system structure that is in place to deal with this problem. Moreover, that problem is also quite new, and there is no historical "system hierarchy" information that can serve as the basis for building a solid system definition in terms of the institutional sphere and the physical domain.

The *strategic impact measurement* tool is quite general in nature and can be applied to all systems. The *value-based segmentation* tool can be used in places where there is significant room for improvement in terms of the value that can be added to enhance system performance. By segmenting the various players we get a deeper understanding of various interactions between the institutional sphere and the sub-systems. The *strategy system-structure matching* tool can be applied to manufacturing and supply chain systems, where operating processes play a significant role in the overall performance and effectiveness of the system. In chapter 6, we have applied one of these tools (the *strategic impact measurement* tool) to three different subsystems in the NEO problem. Let us now examine the four specialized tools that are specifically built for the CLIOS Process using the existing literature.

4.1. Institution-specific Segmentation tool

It is important to remember that problem definition is more important than problem solving, and without a complete problem definition, our analysis will be deficient. A few organizations or government agencies can create a major difference in the CLIOS Process by adding more substance to the system definition, while there are many others that seem important but actually would be inconsequential to any meta-analysis of system dynamics. This is where the institution-specific segmentation tool comes in by helping us to efficiently populate the institutional sphere.

4.1.1. The need for segmentation

The organizations, regulators and government agencies on the institutional sphere that serve the critical parts of the CLIOS System are often difficult to identify. When relating the institutional sphere to the physical domain, the level of importance assigned to a particular entity will have a major impact on the efficacy of the CLIOS Process-based system analysis. For this very reason, a significant amount of research is required in order to generate a complete list of players within the institutional sphere. However, ordinarily, the process of carrying out research and identifying key players is somewhat arbitrary, because we lack a reliable and defined method to work through this kind of analysis.

In fact, much time and effort is wasted when one wrongly identifies insignificant players as key players and vice-versa. Therefore, it is important to gather a correct and comprehensive list of institutions in the nonprofit, public and private sectors at the beginning of any CLIOS Process-based analysis. Ideally, one would make each prospective player demonstrate its process separately in order to determine whether it should be deemed unworthy or considered the right fit within the institutional sphere. It is for this reason that we need to understand how segmentation and complexity in the business-government environment play an important role in the CLIOS System. With several generic, specialized and co-specialized assets within every twenty-first century organization, it is becoming increasingly difficult to decide whether to integrate a solution into the existing system structure or hire a specialized contractor to perform the work. Moreover, most markets are highly fragmented with a plethora of competitors, so there are bound to be several device and process vendors that lack experience in certain domains. These vendors are becoming aware that this adversely affects their recognition and popularity in the market as a whole, so they are tending towards specializing in one application in order to more readily provide resources for a specific component, process or operation. By narrowing their focus and honing specific competencies, these organizations are able to provide application-specific service of high reliability and performance, which in turn allows them to survive in this highly competitive market.

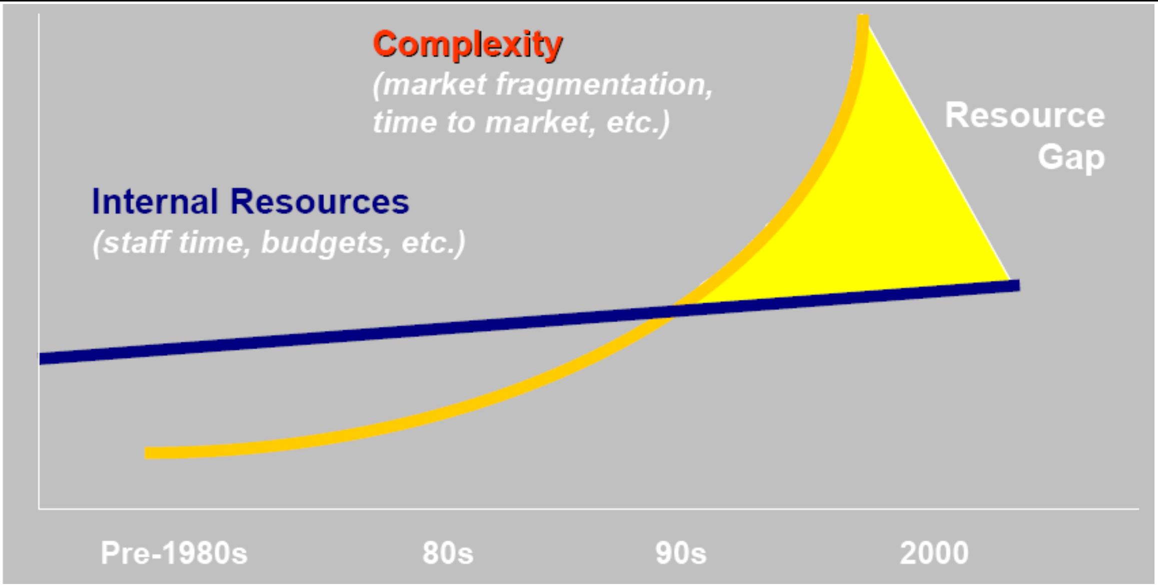

Figure 14: Increasing institution-client mapping complexity, Source: Brookings Institution Metropolitan Policy Program (2005)

The aggregate result of individual organizations specializing is the evolution of highly fragmented market dynamics where the need for complementary assets becomes critical. Complementary assets are those assets than can be used by a player to enter a particular selection system. It is required by every player to compete in the dynamic-paced environment systems in the modern world. When there is no access to complementary assets, there is no longer coverage for existing assets or comprehensive sources for all assets, such as a market-dominating vendor that sets industry benchmarks (Mol, 2005). Thus, complementary assets have become very critical, and most of them must be accessed through industry association, government agencies or regulators, which form the core of the institutional sphere. At the *representation* stage of the CLIOS Process we should make it a point to not eliminate players who don't bring in any complementary assets to the system. This elimination process can be done in the *design, evaluation and selection* stage of the CLIOS Process. "Players with a role in the game, even if ineffectual in the system context, cannot be eliminated at the representation stage of the CLIOS Process (Sussman, 2007)."

4.1.2. Segmentation process dynamics

It is important to remember that reaching across the business-government divide is not simply a customer segmentation process as described in the literature. Thus, we need a distinct process to address the entire segmentation issue in the institutional sphere. The ideal model would be a combined process that seamlessly integrates segmentation in the public, private, and nonprofit sectors as and when lead roles are identified and assigned to the various players. In today's world, the most interesting problems crisscross the boundary between business and government; hence we have the need for frameworks for how segmentation in each sector interacts with other sectors.

In order to satisfy the various constraints and requirements of a CLIOS System, the user would ordinarily want to find either a one-stop commercial solution or an integrated, one-stop, government-based regulatory authority providing the required access to complementary assets. The fragmentation of users based on technological specialization and, eventually, superiority has resulted in the decentralization of several regulatory agencies and commissions. As a result, standards are set by highly-complex market conditions based on the depth of knowledge of industry associations and regulators. In the United States, the governmental entities and individuals who make decisions about the functioning and guidelines for the business world usually are not as familiar with general business trends as those who head industry associations, and industry associations are also somewhat removed from the day-to-day innovations and obstacles of a particular industry. The more these rule-makers know about the industry, the more detailed and precise the standards they create; the less they know, the less comprehensive their industry views. Therefore, in order to accurately apply the CLIOS Process involving a governmental organization or similar regulatory body, it is of utmost importance to enumerate and evaluate institutions that play a role in the complex socio-technical system under question, and furthermore, to correctly classify the magnitude of each institution's impact on the greater system. This would ordinarily require conducting an extensive and costly evaluation of how commercially-available solutions are integrated with non-profits, public and private organizations, and governmental agencies. The institutional segmentation process, as explained below, provides a cheaper and simpler way to determine the level of integration required in the first two stages of the CLIOS Process.

4.1.3. Functioning of segmentation procedure

The process starts by putting each CLIOS System participant through the process-scanner as shown in Figure 15. The scanner first analyzes whether or not the complementary assets are accessible to individual components of the system. These assets are critical for the efficacy, full-functioning and productivity of the system. The unavailability of these assets implies the inability to identify potential contractors, governmental agencies, for-profit and non-profit organizations that could provide the required support for the problem that the CLIOS Process is targeting. Without access to complementary assets in the second stage of the CLIOS Process, the system definition would be incomplete, and the CLIOS Process would need to reiterate again after the organizations are allowed to network with one another. Once we have identified complementary assets, we categorize them as generic, specialized or co-specialized assets. The assets that are essential to improve the productivity from the CLIOS Process point of view are the specialized assets because the generic and co-specialized are not institution-specific, which means that they can be obtained from various alternatives that are available to a specific component or sub-system design.

After this step is completed, the appropriability regimes are checked. Appropriability is defined as the degree of effectiveness of several protection mechanisms for appropriating the benefits of successful innovations. "The appropriability regimes are tight when the technology is relatively easy to protect. An example of this case is the Coca-cola formula. Appropriability regimes are weak when technology is almost impossible to protect. An example of this case is the simplex algorithm in linear programming (Teece, 1986)."

In the case of weak appropriability regimes, the first step to take is to protect intellectual property before seeking any collaboration with various industry associations and regulators in the institutional sphere. Therefore, if the CLIOS System is analyzing a new core technology for solving a particular problem, one should make certain that there are no possible intellectual property thefts or conflicts when the information is made available to players in the institutional sphere.

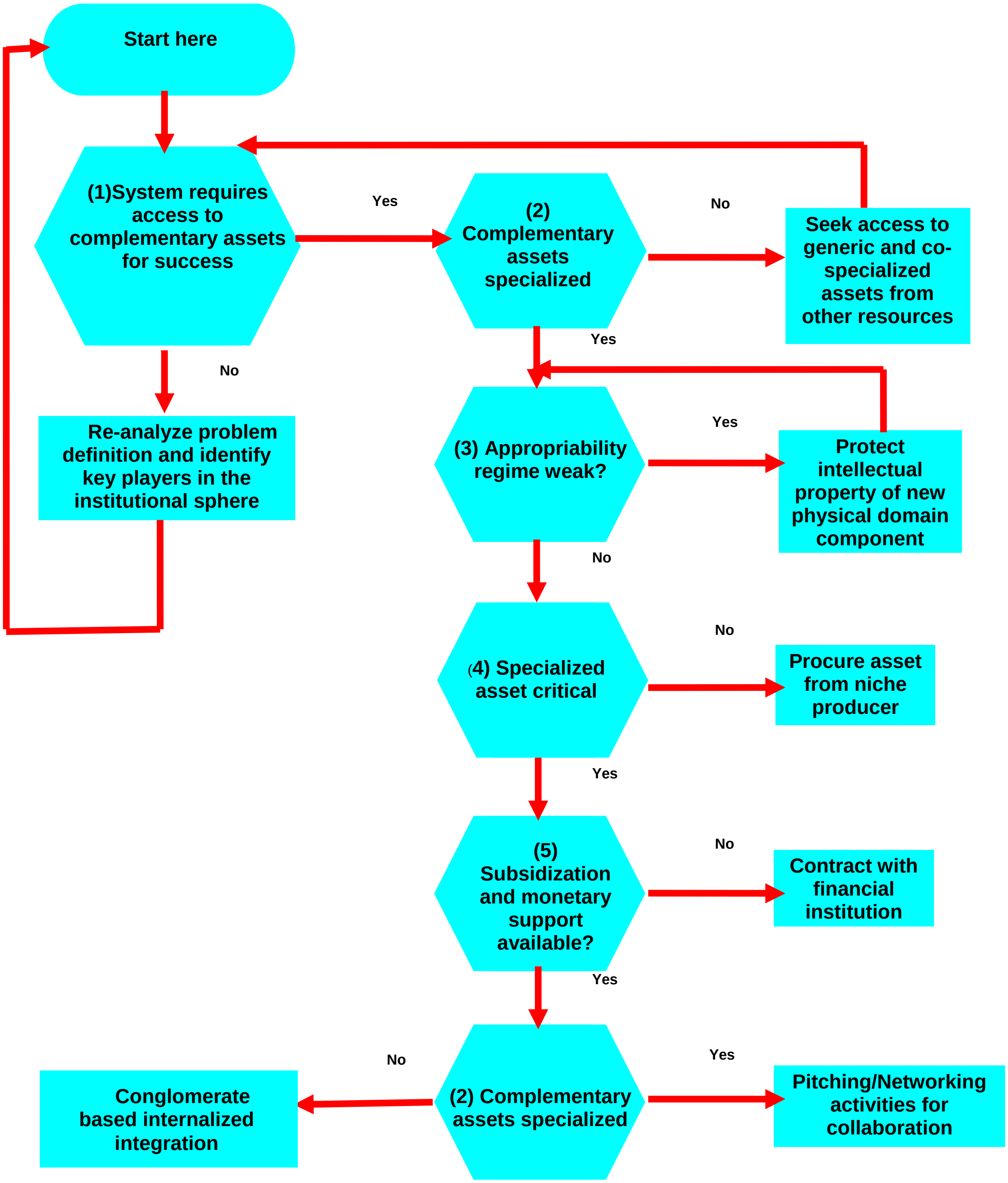

Figure 15: Process Scanner: CLIOS Process based Institution-Specific Segmentation. Source: the author, based on Teece et al. 2006

It should be taken into account that such kind of an analysis, at the intellectual property level, can only be done in the second stage of the CLIOS Process when we have a completed representation of the system structure in terms of the physical domain and institutional sphere. Only at this stage it is possible for us to distinguish between components of subsystems that need intellectual protection and ones that don't need protection. Once the new design component or technology is adequately protected, one would then determine whether there are any possible subsidies available from government agencies that are potential collaborators. If such sources are unavailable, then one would turn to other external sources with which one could contract for financial support. When monetary support becomes available, then it becomes necessary to have an extensive collaboration with the institutional financier. Such a process allows us to focus on system innovation in subsequent CLIOS System iterations, rather than correcting our initial assumptions regarding the CLIOS System.

As illustrated in Figure 15, increasing competition among organizations seeking funding from government agencies and non-profit organizations is also making it increasingly difficult, not only to enter into a collaborative relationship with a funding institution, but also to maintain that funding source for the several years to come. Therefore, with increasing complexity and the uncertainty of future funding, it is necessary to strike the right balance in maintaining relationships with different players within the CLIOS Process.

4.1.4. Inputs and Outputs of this tool

The input-output process of the scanner works quite efficiently as long as we put a comprehensive list of institutions through the scanner. When any specific player is fed as an input to the process scanner we determine whether it has the required complementary assets to be valuable to the system. Complementary assets in this context means assets the system requires, but does not currently have. The appropriability regimes are checked to see how they fit within the system architecture based on the level of innovation. Then, we check whether the specific player under consideration could potentially provide subsidization or monetary support of any kind. Finally, when all these steps are performed on any given input, we determine whether the organization is the right fit within the system by selecting or unselecting it. The selected players are used to fill the institutional sphere. However, it is important to remember that this tool only identifies whether a particular player belongs to the system or not. Therefore, a few players have to be weeded out if they do not belong in the institutional sphere. For example, while identifying players in the institutional sphere for the Near Earth Object problem we will realize that the EPA does not belong in the institutional sphere. If it is selected at all, it will interact with players within the social sub-system, along with the environmental advocacy groups that are against the use of nuclear explosives for NEO mitigation purposes. This is accomplished by the Segment-based value proposition tool which is described below.

4.2. Segment-based Value Proposition tool

Now that we have a tool that allows us to separate and classify the various institutions, we turn to examining how these institution-specific segments can help us devise various strategic alternatives. A segment in this context is a set of organizations that are grouped together based on their level of importance to the system.

4.2.1. Evolution of segmentation

The increasing competition among the deluge of players offering the same support services is complicating the dynamics of several markets, and making the value proposition factor of more importance than ever before. Commoditizing the client can prove disastrous, because lack of client loyalty can easily oust one from key sub-system operations (Hax, 2001). Appropriability regimes are becoming weaker by the day. With superior prototyping tools and rapidly improving reverse-engineering practices, core technologies are becoming much easier to replicate. This is why today's market is flooded with intellectual property conflicts, and this requires a value-based analysis for different CLIOS System players based on the segment they fall under.

4.2.2. Importance of a value-added network

Depending upon the types of strategic alternatives that one wants to design for a system, one can greatly influence the relationships among several key players within the network. Therefore, it is important to segment the institutions that might serve as key players into different categories. This creates a natural starting platform from which one can represent the existing dynamics and design the new dynamics of the physical domain and how they relate to the institutional sphere. An example case of value-add services for a CLIOS Process Analyst working in a consulting firm is described in Figure 16.

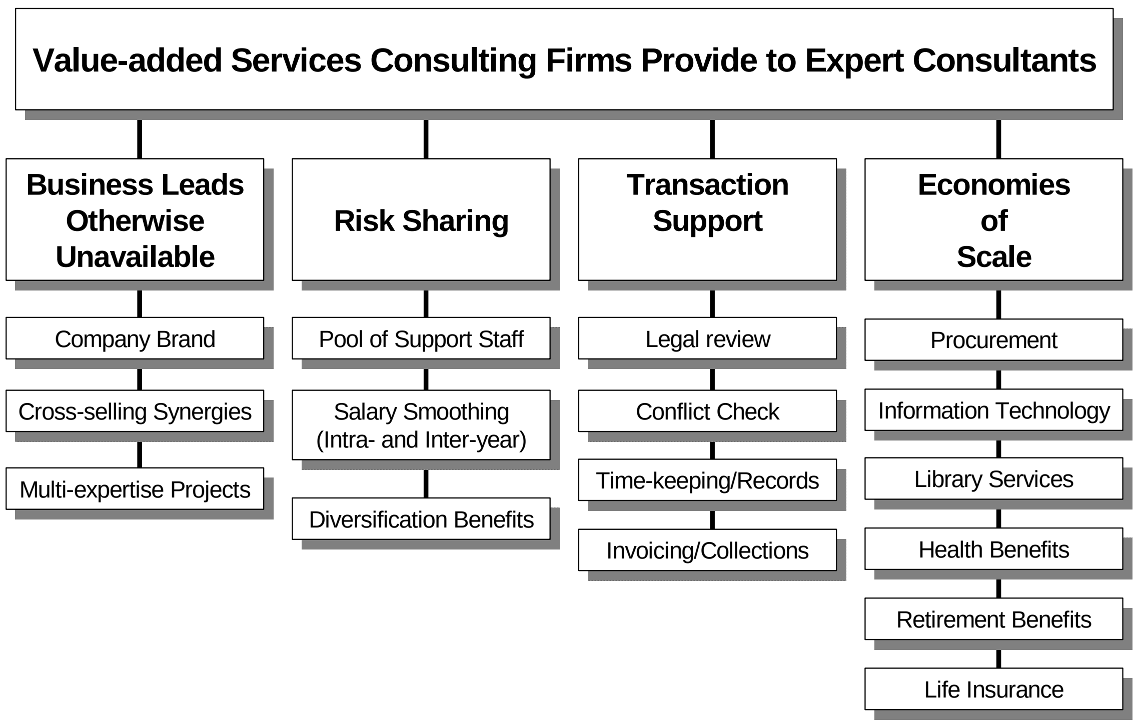

Figure 16: An Example case: Value-added services for a CLIOS Process analyst in a consulting firm. Source: Bodell (2006)

The process of putting each institution under the process-scanner tool helps us to identify characteristic similarities and differences among key players and separate into various segments as described in Table 6. It should be noted that most value propositions stated in Table 6 are general in nature and cannot be applicable to all possible scenarios. This gives us a platform from where we can start analyzing the value proposition of each segment. This tool provides a methodology for arranged the various segments based on the level of importance and the greatest overall value they add to the institutional sphere and different sub-systems in the physical domain.

4.2.3. Value proposition by segment

There are many cases wherein the non-involvement of government agencies and regulators in the key interactions between various sub-systems creates a large void that cannot be filled by other key players in the physical domain, no matter how sound the system architecture and the technical design at the sub-system level. Thus, the interactions between the institutional sphere and the physical domain must be leveraged in such a way that they capture the maximum possible value.

In some cases, the lessons learned from the application of the segmentation process may be so useful that one might be able to omit a few organizations from the desired list of collaborators (at least by the *design, evaluation and selection* stage of the CLIOS Process) in order to simplify the representation of interaction complexities at the sub-system level. One might also want to consider what level of governmental regulation might be imposed on a particular solution to a problem.

Table 6: CLIOS System Value Proposition by Segment. Source: the author, based on Fucoy and Goldi (2006)

Segments of CLIOS System players	**Value Proposition of**
1) Large government agencies	• Tend to be very conservative and formal. • Delegate responsibility to vendor, with very little own involvement in projects. • Public tender buying process (can be long and expensive for vendors). • Looking for full-service vendors for a specific project. • Very competitive pricing is necessary to win tender. • *Relationship in general, with other system elements, is formally project-based, but can be extended when successful.*
2) Innovative large players	• Open to use relatively new technology, but prefer not to be on the cutting edge of innovation. • Business results are more important than the newest technology. • Buying behavior is to tend to hire external contractors for very specific tasks • Semi-formal Request for Proposal (RFP) process. • Not overly price-sensitive, but use purchasing departments to get good price. • Relationship in general, with other system elements, is typically medium to long-term. • *Complex internal structure can be very political.*

3) Innovative smaller players	• Smaller and often regionally-focused players who try to change their processes using latest capabilities. • More flexible, decision processes are straightforward. • RFP process often quite informal, based on recommendations. • Quite price sensitive, but ready to pay for good business value. • Prefer long-term relationships. • *Buying behavior is to tend to focus on a single full-service vendor.*
4) Transformers	• Wide range of products plus aggregates. • Direct delivery. • Clean packaging. • Business development support. • Access to capital. • Business management tools. • Credit sales. • Pricing advantage. • Time-scheduling of physical components. • *Highly reputed brand building for system through exclusive access to institution.*
5) Conservative large players	• Prefer stable and proven technologies over innovation. Often very hierarchical. • Buying behavior is to typically look for a full-service vendor.

	• Wish to establish long-term relationship with their suppliers. • *Very formal and long RFP process, involving several negotiation rounds with purchasing departments.*
6) Collaborators	• Wide range of products. • Access to capital. • Ability to provide bulk delivery. • Express delivery. • Credit sales. • Professional technical consultation. • *High product quality.*
7) Contractors	• Wide range of products plus aggregates. • Ability to provide bulk delivery. • Pricing advantage. • Professional technical consultation. • Multi-functional relationship. • High quality product. • *New product development.*
8) Conservative small players	• Need to meet only basics. • Buying behavior varies strongly. • Often overly formal RFP process. • Very price-sensitive. • *Mostly smaller, regional players with limited budget.*

Some problems might require much governmental authorization and oversight, whereas others might only require a minimal amount of intervention or support from the federal, state or local government. Therefore, the concept of "changes increase the challenge" is the driving force behind the use of this tool to segment the collaboration levels among different players in the institutional sphere and the physical domain.

4.2.4. Inputs and Outputs of this tool

The inputs to this tool are the selected institutions from the institution-specific segmentation tool (described in section 4.1) that have populated the institutional sphere. Once we have the list of players within the institutional sphere the segment based value proposition tool starts to analyze the value added to the overall system performance by each player. Once we know the value proposition of each player, it become easier to categorize them into various groups. The various groups can be large government agencies, transformers, contractors, collaborators etc. These groups are prioritized based on their importance to the CLIOS System. In most complex large socio-technical systems, large government agencies, innovative large and smaller players form the top-level segments.

Transformers and collaborators form the middle-level segments. Contractors and conservative smaller players form the lower-level segments. For example, in the NEO problem, players like Boeing and Lockheed-Martin that form an important part of the business-government divide will be identified as contractors. However, if we are dealing with an airline industry problem, Boeing will be identified a large innovative player. Thus, the output of this tool is a prioritized set of categorized players that is obtained from a list of players in the institutional sphere.

4.3. Strategic impact measurement tool

The strategic impact measurement tool helps us to generate evaluative metrics for the system. These evaluative metrics help us to select the best strategic alternative from the list of available alternatives. The details of the tools are shown in Figure 17.

4.3.1. Methodology

The best strategic alternative identified by the CLIOS Process sets out a path that allows the user to implement a sustainable architecture for the physical domain of the system. Strategic impact can be applied at different levels of system hierarchy. Sometimes, we have to drill down to the CLIOS System component level in order to assign various system impacts. First, one can analyze strategy from the physical domain level, and consequently modify interaction criteria between the organizations on the institutional sphere and the different subsystems. Second, one can move to a system level where one can analyze sustainability and improvement processes specific to certain organizations. Third, when one reaches the organizational level, it becomes apparent that making changes by upgrading or replacing individual components in a CLIOS subsystem will not make a major difference in the overall system performance. At this stage, it is important to specify where one can start allocating different strategic impacts to specific processes based on priorities.

We generate evaluative metrics based on the system goals we have in the preliminary checklists which we described in Chapter 3 of this thesis. There might be systems that require high performance at additional costs, whereas there might be systems that are willing to spend extra costs to get better durability. Figure 17 is a generic view of the strategic impact measurement tool. The evaluative metrics are represented row-wise in the second column. Each evaluative metric has different priorities that are represented by numbers in the first column. Moreover, each evaluative metric is a different Process type. The evaluative metric is derived from the refined system goals that were defined in Step 6 of the CLIOS Process.

Priority/ Process Type	Evaluative Metrics for System goals and issues	Strategic Alternative 1	Strategic Alternative 2	Strategic Alternative 3	Strategic Alternative 4
1/OE	Aggressive quality improvement in product/service offers		1		
2/OE	Commitment to best Practices	1	1	1	2
3/CT	Focused initiatives for most immediate CLIOS System Player	1		1	
4/S	Leverage existing sub-system to meet new tasks	1	1		
5/CT	Reinforce relations with Influencers, regulators and standard-Setters			2	1

6/I	New initiatives in competitor lock-out			1	
7/S	Manpower excellence	1			1

Figure 17: Strategic impact allocation metrics for a CLIOS System. Source: the author, based on Hax et al. (1983)

Key:

1 Key role in formulation and implementation

2 Important role of support and concurrence

S- System model, CT- Client Targeting, I- Innovation, OE- Operational Effectiveness

The concept of classifying these evaluative metrics based on Priority and Process Type was derived from the strategic-thrusts concept proposed by Arnoldo Hax in 1983. The process types for the evaluative metrics can be one of the following four types- Operational Effectiveness (OE), Client Targeting (CT), Innovation (I) or S (System Model). Every player within the CLIOS System needs to address the future in order to maintain its current position and improve its interactions with key players in the institutional sphere.

From the CLIOS Process standpoint, the first priority is adapting to today's transforming marketplace in which contractors and transformers segments are more technically-competent and large behemoth organizations are looking to them for specialized tasks. Given the wide variety of choices available to the buyer today, there are often situations where we have demanding clients. The second priority is to make sure that each player within the CLIOS System carries out its useful function at the most efficacious level and uses the client as the metric for judging its performance. The third priority is to revisit the strategy of forward integration to take advantage of the professionalization of various industries. This will be challenging since various players will see this move as competition from their respective complementors. The fourth and fifth priorities are continuations of prior initiatives to achieve higher status within the CLIOS System hierarchy. The sixth priority is responding to the need to develop the best internal culture for optimal execution of solutions to client problems. For example, process management tools and third-party financing can be provided for smaller innovative players. Efficient execution of these priorities assures impeccable formulation and execution of strategy (Fucoy, 2006).

Thus, the evaluative metrics for a system may be completely different based on the system goals. Various metrics help us evaluate the inherent risk and the sustainability of various strategic alternatives. What may seem as significant advantage in one system, may offer several disadvantages in other systems. To address this question we might need to assess the cost of a given system as a function of the benefit that can be derived. This is the cost-benefit analysis (CBA) tool that is often used in the CLIOS Process. There are several other tools in the CLIOS Process like the CBA tool that can help us come up with the best possible evaluative metrics.

4.3.2. Inputs and Outputs of this tool

The inputs of the strategic impact measurement tool are various strategic alternatives that are obtained from step 7 of the CLIOS Process where we identify and design strategic alternatives for system improvements. Once we have a list of strategic alternatives these are fed column-wise into the tool. The best possible evaluative metrics are fed in row-wise into the tool to gauge the performance of each alternative in the context of overall system performance. It is important to choose the right metrics to evaluate the various strategic alternatives in order achieve the desired output. So, it is important to select metrics which closely align with system goals and issues that we identified in Step 1 of the CLIOS Process.

We assign numbers 1 and 2 for each strategic alternative while analyzing a specific evaluative metric. Each metric is evaluated based on the process types that might be system level processes or operational processes. A few processes might also be innovative and client targeting in nature. Once we have identified the right set of evaluative metrics for the bundle of strategic alternatives, we start assigning numbers 1 and 2 against them. 1 represents that the alternative has a key role in formulation and implementation, and 2 represents that it has an important role of support and concurrence. There are various ways to allocate points to the numbers 1 and 2. One possible way is to assign 10 points for 1, and 5 points for 2. Then, the points for each alternative are added up. The alternative that receives the most number of points is considered as the best alternative. However, we cannot be sure that we have selected the right alternative at this stage. It is for this reason that we have to iterate through the CLIOS Process again, until we are certain that we have identified the right metrics. Moreover, the CLIOS Process by itself is an iterative methodology. It is for this reason that this tool fits in solidly into the CLIOS Process.

4.3.3. An example case: Applying the tool to the Spent Nuclear Fuel (SNF) case

Let us suppose we are dealing with the problem of transporting all Spent Nuclear Fuel (SNF) to a central repository in Yucca Mountain. This problem has been analyzed in detail by the

Nuclear and Radiation Studies Board in the book "Going the Distance? The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States (2006)." In this case, of course, we have various strategic alternatives to deal with that problem. Let us assume that we have four strategic alternatives as for the problem of handling SNF waste. Consider that we need to design a CLIOS System bundle to address problems pertaining to SNF management. A bundle in this case is a set of strategic alternatives. This bundle could supposedly be used to give key insights to the Department of Energy in designing a final solution for the SNF problem. Two or more of these alternatives can be combined to provide an efficient solution. However, to find the best solution we need a tool to allocate priorities and importance levels to the alternatives and select the best alternative. This is where the *strategic impact allocation metrics* tool comes into play by helping us to choose the right set of strategic alternatives for the SNF management problem.

Priority/ Process Type	Evaluative Metrics from System goals and issues	Strategic Alternative 1: Reprocess SNF	Strategic Alternative 2: Transport SNF to repository site using a combination of rail and truck	Strategic Alternative 3: Smaller Decentralized repositories	Strategic Alternative 4: Use other non-carbon and renewable energy sources
1/OE	Lesser amount of SNF waste	1		2	
2/OE	Commitment to best Practices	2	1		

3/CT	Focused initiatives	2		1	
4/OE	Number of Shipments		1	2	
5/S	Leverage existing sub-system to meet new tasks	2	1		1
6/CT	Reinforcing relations with Influencers, regulators and standard-Setters		2		1
7/S	Retrofitting Costs		1	2	
8/I	Reduced Carbon footprint	2			1

Figure 18: Strategic impact allocation metrics for the SNF problem. Source: the author, based on MIT 1.041 course (2007)

Key:

1 Key role in formulation and implementation

2 Important role of support and concurrence

S- System model, CT- Client Targeting, I- Innovation, OE- Operational Effectiveness

As explained earlier, the evaluative metrics are based on the system goals. These set of evaluative metrics are juxtaposed against the strategic alternatives in Figure 18. The tool then helps us to analyze the proposed alternatives against the evaluative metrics in order to arrive at a solution that addresses the quantity of SNF to transported, method of transportation, and storage issues. The strategic alternatives listed in Figure 18 are possible practical solutions for the SNF management problem. We used the five and ten point methodology as described in section 4.3.2 to realize that strategic-alternative-2 had 45 points, which was the maximum number of points among all alternatives. By using this tool the Department of Energy (DoE) could have finally narrowed down its options to using an optimized combination of rail and truck to transport SNF to Yucca because strategic-alternative-2 in Figure 18 had the maximum number of points. Thus, the tool could have served its purpose by giving the DoE key insights to design a final bundle of strategic alternatives to deal with the SNF.

4.4. Strategy System-Structure Matching

The concept of Strategy System-Structure Matching was proposed in the business context by Arnoldo Hax in his book *The Strategy Concept and Process* (1996). We will design a similar tool in the CLIOS Process context. The slightest change in the architecture and operating procedures of a system may require the selection of a new strategic alternative. We need to synthesize the structure of the system in terms of strategy, such that both can map to each other. By using the CLIOS Process, we can come up with metrics to evaluate the operating procedures within a system. The modification of these operating procedures (based on the results from the application of evaluative metrics) will in turn affect the socio-economic environment in the system. The need to adapt to these changes requires a change in strategy. Selecting a particular strategy drives the system (favorably or unfavorably) by making several changes in the system architecture. This is a recursive process because nothing remains "favorable" forever. It is for this reason that we need a tool that matches system-structure and strategy, using which we decrease the number of iterations in this kind of a feedback loop.

4.4.1. Levels of Competency

A small modification in the strategy to address the system level change may not be an effective way to address the modification in the institutional sphere or the physical domain. Therefore, there has to be some process in place to synthesize the system structure and develops a tangible representation of that structure, which easily translates into choosing the right strategic alternative. The method we have chosen in Figure 19 to breakdown the system structure is the management competency pyramid. As illustrated in Figure 19, managing data is the most basic function that a system can provide.

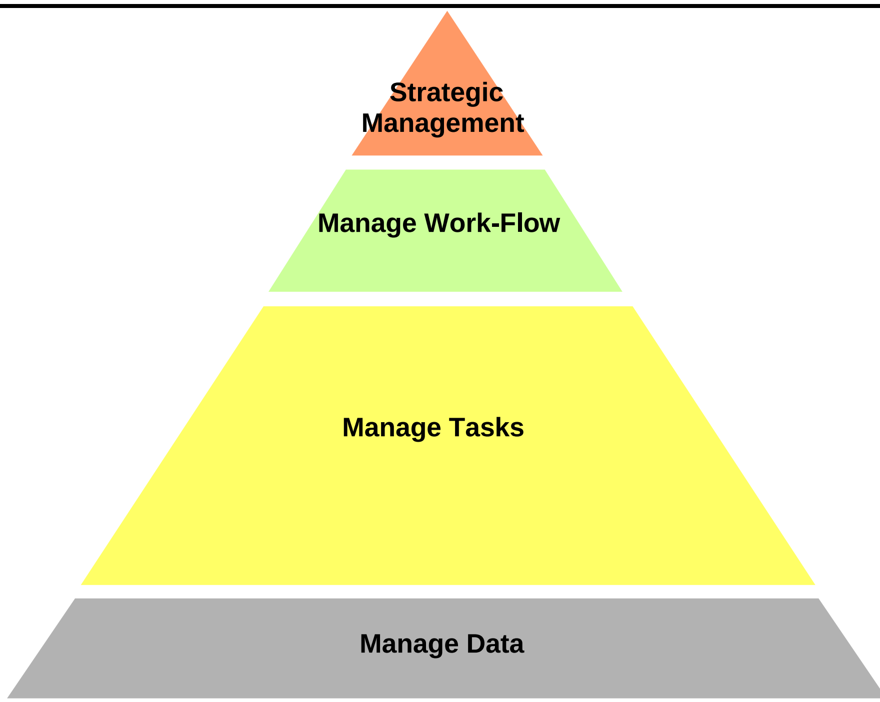

Figure19: Levels of System Competency. Source: Daines (2006)

"In managing tasks, the system provides functional support for performing all administrative duties that keep the entire system functioning. At the next level, managing the workflow of a system provides the framework for determining which players in the system should perform which tasks and ensuring that no single player is either over- or underutilized. This also supports overall system optimization by enabling system designers to eliminate bottlenecks and reduce the number of steps necessary to complete tasks. Finally, at the top of the pyramid are those capabilities that support interpreting internal and external data and extrapolating what ideas to pursue and how to position strategically position the system's assets (Daines, 2006)."

4.4.2. System interaction dynamics

This hierarchy of system competency provides a means to separate the key elements of the system architecture such that they can be mapped to a responsive strategy. This allows the user to see how the architecture of the system allows us to adopt a particular strategy framework based on the following interactions within the CLIOS System-

1) Relationship categories- ""Tangible relationships arise from opportunities to share activities in the value chain among related business units due to the presence of common buyers, channels, technologies and other factors. Intangible Interrelationships involve the transfer of technical knowledge and management competencies in separate value chains. Players that do not share specific activities may nevertheless be similar in other general aspects, such as client types, product types, and types of manufacturing process (Porter, 1985)."

2) Collaboration levels- The three main levels of collaboration among players in the CLIOS System are program buyers, transaction buyers and relationship buyers. This sort of categorization was proposed by Paul Wang from Northwestern University. "A program buyer is one who follows some sort of internal procedure in order to make their business purchases. This is typical of governments or mature institutions that have developed complex manuals that govern their buying process. Typically, such buyers try to spread their purchases in any one category among several suppliers according to a fixed schedule. Such program buyers are almost immune to external marketing stimuli, because of their breadth of partnership, and they are very unlikely to be early adopters. The second type of collaboration level is the transaction buyer, which are clients that are primarily motivated by price. They actively compare prices in suppliers' catalogs, and they are willing to shop around in order to receive a bargain on every purchase. These buyers are the antithesis of loyal customers, and they also are unlikely to be early adopters (Wang, 1995)." Therefore, the best reception will be found in the relationship buyers[6]. These are clients who like the products and services offered by a specific player in the CLIOS System, and they may think about or treat this player as their primary or only supplier.

3) Geographical Scope- The system structure can also be broken down in terms of geographical scope, where regional variables are used to gauge the system's reach. The regional variables are

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[6] Dr. Paul Wang was one of the two founders of the Database Marketing Institute in 1994. His details were retrieved from the following webpage:
http://www.dbmarketing.com/Who%20We%20Are/Paul%20Wang.htm

geographic boundaries, climate, population density and population growth rates (Brooklings Institution Metropolitan Policy Program, 2005).

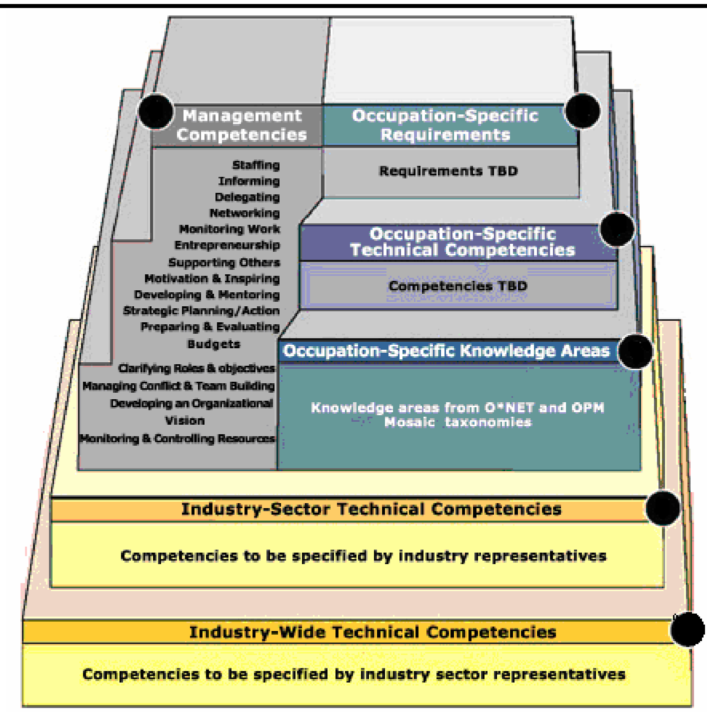

Figure 20: System Competency Model Building Blocks. Source: Personnel Decisions Research Institutes, Inc. (PDRI) and Aguirre International.

4) Organizational Dynamics- Finally, the operating norms of a particular component or subsystem within the CLIOS Process are important for determining its location and interaction within a CLIOS System. These can be psychographic dynamics, which include organizational attitude and value of people, or behavioral dynamics, which are based on variables such as loyalty, price sensitivity, benefits sought, and usage rate and patterns (Brooklings Institution Metropolitan Policy Program, 2005). It is always important to remember that when measuring "value of people" there will continuously be improvement, movement and feedback. Value for people generates continuous improvement, and continuous improvement instills value for people.

4.4.3. Evaluative metrics based mapping

The system performance is one of the most crucial factors in this process of mapping system structure to strategy, because they have the greatest effect on changing the operating procedure within a particular subsystem. Figure 21 shows the feedback loop where system structure is affected by strategy, which in turn affects the processes and performance at both the system and component level.

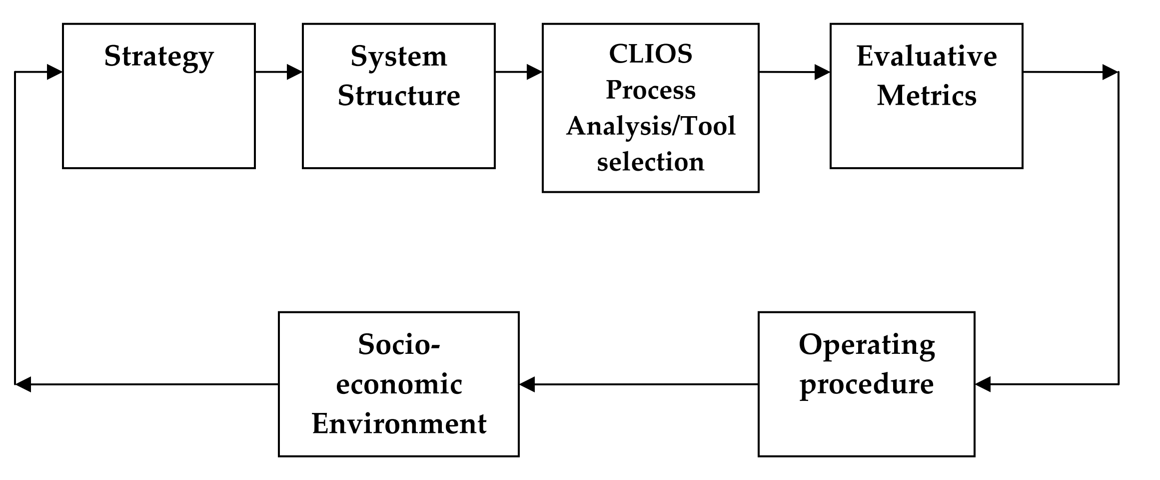

Figure 21: Continuous Improvement Loop for Strategy-System Structure Dynamics. Source: the author, based on Hax (1996)

The performance affects the socio-economic environment either positively or negatively based on how different current performance is from past performance. Table 7 describes how the operational procedure of a CLIOS System changes, based on the different metrics which are used to evaluate these operating procedures. This can result in a slightly different system definition in the representation stage, and this change in the processes will require different tools to be used to in the design, evaluation and selection stage.

Table 7: Key metrics in System Operating Procedures within a CLIOS System. Source: the author, based on Padgalskas (2007)

System Operation Area	Metrics affecting System Operating Procedures
Vertical Integration	• Processing capability: minimum processing, intermediate, or maximum. • Availability of forward integration
Plant Size	• Large plant • Smaller plants in hub and spoke configuration • Smaller plants in point to point configuration
Plant location	• Centrally located • Suburbs-Near markets • Far suburbs-Access to markets
Investment	• Highly leveraged • Liquid deposits • Fixed investment
Inventory Size	• Larger – driven by number of branches and product lines • Smaller – aggregated at central facility, with fewer product lines • Goods for sale- Raw Materials • Work in Process, Finished goods resale goods • Organizations - manufacturers, service-providers and not-for-profits

Quality Control	• Higher quality (faster delivery time, custom orders) • Lower quality (slower delivery times, bulk as opposed to custom orders)
Job specialization	• Centrally located product managers • Product specialization at each branch
Supervision	• Loose supervision- Power to branch managers • Tight supervision – consolidation and centralized processes
Size of Product Line	• Larger- Higher number of line items • Smaller- Smaller number of line items
Design Stability	• Client is never refused: Flexible ordering system • Client is turned down: Order system is rigid
Client Type	• High proportion of raw material to total manufactured cost, larger Clients • Low proportion of raw material to total manufactured costs, smaller Clients • Size of Client base
Procurement	• Small orders made by key players at the sub-system level in the physical domain • All players and orders are evaluated and aggregated by key players in the institutional sphere

From Table 7 we see how different operating procedures can be evaluated and modified more effectively if we have the right metrics to evaluate them. The net performance of a particular subsystem or component can be evaluated as the aggregate of the different metrics that were used to evaluate a particular operating area. These operating procedures can generate favorable, unfavorable or mixed reactions from the general media, public and advocacy groups.

Thus, they affect the socio-economic situation, which results in major changes in political and technical strategy of all players involved in the CLIOS System. This feedback drives the functioning of the continuous improvement loop for strategy and system structure.

4.4.3. Inputs and Outputs of this tool

In this tool, we try to align the system architecture with the strategy. Since we cannot compare apples to oranges, it is important that we represent structure of the system in terms of levels of competency. This is done by organizing the various sub-systems in terms of their level of competency. The levels of competency are organized with respect to importance of a sub-system to the overall system functioning. For example, we might find that a particular subsystem handles only data and tasks whereas another subsystem handles a major chink of the workflow.

Once we have identified the levels of competency, we start to analyze the various system operating procedures affecting these competencies. It is not possible to evaluate system operation without the right kind of metrics, so we must identify the right set of metrics affecting different operating areas. It is important to note that the operating procedure effects the socioeconomic environment in a system. This is especially important from the CLIOS Process standpoint. *Thus, once we have identified a set metrics affecting different operating areas the tool produces relevant operational procedures that favorably drive the socio-economic environment of the system.* This is very useful because the operation areas that are identified through this tool are used to drive future strategy. For example, the Toyota Production System (TPS) generates respect for people (employees in this case) by its continuous-improvement based operational procedure in certain areas. If these continuous improvement procedures are applied in all areas, the result is increasing employee workload which adversely affects the socioeconomic environment. This results in the failure of a useful idea that was not applied to the correct operational areas. It is for this reason that we need to identify the correct operational areas to which we can apply different system procedures.

4.5 Aligning these Specialized Tools with the CLIOS Process

Now, that we have described various tools let us analyze as to how they fit within the CLIOS Process. This will provide us key insights on how to go about while applying them to any problem. Figure 21 shows how the tools proposed in this thesis would fit into the CLIOS Process. The first step of the CLIOS Process would be carried out as usual. During step two, the Institution Specific Segmentation Tool (3A) would be employed to ensure that the key groups of institutional players are appropriately identified. Outputs from this tool (3A) would be fed into step three, which would employ the Segment-Based Value Proposition tool (5A) to ensure that the degree of influence of institutional players is appropriately designated. This ensures that certain players are not labeled as key players when, in fact, they play only a minor role and that the role of key players is not diminished due to mislabeling. Outputs from Segment-based Value Proposition tool would be fed into steps five and six, where this information would help smooth the transition from description to prescription, refine the system goals and identify performance measures.

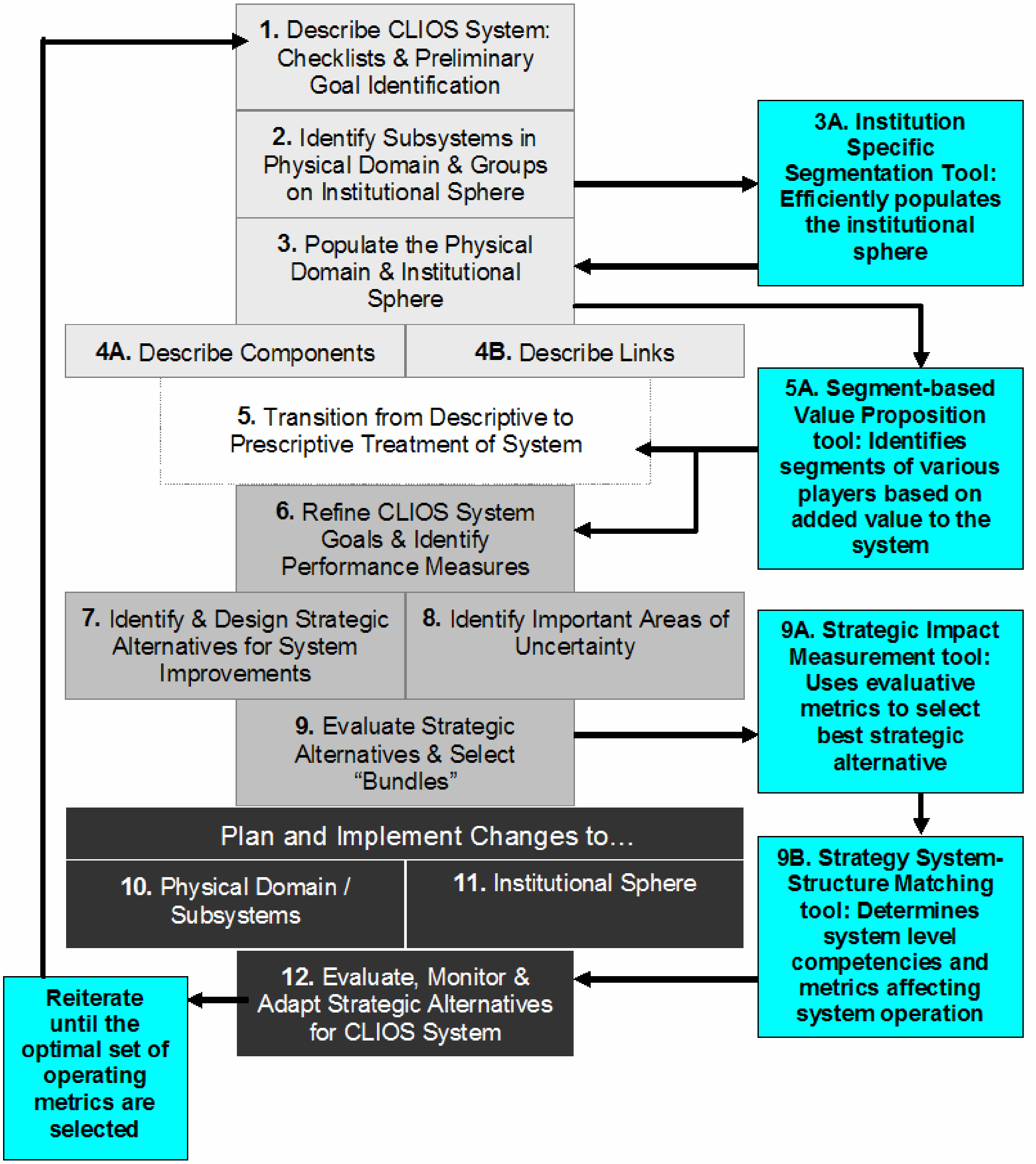

Figure 22: The New CLIOS Process: Aligning the 12 step process with specialized tools and procedures. Source: the author

Steps seven and eight would then proceed as usual. During step 9A, the Strategic Impact Measurement Tool would be employed to evaluate the efficacy of the strategic alternative “bundles” selected in step nine and revise those bundles as necessary to produce the best strategic alternatives for the system. During step 9B, the system would employ the Strategic System-Structure Matching tool in order to improve the number and quality of strategic alternative generated, and generate the best “bundles” for implementation. Steps ten and eleven would then proceed as usual. The Strategic Impact Measurement Tool is best utilized by successive iterations. Thus, the first two stages of the CLIOS Process should be repeated until the user is certain that tool has produced its optimum output. It does not make sense to iterate through the third stage of the CLIOS Process because at this stage our bundle of strategic alternatives is implemented.

Together, these tools offer the best means to counteract the limitations of various users of the CLIOS Process with different fields of expertise. CLIOS Process users who are very familiar with the technical elements of the physical subsystem domains often find it difficult to identify appropriate players and develop a hierarchy within the institutional sphere. The tools implemented at 3A and 5A can help such a user identify those players, recognize the ones that are the most or least influential and illustrate this hierarchy appropriately within the CLIOS representation.

CLIOS Process users who are very familiar with the elements of the institutional sphere often find it difficult to understand the structure, functioning and links between the subsystems of the physical domain. Given that interactions within the institutional sphere often cannot be modified simply by suggestion, the most readily employable strategic alternatives generated by the CLIOS Process are those that are easily adapted for the physical domain. Thus, the CLIOS Process user can use the tools implemented at 9A and 12A to develop complex strategic alternatives for physical domain subsystems that he or she may not normally be able to understand. Now, that we have designed these four specialized tools for the CLIOS Process, let us apply the CLIOS Process to the NEO problem in Chapter 5.

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Chapter 5: Application of the CLIOS Process to the NEO problem

In the previous chapter we have seen that the CLIOS Process provides an excellent framework for analyzing Complex, Large Interconnected Open Socio-Technical (CLIOS) Systems through an iterative methodology. The Near Earth Object problem can have catastrophic results, which makes it a complex socio-technical problem that generates many conflicting opinions on how to deal with the problem. The nested complexity that is inherent in the subsystems is brought to the forefront by the CLIOS Process, which provides a platform from where we can analyze the system behavior and evaluate strategic alternatives.

In this thesis, we focus on applying the representation stage of the CLIOS Process to the NEO problem, and apply the specialized tools described in Chapter 4 to each of the subsystems. In this thesis we focus on applying the first two stages (Representation, and Design, Evaluation and Selection stage) of the CLIOS Process to the NEO problem. We focus on gaining insights into system behavior by using the concepts of the CLIOS Process to construct our subsystem diagrams in the physical domain. We begin by applying the first step of the representation stage of the CLIOS Process, which we described in Chapter 3 of this thesis. We construct checklists for the characteristics, opportunities, issues, challenges, and preliminary goals of the system being analyzed by the CLIOS Process.

5.1 Checklists and preliminary goal identification:

In this step of the CLIOS Process, we analyze a CLIOS System by identifying a set of characteristics and goals of the system. These characteristics and goals are complemented by the opportunities, issues and challenges checklist, which provides a roadmap for thinking about ways to approach the problem. Most of the points in these checklists were taken from the 1998 report of the Commission on Physical Sciences (1998), Mathematics, and Applications (CPSMA) and Space Studies Board (SSB) because of the credibility of their data and factual information.

5.1.1 Characteristics:

1) NEOs are derived primarily from fragments produced by collisions between asteroids in the main asteroid belt.
2) The threat of NEOs is real, and this is supported by substantial evidence of collision histories which is described in Figure 2 of this thesis.
3) The key physical characteristics of NEOs are their shapes, sizes, albedos, spin characteristics, and masses.
4) It is estimated that approximately 5% of NEOs are readily accessible extraterrestrial bodies for exploration by spacecraft.
5) The key characteristics of potentially dangerous NEOs are their size, density, velocity and chemical composition.

6) As of April 20, 2007, 4669 Near-Earth objects have been discovered (NASA NEO Program Office, 2007).

7) 709 of the NEOs discovered so far are asteroids with a diameter of approximately one kilometer or larger (NASA NEO Program Office, 2007).

8) 848 of the NEOs discovered so far have been classified as Potentially Hazardous Asteroids (NASA NEO Program Office, 2007).

9) Orbital Distribution Asteroids in near-Earth space are categorized as Amor, Apollo, or Aten objects, depending on whether their orbits lie outside that of Earth, overlap that of Earth with periods greater than one year, or overlap that of Earth with periods less than one year, respectively.

10) Information on the internal structure and composition of comets and asteroids is provided by albedos (as functions of wavelength), reflectance spectra, and the estimated densities.

11) Comets are classified as short period or long period, depending on whether their orbital periods are less or greater than 200 years.

12) All near-Earth objects (NEOs) are in chaotic, planet-crossing orbits; their orbits evolve as a consequence both of long-range (secular) perturbations, due chiefly to the gravitational attraction of Jupiter and Saturn, and of close-range perturbations due to infrequent close encounters with one or more of the terrestrial planets.

13) The NEO problem has not been taking seriously for a long time. Therefore, it is important to analyze the details of the social subsystem in the NEO context.

5.1.2 Opportunities, Issues and Challenges

1) NEO discoveries present an opportunity to investigate extraterrestrial bodies while also providing an indirect assessment of the hazard to life on Earth that they pose.
2) There is a growing issue of an increased level of threat-awareness among the general public about the NEO issue. This spreading realization has led to increased support by NASA for systematic surveys of potentially hazardous objects.
3) The energy requirements to rendezvous with and land on these bodies are less than those to land on the surface of the Moon, which give us an opportunity to carry out many experimental missions on discovered NEOs.
4) Significant research on the nature and origin of Earth-approaching objects is required in order to deal with the threat of an NEO.
5) There is a significant issue of overlapping in NEO orbits that as a result of secular changes in eccentricity can intersect Earth's orbit during precession.
6) It is a challenging task to quantify mineralogies of NEOs in order to bridge the gap between asteroid spectroscopy and studies of meteorites.

5.1.3 Preliminary System Goals

1) A systematic inventory of NEOs needs to be gathered in order to permit a better understanding of their orbital distribution, as well as the relationships among asteroids, comets, meteorites, and interplanetary dust.

2) An emergency response system must be constructed to analyze complex interactions in between technical subsystems and the socio-political domain.
3) There is a need for a classification scheme for potentially dangerous NEOs.
4) We need to understand the orbital and size distributions, and the physical characteristics of NEOs for devising the right strategic alternatives for mitigating impact hazards.
5) There is no comprehensive set of pre-planned mitigation options based in the characteristics of the NEOs. This needs to be constructed as soon as possible.
6) We need to construct a comprehensive classification scheme in order to calculate the thermal and collisional histories of NEOs, and their relationships to meteorites and other bodies in the solar system.
7) The rate of discovery of NEOs has to be increased in the next few years as additional charge-coupled device (CCD) detection systems are installed at dedicated search telescopes in the United States and abroad.
8) Significant research about the composition, origin and history of near-Earth objects has to be funded in order to prepare for or protect our self from future NEO threats.

5.2 Actor Groups on the institutional sphere

Before we define the various actor groups on the institutional sphere, let us introduce the three subsystems in our physical domain which are the (i) Detection subsystem, (ii) Prevention subsystem, and the (iii) Social subsystem. We will describe each of these subsystems in detail in Chapter 6. Now, let us examine the actor groups. The Government was chosen as an actor group because many entities of the government control key decisions in dealing with a potential NEO threat. Similarly, the Private Sector has large stakes in building NEO mitigation technology. Citizens in various countries are obviously affected by the decision making strategy to deal with an incoming threat. These three groups form the major players of the institutional sphere in the NEO problem, and players in these groups have a huge effect on how NEO disaster management programs are developed and carried out.

5.2.1 Structure of the institutional sphere

The institutional sphere includes the National Command Authority (NCA). The term NCA is used by the United States military and government to refer to the ultimate lawful source of military orders. The term refers to the President of the United States and the Secretary of Defense[7]. In the NEO problem, NCA acts as a clearinghouse taking inputs from the monitoring subsystem and its United States government commander, sending the appropriate outputs to the payload delivery services, and strengthening the risk assessment. The National Command Authority (NCA) would oversee the efforts of the primary players and coordinate their activities. This coordination would take place through a new entity proposed by Urias et al. (1996) through the Planetary Defense Coordination Council (PDCC). Although having one nation at the head of the United Nations would be tyranny, having one nation at the head of the PDCC produces the opposite: unity. In the time of crisis, there is not much room for political

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[7] Definition of NCA retrieved form the following webpage: http://en.wikipedia.org/wiki/National_Command_Authority

bickering; the debate should only be about timing, appropriateness and execution of the response. Thus, having one nation at the helm is best for keeping order and ensuring smooth execution of the Preventions Sequence Mechanisms (PSM).

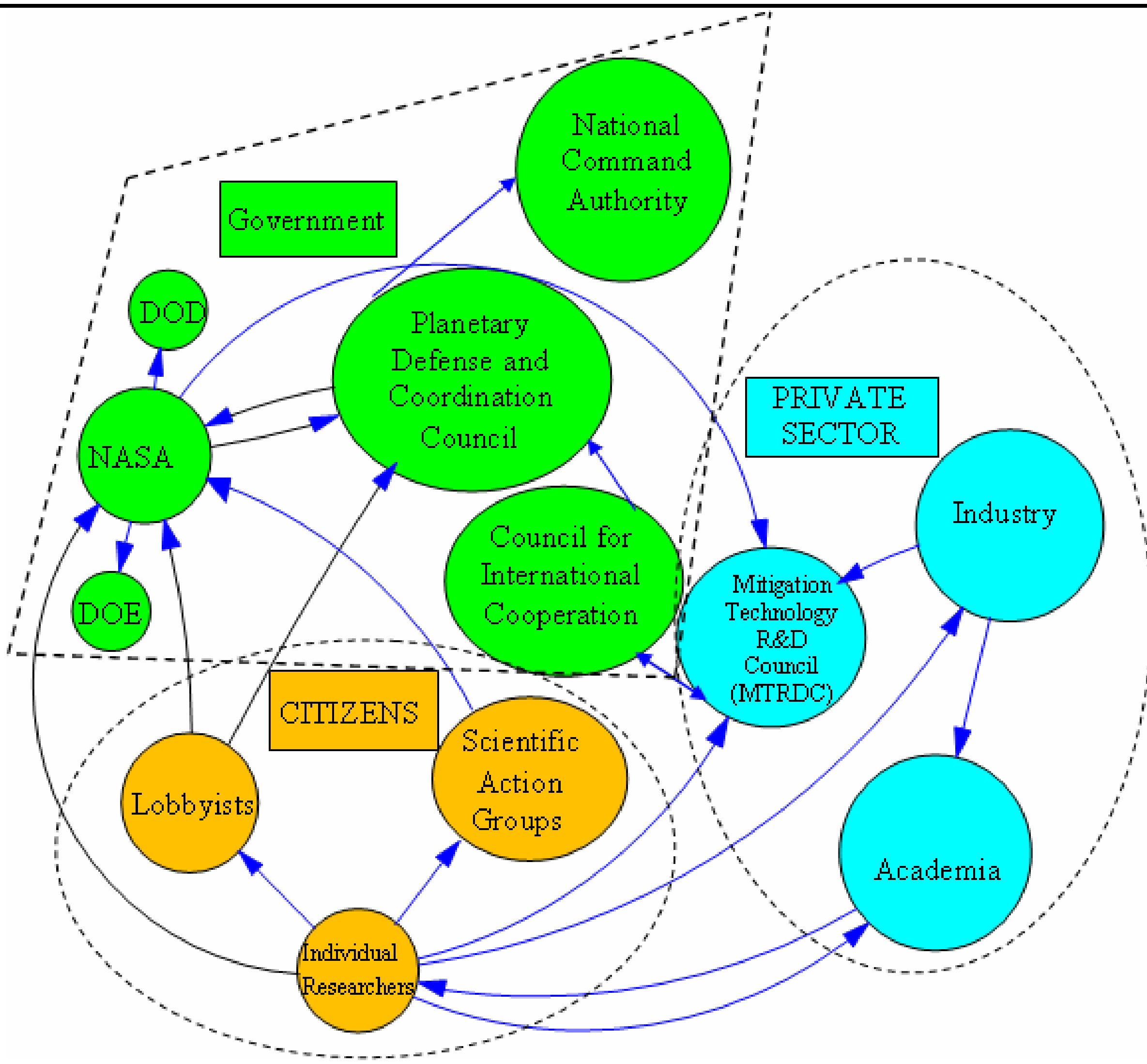

Figure 23: Institutional Sphere Diagram. Source: the author, based on MIT 1.041 course (2007)

The central feature of the institutional sphere is the fact that the PDCC is both the nucleus of and the common reference point among all the actor groups. All the actor groups on the institutional sphere have several interactions with the subsystems in the physical domain. The input from governments of other countries is fed into the PDCC, and localized research and development efforts are fed into the Mitigation Technology Research and Development Council (MTRDC). The first major physical component of the physical domain involves monitoring outer space to detect objects in and around our solar system that have the potential to become NEOs. We introduced three subsystems at the beginning of this chapter. These were the detection, prevention and social subsystems. The monitoring procedure is similar to the detection subsystem that we have described in section 6.1, except that this monitoring is more for classification and tracking purposes. The second major physical component of this prevention subsystem is response implementation, which is similar to the prevention subsystem, except that the prevention subsystem response involves more planning than action.

The institutional sphere takes care of improving policy responses both at the NCA level and below. These inputs combine to create methods for tracking objects, running simulations, grouping NEOs and mapping them to the PSM (Prevention Sequence Mechanisms) framework. The goal is to classify NEOs and identify their corresponding PSMs long before they become threats. This is particularly useful if the technology to execute the appropriate PSMs does not currently exist, because then the institutional sphere would have more time to develop it. Information regarding the movement of targets, NEO classification and PSM framework would be constantly fed to the NCA so that it can implement the appropriate policies.

5.2.2 Emergency Response Implementation

Response implementation involves two main entities: the National Command Authority (NCA) and the Planetary Defense and Coordination Council (PDCC); NCA processes all the inputs from the monitoring subsystem, orders the PSM payload to be prepared, and strengthens the risk assessment.

R&D Investment develops new technologies to implement PSMs that are more effective and develops new mitigation technologies, including the use of nuclear energy. The GDP of the major nations involved affect how well they are able to enable a policy-level response thereby strengthening the risk assessment that NCA may order. From the command structure illustrated in Figure 24 it is clear that role of the USSPACECOM (United States Space Command) and the USSTRATCOM (United States Strategic Command) is restricted to providing inputs only through the DoD. They do not have a final say in the sequence of events before a deterrence mechanism is implemented for a particular NEO. The final command is given by the NCA.

Three independent components affect the response implementation subsystem. The first one is the increasing NEO detection rate, which directs policy responses thereby improving the overall effectiveness of the system. The second involves deficiencies in tracking and honing capabilities, which can hinder both monitoring and response. The third involves improving the use of backup prevention methods, which would greatly reduce reliance on any one PSM by providing more than one PSM alternative in any given threatening situation.

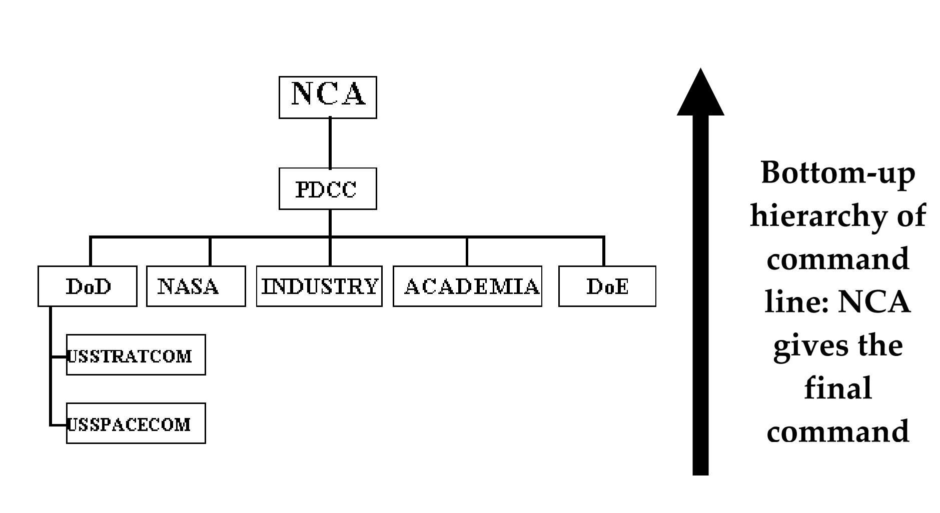

Figure 24: Proposed Unilateral US Command Structure for dealing with an NE. Source: Urias et al. (1996)

CLIOS Process-generated improvements to the response subsystem would involve putting increased energy towards developing alternatives to PSMs or alternative ways to implement PSMs, increasing funding for R&D Investment, using more GDP for policy response, and ensuring that they entire subsystem is giving correct feedback to the PDCC and NCA. NCA acts as a clearinghouse taking inputs from the detection subsystem and its United States government commander, sending the appropriate outputs to the payload delivery services, and strengthening the risk assessment. Now, that we have seen how the organizations and actor groups operate on the institutional sphere, let us examine the details of the physical domain in Chapter 6. In this chapter we also see the detailed interactions between the three subsystems in the physical domain and the institutional sphere.

Chapter 6: Subsystems in the Physical Domain

The subsystems that the user would analyze in the physical domain are the Detection, Prevention, and Social subsystems. Let us now examine each one of them in detail, beginning with the detection subsystem. In this Chapter, we also apply the *strategic impact measurement* tool which we described in Chapter 3 to three different subsystems. It should be noted that by applying the *strategic impact measurement* tool we progress from the *Representation* stage of the CLIOS Process to the *Design, Evaluation and Selection* stage of the CLIOS Process because we refine the system goals and start selecting the best strategic alternatives.

6.1 Detection Subsystem

One of the essential functions of the Prevention Sequence Mechanisms (PSM) system is the ability to correctly detect an NEO, identify it as a threat, and deal with the threat before the time has passed when disaster can be averted. Figure 25 illustrates the subsystem for threat detection and elimination. This subsystem is designed to be a recursive, continuous feedback loop, but for the sake of clarity, this explanation will assume that the subsystem is detecting its first threat ever.

6.1.1 Threat Detection and PSM Determination

Beginning at component named "monitor sky," the subsystem would scan the sky to see whether there is anything out there worth investigating. Under this component, nearly every

NEO (no matter how small) would be detected, and later components would take on the task of determining whether the object is a threat. An example of a CLIOS Process Step-7 improvement (designing strategic alternatives) to this component would be installing more advanced monitoring systems that could detect objects farther from Earth. Suppose while monitoring the sky, an object is detected. Then, the "sighting confirmation" component would then be employed to confirm that what was detected was an NEO. For example, it is possible that the system detected a random object or interference from some other device that generated readings resembling a celestial body when, in fact, there actually exists no NEO.

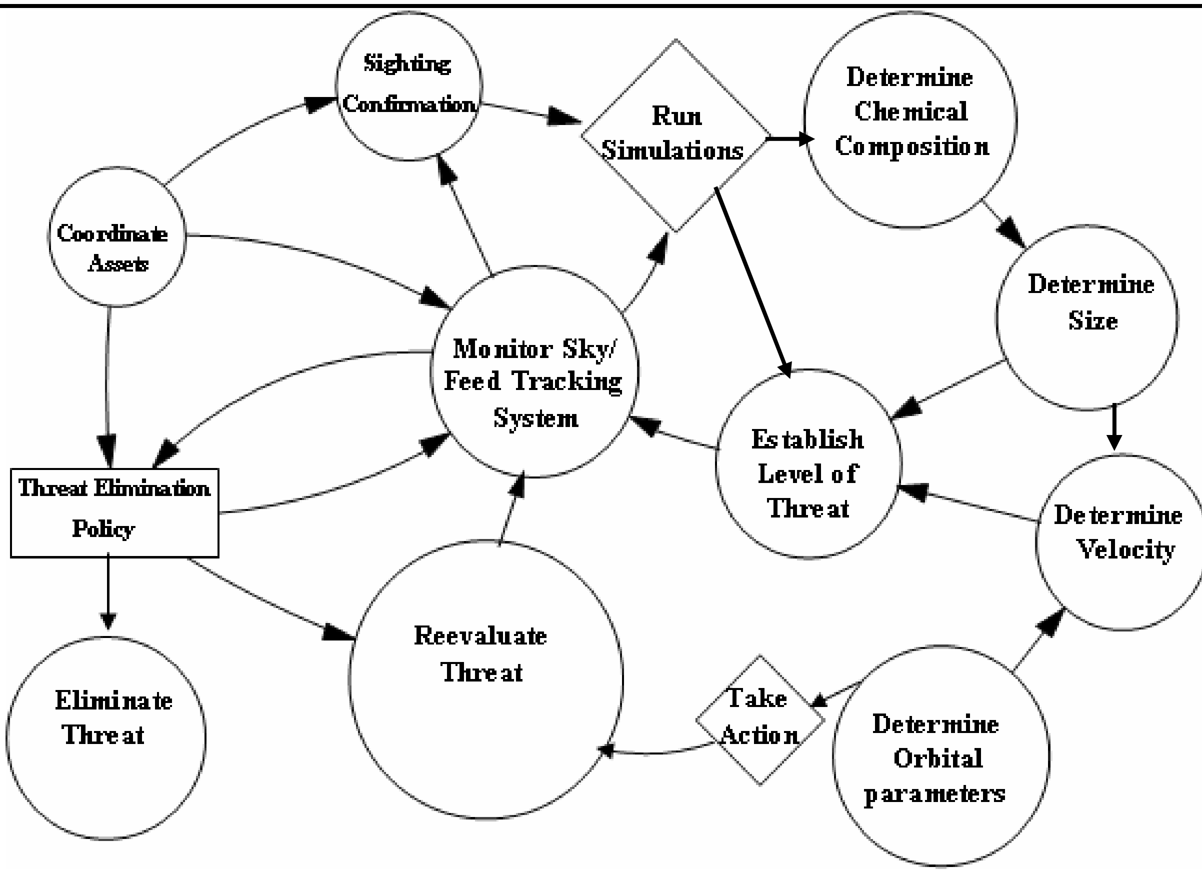

Figure 25: Detection Subsystem Diagram. Source: the author. based on Taylor et al. (2006) and MIT 1.041 course (2007)

An example of a CLIOS Process generated Step-7 improvement (designing strategic alternatives) to this component would be improved methods of distinguishing between true NEOs, non-NEO objects and equipment errors. The subcomponent for reevaluating the threat would not be employed until after at least one pass through this loop, so it will be addressed later in this section when the recursive functioning of this subsystem is triggered.

When an object is confirmed to be an NEO, then several components would be engaged simultaneously in order to determine key characteristics of the NEO: material composition, size, velocity and orbital elements. Each of these components is crucial, and an error in one measurement can ruin the output of the system. For example, the composition, velocity and orbital elements of an object become much less important when the object is the size of a baseball rather than the size of a mountain. Similarly, even a mountain-sized object composed of rock that is traveling very rapidly may not be a threat if its orbital elements suggest that it is moving away from the earth. Thus, all of these components must be running at their peak in order for this threat-detecting subsystem to function at its highest level.

Some CLIOS Process-generated improvements to these components would be as follows. For the "determine chemical composition" component, improvements would include making finer distinctions between various possible compositions and honing the capability to detect key information, such as mass and density of unknown substances and percentage makeup of NEOs that contain more than one substance. In the "determine size" component, improvements would be developing tools to determine the shape of an object in addition to its size, and to determine the size of an object that does not have a regular shape or that is not rotating (which would mean that the system could not observe all sides of it). For the "velocity determination" component, improvements would be developing tools to determine the object's rate of acceleration and to predict whether its velocity will be affected by nearby objects that have gravitational pulls (other than the Earth) or by colliding with other objects in its path. An additional improvement would be to create a recursive loop between size, velocity and chemical composition components in order to simultaneously process the increasingly more accurate inputs as the object moves closer and redraw the predicted orbit again on each pass through the sub-loop. This would make the orbit predictions increasingly more accurate as the object approaches the Earth.

6.1.2 Threat Elimination

Assuming that all these components above have produced reasonably accurate and useful results, then the simulation component would be employed to run simulations regarding whether, when and how the NEO would come in contact with Earth. This simulation is the core of the PSM system which is described in Chapter 7, because the accuracy, swiftness and variety in creating simulations are what determine the effectiveness and usefulness of the simulations. For instance, an inaccurate simulation is just as dreadful as receiving inaccurate inputs on the characteristics of the object from aforementioned components. Swiftness in creating the simulations is crucial for planning within the institutional sphere and for determining the correct PSM to employ, particularly if the object is moving quickly and has a short time to impact, which is less than 2 years. A variety of simulations is important because at any given moment there is a multiplicity of factors in outer space that are influencing whether an object will come towards the Earth, so having the ability to model multiple scenarios is key. CLIOS Process generated Step-7 improvement (designing strategic alternatives) to this module would include monitoring the Earth and the parts of the solar system near Earth's orbit in order to increase the accuracy of the base assumptions for the simulations, using more powerful computers or multiple computers simultaneously in order to speed up the simulation process, and generating statistics on the probabilities for each of the proposed simulations to determine which deterrence mechanism should be implemented first and the most likely scenario(s) for which the institutional sphere should plan.

We now apply *strategic impact measurement* tool which is a Stage-2 tool of the CLIOS Process. The list of various detection alternatives derived from the *strategic impact measurement* tool is listed in Figure 26. After generating a collection of appropriate simulations, the system would determine the level of the threat. Generally, this determination would be based on a combination of inputs from components that determine NEO characteristics as well as the simulation component, and the accuracy of all components would be crucial in order to determine precisely the level of threat. For example, even if the simulation component determines that the a metal object is hurtling at intense speed directly towards New York City, the object would have a much lower threat if it was smaller in terms of size, density and velocity. Furthermore, if according to the majority of simulations, there is a high probability that the object will hit the Earth, then the institutional response would be very different than if the probability were very low. CLIOS Process-generated step 7 improvements to this component would include honing the criteria for determining the level of threat and what the term "threat" means (i.e. threat as a measure of whether an NEO will hit the earth versus threat as a measure of how much damage a colliding NEO will inflict on the Earth). By assigning points through the strategic impact measurement tool in Figure 26, it was found that the best strategic alternative would be the space-based detection systems. This is because it had 40 points (the highest among all alternatives) when we applied the five and ten-point methodology to the 1's and 2's which were assigned to each alternative. . It should be noted that the numbers "1" and "2" are assigned to each strategic alternative based on my personal opinion. Someone else may have a different opinion if they are viewing the issue from a different lens.

Priority/ Process Type	Evaluative Metrics for System goals and issues	Strategic Alternative 1:Ground Based Optics (infra-red and visible)	Strategic Alternative 2: Ground based radio-telescopes	Strategic Alternative 3: Space-based optics(infra-red and visible)	Strategic Alternative 4: Combinational Moon-based telescopes
1/OE	Availability of detection assets	1	2		
2/OE	Better coverage area			1	2

3/CT	Focused initiatives		2	1	
4/OE	Lesser deployment complexity	2	1	2	
5/S	Grid Availability	1	2		
6/S	Ability to leverage existing sub-system to meet new tasks			2	1
7/OE	Accuracy of size, composition, orbit and state vector			1	2
8/I	Adaptable simulation feed	1	2		

Figure 26: Strategic impact allocation metrics for the Detection subsystem. Source: the author, based on Taylor et al. (2006)

Key:

1 Key role in formulation and implementation

2 Important role of support and concurrence

S- System model, CT- Client Targeting, I- Innovation, OE- Operational Effectiveness

Once the level of threat is established, then the “Take Action” component would both generate the appropriate PSM diagram and interact with organizations on the institutional sphere in order to decide on the appropriate action. The PSM diagram would provide pre-planned mitigation options against the threat, while the actor groups on the institutional sphere would oversee the implementation of the PSM along with the other socio-political issues. CLIOS

Process-generated improvements to this component would include improving communication and information sharing across subsystems and between the physical domain and the institutional sphere.

After deciding on an action, the system reaches a decision node at the "threat elimination policy" component, which acts on whether the decision was to ignore the NEO or to try to combat it. If the decision was to ignore the NEO, then the system returns to its starting point and monitors the sky for the next NEO. If the decision was to combat the NEO, then the subsystem proceeds to Eliminating the Threat, which is the subcomponent that carries out the actions specified by the appropriate PSM. CLIOS Process-generated improvements to this subsystem would include improving technologies to view objects farther away from Earth, improving tracking technologies, developing alternatives to futuristic PSMs by using technology currently available, and making the NEO and PSM classification systems more detailed.

6.2 Prevention Subsystem

Neutralizing an impending threat is one of the most important functions of the PSM, but it is not necessarily the best way to save Earth from disaster. In natural disasters as in medicine, prevention is nearly always cheaper and more effective than the cure. Thus, the prevention subsystem works to warn key players long before an object truly threatens the Earth. While this subsystem alone cannot actually prevent an NEO from hitting the Earth, it can inform the other subsystems earlier in order to give them more time to prepare for the actual PSM execution.

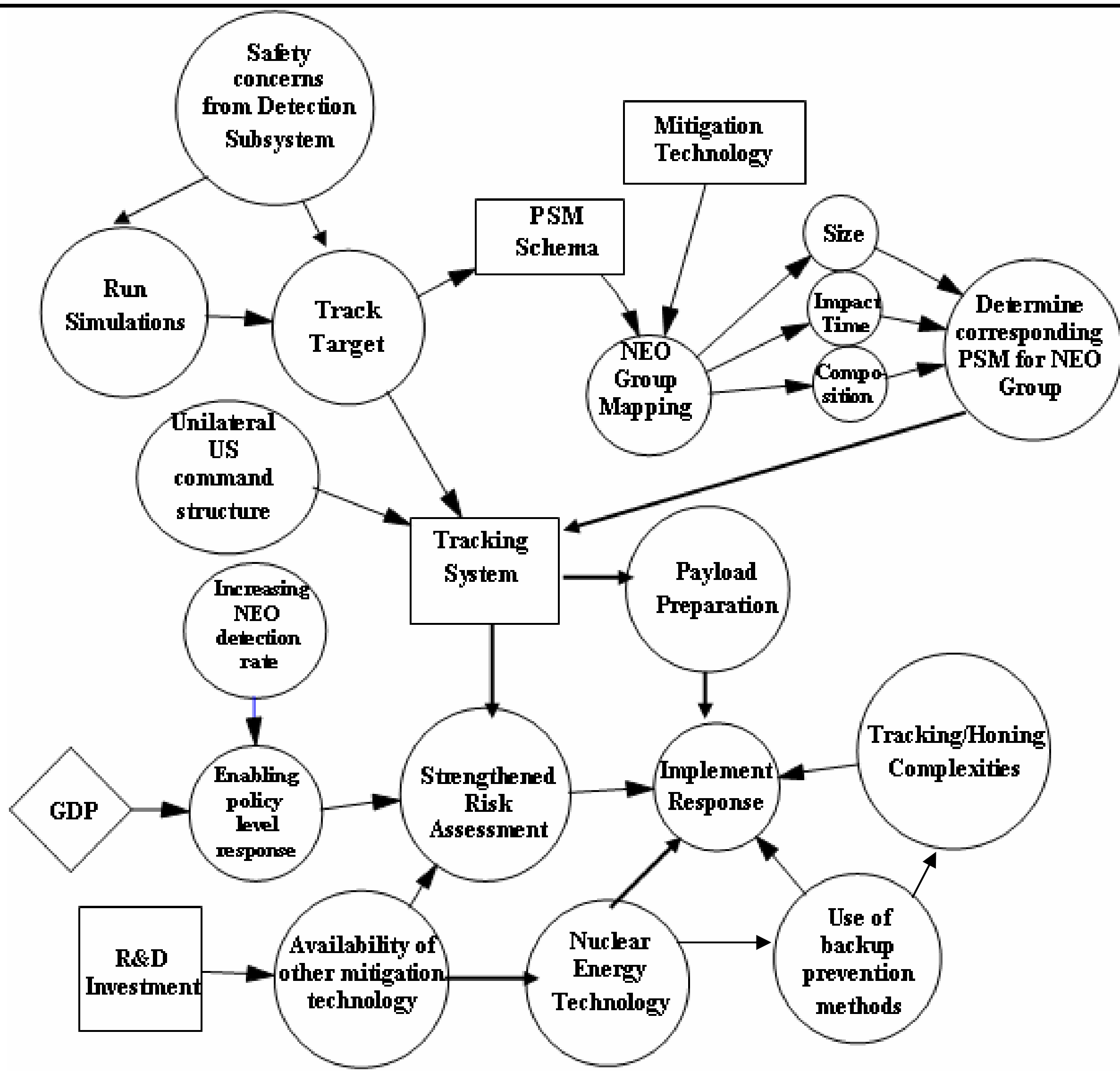

Figure 27: Prevention Subsystem Diagram. Source: the author, based on MIT 1.041 course (2007)

Thus, the prevention subsystem acts as a scouting or reconnaissance system which scopes out a situation long before it becomes dangerous (at the current level of detection technology this would be a time period of lesser than 2 years). The first major physical component of the prevention subsystem involves monitoring outer space to detect objects in and around our solar system that have the potential to become NEOs. This methodology is similar to the threat detection subsystem, except that this monitoring is more for classification and tracking.

The second major physical component of this prevention subsystem is response implementation, which is similar to the threat elimination subsystem, except that in the prevention subsystem response involves more planning than action. The institutional entities involve improving policy responses both at the NCA level and below.

6.2.1. Monitoring and Classification

The monitoring subsystem involves inputs from the detection subsystem in the physical domain and the actor groups dealing with mitigation technology on the institutional sphere. These inputs combine to create methods for tracking objects, running simulations, grouping NEOs and modifying the PSM schema.

Priority/ Process Type	Evaluative Metrics for System goals and issues	Strategic Alternative 1: Propulsive Deflection System	Strategic Alternative 2: Explosive System	Strategic Alternative 3: Kinetic Impactors	Strategic Alternative 4: Mass Driver Systems
1/OE	Lesser Need for complementary mitigation assets		1		2
2/OE	Need lesser lead time		1	2	
3/CT	Focused initiatives	1		2	1
4/OE	Lesser deployment complexity		1	2	

5/S	Capable to deal with large NEOs		1		2
6/S	Higher probability of success		1	2	
7/I	Ability to leverage existing sub-system to meet new tasks	1			2
8/OE	Greater magnitude of deflection/ destruction		2	1	

Figure 28: Strategic impact allocation metrics for the Prevention Subsystem. Source: the author, based on Taylor et al. (2006)

Key:

1 Key role in formulation and implementation

2 Important role of support and concurrence

S- System model, CT- Client Targeting, I- Innovation, OE- Operational Effectiveness

The goal of this subsystem is to classify NEOs and identify their corresponding PSMs long before they become threats. This subsystem is particularly useful if the technology to execute the appropriate PSM does not currently exist, because then the institutional sphere would have more time to develop it. Information regarding the movement of targets and their NEO and PSM classifications would be constantly fed to the PDCC so that it can implement the appropriate policies. If the threat case is a large NEO with a short lead time, then the best alternative as represented in Figure 28 is the Explosive-System Strategy because it had 40 points (the highest among all alternatives) when we applied the five and ten-point methodology to the

1’s and 2’s which were assigned to each alternative for different metrics. The evaluative metrics will accordingly change if the threat case is a smaller NEO with a longer lead time. It should be noted that the numbers “1” and “2” are assigned to each strategic alternative based on my personal opinion. Someone else may have a different opinion if they are viewing the issue from a different lens. CLIOS Process-generated improvements to this subsystem would include improving technologies to view objects farther away from Earth, improving tracking technologies, developing alternatives to futuristic PSMs by using technology currently available, and making the NEO and PSM classification systems more detailed.

6.2.2. Response Implementation

Response implementation involves two main branches: R&D Investment and GDP. NCA processes all the inputs from the monitoring subsystem, orders the PSM payload to be prepared, and strengthens the risk assessment. R&D Investment develops new technologies to implement PSMs that are more complicated and develop new mitigation technologies, including the use of nuclear energy. The GDP of the major nations involved affect how well they are able to enable a policy-level response thereby strengthening the risk assessment that NCA may order.

Three independent components affect the response implementation subsystem. The first one is increasing the NEO detection rate (ratio of discovered NEOs to expected number undiscovered NEOs) which directs policy responses thereby improving the overall effectiveness of the system. The second involves deficiencies in tracking and honing capabilities, which can hinder both monitoring and response. The third involves improving the use of backup prevention methods, which would reduce reliance on any one PSMs by providing more than one PSM alternative in any given threatening situation.

CLIOS Process-generated improvements to the response subsystem would involve putting increased energy towards developing alternatives to PSMs or alternative ways to implement PSMs, increasing funding for R&D Investment, using more GDP for policy response, and ensuring that they entire subsystem is giving correct feedback to PDCC and the NCA.

6.2.3 Challenges for the Prevention Subsystem

The main challenge for the prevention subsystem is increasing the distance at which the monitoring system can detect objects and making the policy response more direct and relevant to the reality of physical conditions. Many policy makers are unable to fathom how a real emergency would play out, so running simulations is key. In addition, the system must ensure that NCA has the most accurate inputs available so that it can produce the most effective policy outputs. Finally, NCA must ensure that its internal functioning requires as little bureaucracy as possible in order to prevent delays in the chain of command between monitoring and response.

6.3 Social Subsystem

Citizens have strong opinions about nuclear weapons in space. The stigma of nuclear weapons can affect the use of nuclear explosives for NEO mitigation purposes. The US has not constructed any new reactors after the three-mile island incident. The interaction between various components in the social subsystem is shown in Figure 29.

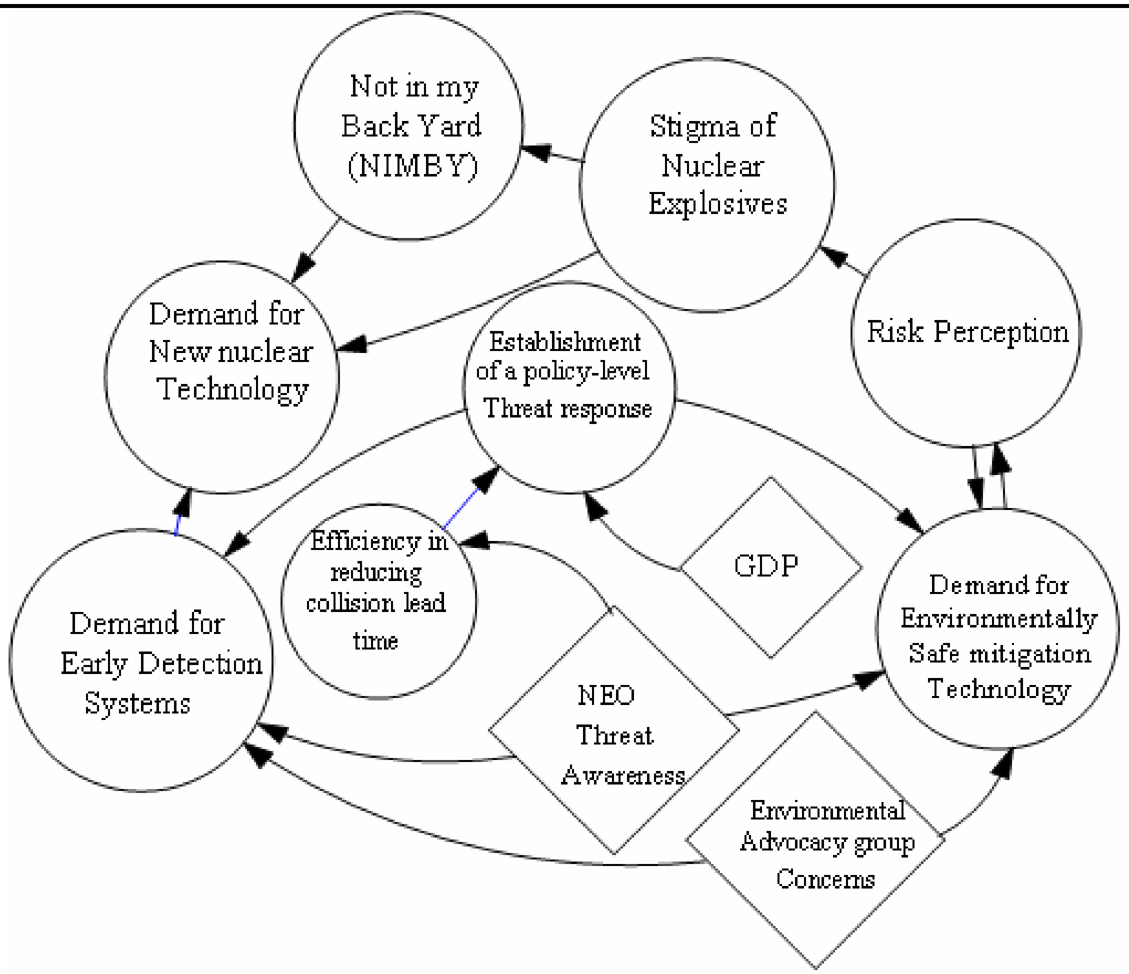

Figure 29: Social Subsystem Diagram. Source: the author, based on MIT 1.041 course (2007)

Political action groups and lobbyists, who form a part of the institutional sphere, have several interactions with the components of the social subsystem. Moreover, these groups have a great impact on the legislature the government passes regarding nuclear weapons in space. The bundle of strategic alternatives generated by the CLIOS Process is listed in Figure 30. We now apply the strategic impact measurement tool to select the best strategic alternative. The system can handle either real time decision-making based on the level of incoming threat, or it can follow a pre-planned decision making strategy. There are various alternatives for "who" executes the pre-planned or real-time decision strategy. This can be a sole effort by the US government, where planning and coordination time is saved by having aligned resources within the US. The other option is to have a coordinated effort at the international level with the Planetary Defense and Coordination Council (PDCC) acting as a facilitator between all the countries participating in mitigation procedures.

Priority / Process Type	Evaluative Metrics for System goals and issues	Strategic Alternative 1: Planned decision making	Strategic Alternative 2: Real-time decision making	Strategic Alternative 3: U.S. Only National Command Authority based execution	Strategic Alternative 4: International partnership based execution
1/OE	Pre-determined decision criteria	1			2
2/OE	Capability for real-time data transfer		1	2	
3/CT	Higher level of partnerships		1	2	
4/OE	Access to ground assets	1		2	1
5/S	Increased level of flexibility		1	2	
6/S	Lesser Need for complementary	2			1

	mitigation assets				
7/I	Ability to leverage existing sub-system to meet new tasks	1		1	2
8/CT	Focused initiatives	1		2	

Figure 30: Strategic impact allocation metrics for the Social Subsystem. Source: the author, based on Taylor et al. (2006)

Key:

1 Key role in formulation and implementation

2 Important role of support and concurrence

S- System model, CT- Client Targeting, I- Innovation, OE- Operational Effectiveness

It is evident from the strategic impact measurement tool in Figure 30 that the best way to address the NEO problem is strategic alternative 1, which is the planned execution system (which has 45 points, the highest among all alternatives). The second best strategic alternative was a US only command structure with 35 points. Therefore, the best possible bundle of strategic alternatives to deal with the threat of an NEO is a- U.S. only, planned national execution system. The planning part is addressed by having readymade PSMs for different NEO groups, which we have discussed in detail in this thesis in Chapter 7. . It should be noted that the numbers “1” and “2” are assigned to each strategic alternative based on my personal opinion. Someone else may have a different opinion if they are viewing the issue from a different lens.

The perception of risk and increased level of threat awareness might convince a large segment of the population that nuclear weapons are the way to go. In spite of this perception, there is still a major demand in the social subsystem for new mitigation technology (apart from ones that use nuclear explosives in space). Even a small leak of 5 pounds of Plutonium in the Eastern seaboard during a launch failure can have devastating environmental effects. Moreover, another factor affecting the development of new NEO mitigation technology is that the development centers have NIMBY (Not In My Back Yard) concerns because of the overall stigma associated with nuclear weapons in space. Now, that we have applied the CLIOS Process let us examine the details of the classification scheme and the PSM framework in Chapter 7. We have also designed a software application called PDTS 1.0 to demonstrate the functionality of the classification scheme and PSMs.

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Chapter 7: PDTS 1.0 System

The PDTS 1.0 System is a software application that was built specifically to demonstrate the working of the three parameter based classification scheme and the corresponding PSM framework. Let us now examine the classification scheme in detail.

7.1. Three-Parameter based Classification Scheme

There have been several scales that represent the hazard level of different NEOs. However, there has been no classification scheme which covers all the types of NEOs- meteoroids, asteroids and comets. Our classification scheme aims to do this by using the three most important parameters as the primary parameters. The three primary parameters that were used to classify NEOs in our classification scheme were size, time-to-impact and chemical composition. The size-based classification of NEOs are further divided into secondary parameters based on different class names. Each class name has a different size range.

Any NEO below 10 meters in diameter will most definitely burn up in the atmosphere. It is for this reason that class A in our size-classification starts from 10 meters in diameter. NEOs between 100 meters and 1 kilometer fall under class B. The majority of the NEO population falls under this class. Class C NEOs are between one and three kilometers in diameter and can cause significant damage and destroy major cities irrespective of whether they collide into the land or sea. Huge tsunamis caused by a class C impact can cause significant damage to coastal areas. Any NEO that is larger than three kilometers in diameter belongs to Class D. Thus, by using this size-based classification scheme with class names we are able to classify every possible size of potentially hazardous NEOs.

Table 8: Classification based on Size of the NEO. Source: the author

Class Name	Size Range(in diameter)
A	10 to 100 meters
B	100 meters to 1 kilometer
C	1 to 3 kilometers
D	>3 kilometers

This classification scheme comes into play only when we are certain that a detected NEO is on collision course with the Earth. It is for this reason that we have a primary parameter as time-to-impact. When we classify NEOs based on time-to-impact we have various class names for different time periods. If an NEO is detected more than 10 years before it is supposed to impact the Earth, then we assign class name “1” to it. At the present level of detection surveys, most potentially hazardous NEOs will fall under this class name. NEOs that have 2-10 years to impact the Earth fall under class name “2”. Class names “3” and “4” are NEOs that have an extremely short time-to-impact. Of course, this is very unfavorable, because many deflection mechanisms cannot be used for NEOs in these categories. It is important to remember that a deterrence mechanism with a smaller deflection rate needs longer time to create a large net effect on the NEOs course. We give class names to only those aspects of the NEOs composition that affect the PSM framework. In terms of PSMs, this is the least important primary parameter that affects the PSM for a particular NEO group.

Table 9: Classification based on the Time-to-impact of the NEO. Source: the author

Class Name	Time Period (years)
1	>10
2	2-10
3	0.25-2
4	< 0.25

The secondary parameters within the chemical composition are expressed in terms of stony, metallic and icy composition. The S-type asteroids are of stony (siliceous) composition. In our classification scheme, the S class also encompasses carbonaceous NEOs. M-type NEOs are metallic in nature, and cause the maximum damage upon impact because they have the lowest probability of air-bursts while entering the earth's atmosphere due to their exceedingly rigid structure. There will be minimal loss of surface material in their journey through the Earth's atmosphere. The I-type composition is used to refer to potentially hazardous long and short period comets, which are primarily composed of ice. The chemical composition of NEOs can further be categorized in terms of tertiary parameters that are based on spectral shape, albedo and color.

Table 10: Classification based on Composition of the NEO. Source: the author

Class Name	Composition Description
S	Stony
M	Metallic
I	Icy

These parameters correspond to an asteroid's surface composition. "For small bodies which are not internally differentiated, the surface and internal compositions are presumably similar[8]." For example, the S-types are moderately bright with an albedo of 0.10 to 0.22. NEOs can further be classified into various other tertiary parameters based on detailed compositions as to whether they have iron or magnesium-silicates.

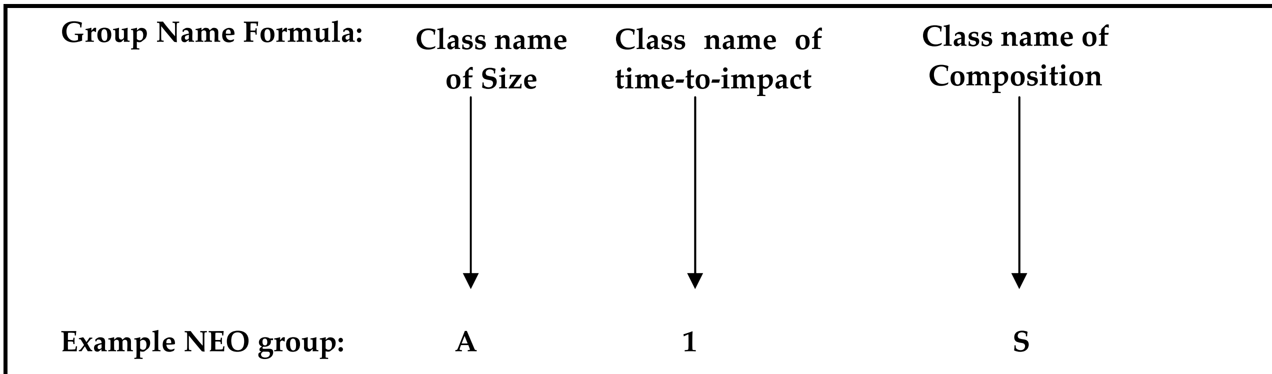


Figure 31: Group Nomenclature in the three-parameter based classification scheme. Source: the author

Thus, according to our classification scheme, any NEO can be classified into a particular group based on its size, time-to-impact and composition with the following method of

[8] Details retrieved from the following webpage: http://en.wikipedia.org/wiki/Asteroid_spectral_types

grouping. This method is explained in Figure 31. A C3M NEO is one to three kilometers in diameter with a time-to-impact period between three months and two years. By using this methodology we can assign any NEO into its corresponding group. In summary, there are three primary parameters which are the size, time-to-impact and the chemical composition of an NEO. These have subclasses within them. There are four subclasses each for size and time-to-impact, and three for chemical composition. Thus, we have 11 subclasses that represent secondary parameters.

Table 41: Overview of the new classification scheme applicable to the PSM framework. Source: the author

Size		**Time to Impact**	
Class Name	Range	Class Name	Period
A	10 to 100m	1	>10 years
B	100m to 1m	2	2 to 10 years
C	1 to 3km	3	0.25 to 2 years
D	>3km	4	<0.25 years
Class Name	**Composition**	**Group Nomenclature**	
S	Stony	Group Name Formula = Class name of Size. Class name of time-to-impact. Class name of Composition	
M	Metallic		
I	Icy	Example NEO Group = A.1.S or B.2.M	

- **3 primary parameters**
- **11 secondary parameters**
- **48 NEO groups**
- **Future Expansion to tertiary parameters**

By applying the principle of permutation between the primary and secondary parameters we get 48 NEO groups (4*4*3=48). This classification scheme can also be expanded to tertiary parameters that include detailed physical, chemical and orbital parameters of an NEO. However, in terms of the PSM framework they were deemed unnecessary because a detailed description of chemical composition is not going to make a huge difference in the terms of the type of the deflection or destruction mechanism that we will use for deflecting or destroying the NEO.

Once we know an NEOs size, time-to-impact and composition, then we conduct two procedures for a deterring an impact: 1) map the NEO into its corresponding group based on the above three parameter based classification scheme, and 2) implement the corresponding Prevention Sequence Mechanism (PSM) for that particular group. The various PSMs are tailor made for each group. They constitute a collection of various mechanisms for deflecting or destroying an NEO in a suitable order. Thus each NEO group has its own PSM. Through this methodology the above classification scheme works in tandem with the PSM framework for dealing with potentially hazardous NEOs.

7.2 PDTS 1.0 Software Modules

A software application called PDTS 1.0 was created to demonstrate how the classification scheme worked in tandem with a tracking database. PDTS stands for Planetary Defense and Tracking System. We used Visual Basic 6.0 and Microsoft Access XP to design the PDTS 1.0 System, which acts as a database for storing NEO information in accordance with the classification scheme that we just explained. The classification scheme was in turn mapped to the PSM framework which was pre-loaded into the application. The application has four different modules: 1) Authentication Module, 2) Classification Management Module, 3) Backups and Reports Managements Module, and 4) Tracking and Planetary Defense System Management Module. We will now examine how each module functions.

7.2.1. Authentication Module

The tools in the authentication module are primarily used for providing access rights to the PDTS system. This module can be considered as the entry point for the entire system. It recognizes and authenticates the user trying to enter the system through a validation procedure. It differentiates between an administrator and ordinary user, and provides access to corresponding elements of the system. For example, it provides restricted access to the classification management module because of the sensitive nature of processes in that module.

The dataflow diagram for the authentication module is described in Figure 32. It describes how the various components in this module interact with each other. The authentication module is also responsible for providing restricted access to the system administrator for generating scheduled backups and reports. Therefore, a user of the system could only login to access the tracking module where he is allowed to store NEO information of a potentially hazardous NEO.

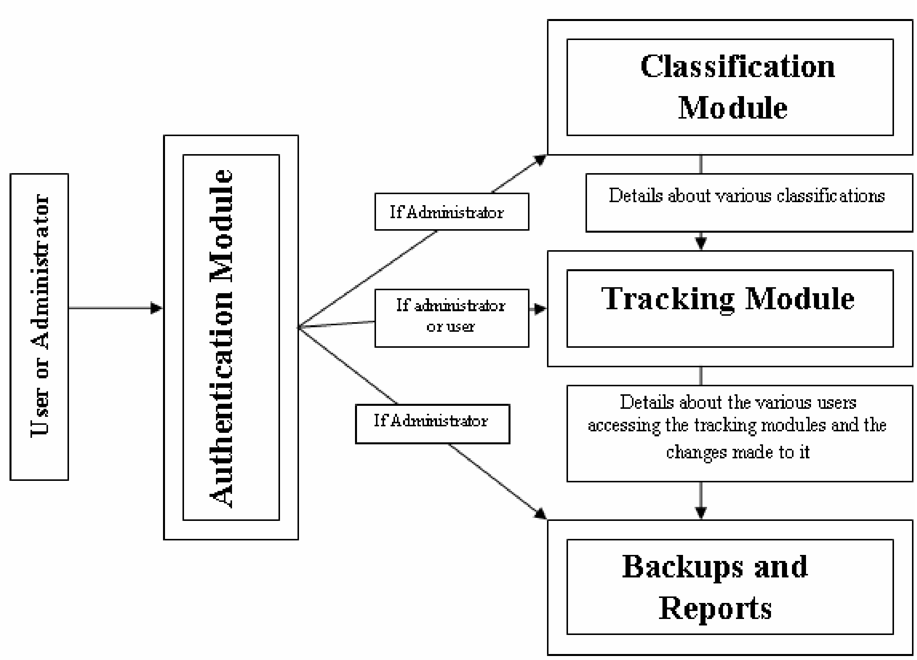


Figure 32: Dataflow diagram for the authentication module. Source: the author

Figure 33: Screenshot of the Authentication Module of the PDTS 1.0 System. Source: the author

7.2.2. Classification Management Module

The classification management module is a protected module that allows the user to modify parameters that are used to classify a particular NEO. Therefore, by modifying the parameters used to classify NEOs, the user could apply a new schema to categorize them. For example, the classification scheme we discussed in the earlier chapter is a three-parameter based scheme that was based upon primary and secondary parameters. If we were to upgrade the classification scheme to include tertiary parameters like albedo and spectral characteristics, then we would need a different classification scheme to categorize any given NEO. This is where the classification management module would come into play. The sensitive nature of the classification schema and its importance in storing NEO information into PDTS system mandates that it can only be accessed by the system administrator.

The administrator can create or delete users using the "User Master" procedure of the system. In this sub-module, the administrator manages user information and stores corresponding information. The passwords of users are also managed through the "Access Mangers" sub-routines in this procedure (source code attached in Appendix 2). Thus, any specific user can be denied or granted access. The User-Master sub-module also stores information on the specific user. We store every detail of the employee- right from the department where he works to his employee code. This is done to tag each NEO data-entry into the system. The user information is tagged along with the NEO information that is entered into the system.

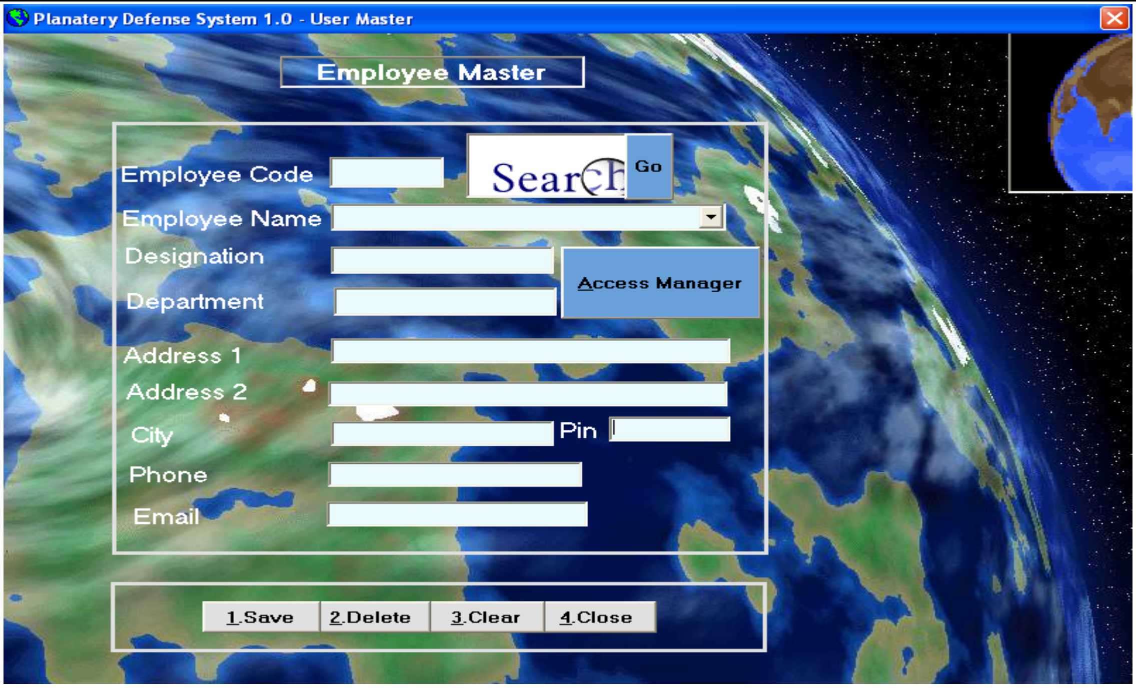


Figure 34: Screenshot of the User-Master module with the Access-manager subroutine. Source: the author

The four forms of the classification management module are InsertData, ClassificationMaster, ModifyData, and DeleteData. Each of them can only be accessed by the administrator when he wants to upgrade to a new classification scheme or change the parameters based on which he will classify a group of NEOs.

The classification management module provides flexibility for the administrator, in case there is a need to modify an accepted standard for classifying potentially hazardous NEOs. Simultaneously, the system provides security by not allowing the users to change the classification scheme. The default classification scheme for categorizing the NEOs is the three-parameter based scheme which was explained in the earlier chapter. The dataflow diagram for the classification management module is described in Figure 35.

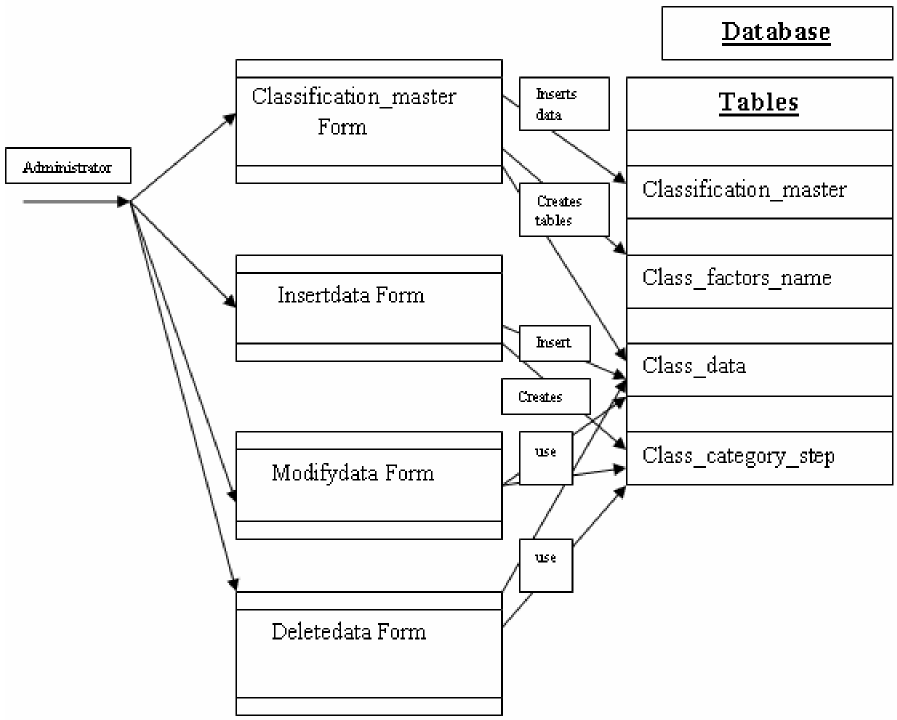


Figure 35: Dataflow diagram for the classification management module. Source: the author

Figure 36: Screenshot of the classification management module. Source: the author

7.2.3. Backup and Reports Management Module

This module generates various reports in different formats for the different NEO categories. As explained earlier this can only be accessed by the system administrator to maintain data integrity and security. Reports can be generated at the end of each day by the administrator. Any attempt to access this module by a user (other than the system administrator) will trigger message displays of non-authentication.

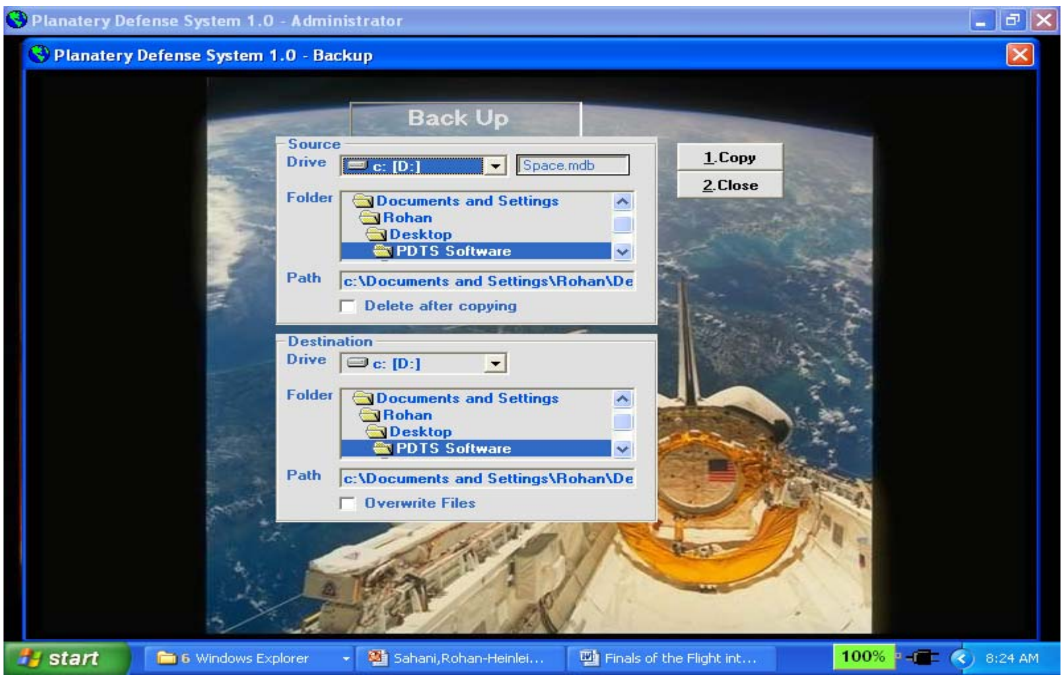


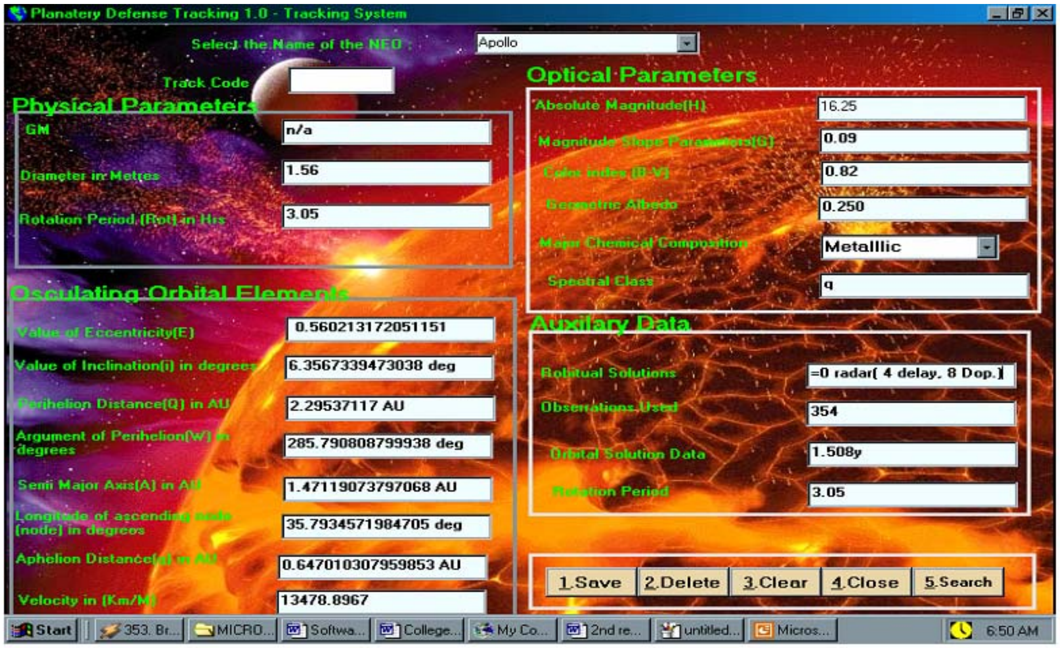
Figure 37: Screenshot of the backup and reports management module. Source: the author

This module is an important tool for the administrator because it allows him to store information in an organized manner, and also accounts for data storage failures. Moreover, each NEO entry is tagged along with detailed system user information. Thus, the saved reports contain the various details of each entry, including information of the system user who entered the data. Thus, entered tracking data can always be cross-checked with a particular user at some point in the future.

7.2.4. Tracking Module

This module manages the data that has been previously entered into the system. It also triggers various events once all the information is successfully entered into this module. This module also maintains the overall database. The tracking module stores NEO data by dividing it into four different parameters. These parameters were based on the methodology that Jet Propulsion Laboratory (JPL) uses to store information in its NEO tracking database (JPL, 2003). The four different parameters that are used to store NEO information are: (1) Physical Parameters, (2) Osculating Orbital Parameters, (3) Optical Parameters, and (4) Auxiliary Data. These four categories store various characteristics of the NEO. The diameter, rotation period, and the product of the gravitational constant and mass of the NEO are the three different physical parameters that are stored in the PDTS 1.0 system. The osculating orbital parameters stored in the system are the eccentricity, inclination, orbital period, mean motion and mean anomaly. Several characteristics with respect to the distance and argument of the perihelion and aphelion are also stored.

One of the most important characteristics of an NEO is absolute magnitude (H) and geometric albedo. Some of the optical parameters that are stored are the magnitude slope parameter (G) and the color index, which ranges from B to V.



TRACKING SYSTEM NOMENCLATURE

Osculating Orbital Elements Legend	
e =	Eccentricity
i =	Inclination
q =	Perihelion Distance
w =	Argument of Perihelion
a =	Semi-major Axis
node =	Longitude of the Ascending Node
Q =	Aphelion Distance
M =	Mean Anomaly
P =	Orbital Period
n =	Mean Motion
TP =	Time of Perihelion Passage

Asteroid Optical Parameters Legend	
H =	Absolute Magnitude
G =	Magnitude Slope Parameter
B-V =	Color Index (B-V)
albedo =	Geometric Albedo
spectral class =	Spectral Class

Auxiliary Parameters Legend	
#obs =	Observations used in Orbit Solution
data-arc =	Orbit Solution Data Arc

Physical Parameters Legend	
GM =	Gravitational constant * Mass of Asteroid
Radius =	Radius
P_{rot} =	Rotation Period

Figure 38: Screenshot and Nomenclature of the Tracking System Module. Source: the author

"The color index is a simple numerical expression that determines the color of an object. To measure the index, one observes the magnitude of an object successively through two different filters, B and V, where B is sensitive to blue light, and V is sensitive to visible (green-yellow) light. The filters are selected in such manner that the mean wavelengths of response functions are 442 nm for B, 540 nm for V[9]." The track search module is responsible for finding an existing NEO entry in the PDTS 1.0 database. Each NEO can be tracked by using one of the following parameters: (1) Tracking Code, (2) NEO name, (3) Month, and (4) Year.

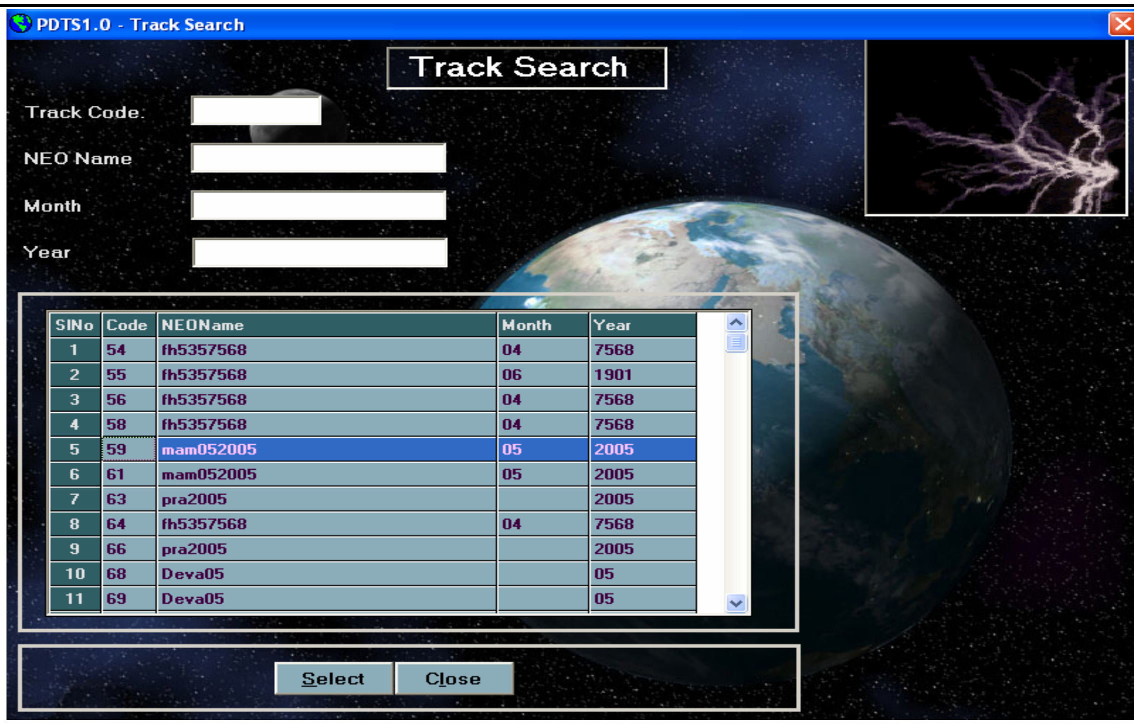


Figure 39: Screenshot of the Track Search routine within the Tracking Module. Source: the author

A straightforward method of searching for an NEO is to use the track code. This process is the fastest method for searching for an NEO in the PDTS1.0 system. Once the numbers are

[9] Details retrieved from the following webpage: http://en.wikipedia.org/wiki/Color_index

typed in the Track-Code textbox, the corresponding NEO is highlighted. This is the target NEO for which we are searching. However, it is difficult to remember a track code unless we have stored it in a place from where it can be retrieved. The NEO name search works in similar manner. As we type in the first few letters in the name of an NEO, a table displaying the list of NEO names pops up. Once, the unique NEO is found (when sufficient number of letters are typed), the specific NEO being searched for is highlighted. This is the target NEO. The month and year criteria can also be used to retrieve NEO data. However, the downside of using the month or year criteria is data redundancy.

7.3. PSM Search/Retrieval Process

The perihelion and aphelion parameters that are entered in the osculating orbital parameters category are used to determine the distance of a potentially hazardous NEO. The major chemical composition is derived from our secondary parameters in the classification scheme. Objects are named as S, M or I. The spectral class definitions are also loaded within the optical parameters characteristics. We then use the velocity information of the NEO, which is stored in the osculating orbital parameters section, to calculate the time-to impact of the NEO. The button "save" is then clicked to store the data. We now move over to the validation stage where we press the "search" button to initiate the validation procedure. Figure 40 is the dataflow diagram for this validation procedure. The validation procedure checks the major chemical composition that is stored in the optical parameters section in the tracking module. Then, it retrieves information about diameter of the NEO from the physical parameters section.

This data is then linked to the velocity, perihelion and aphelion parameters. Based on all this information the corresponding NEO group is found by our three-parameter based classification scheme.

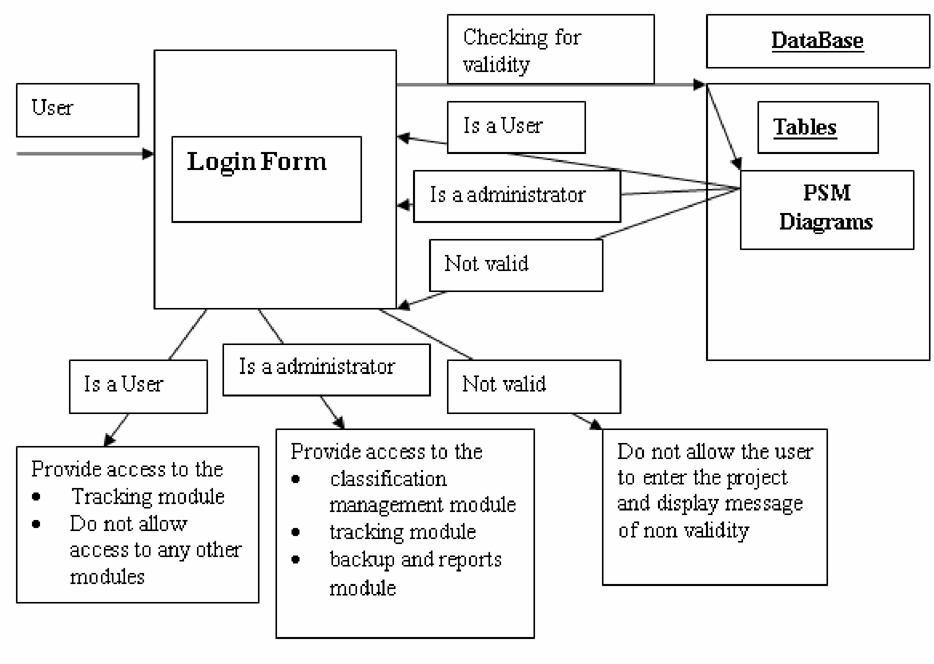


Figure 40: Validation procedure for the PDTS 1.0 System. Source: the author

Once, the NEO group of the potentially hazardous NEO is known, we retrieve the corresponding PSM for that particular NEO group which is pre-loaded into the system. Additional PSMs can be pre-loaded into our system if we use tertiary parameters in the future to classify NEOs. The advantage of the PDTS 1.0 system is that it is one of the first software applications to combine two concepts useful for handling the NEO problem, both of which were first proposed in this thesis. The first concept is the three-parameter scheme based classification scheme. The second concept is the PSM framework. The PDTS 1.0 system integrates these two concepts into one single application, while also acting as a database to store information for potentially hazardous NEOs. Flexibility is added into the PDTS 1.0 system by allowing administrators to change the classification scheme that is used to categorize NEOs.

7.4. Deflection using PSM

We just learned from the three-parameter based classification scheme that any NEO can be mapped into any one of the 48 NEO groups. We have developed deterrence mechanisms to deal with the threat of an NEO. The PSM (Prevention Sequence Mechanisms) contains these methods. These methods are the compilation of NEO mitigation methods mentioned in the paper by Brown et al. in 1994. Most of these methods are well-established in the literature, and trace back to different proposals of various individuals and organizations.

The methods in our PSM are ordered in such a way that they give the optimal possible solution for dealing with the corresponding NEO group. The PSMs also provide backup solutions for every method executed against an NEO. Therefore, if one method in a specific PSM fails, the same PSM will provide more methods to deal with the specific NEO that remained unaffected by the failure of the previous method.

Since the targets in the A1S group are generally the smallest and farthest away, they offer us the most time to deflect or destroy the NEO and the least threat upon impact. Thus, we have eleven possible options in the prevention sequence, which is the maximum for any PSM category. The first option is to use a powerful laser pointed at the NEO from some point on Earth to try to deflect or destroy the object.

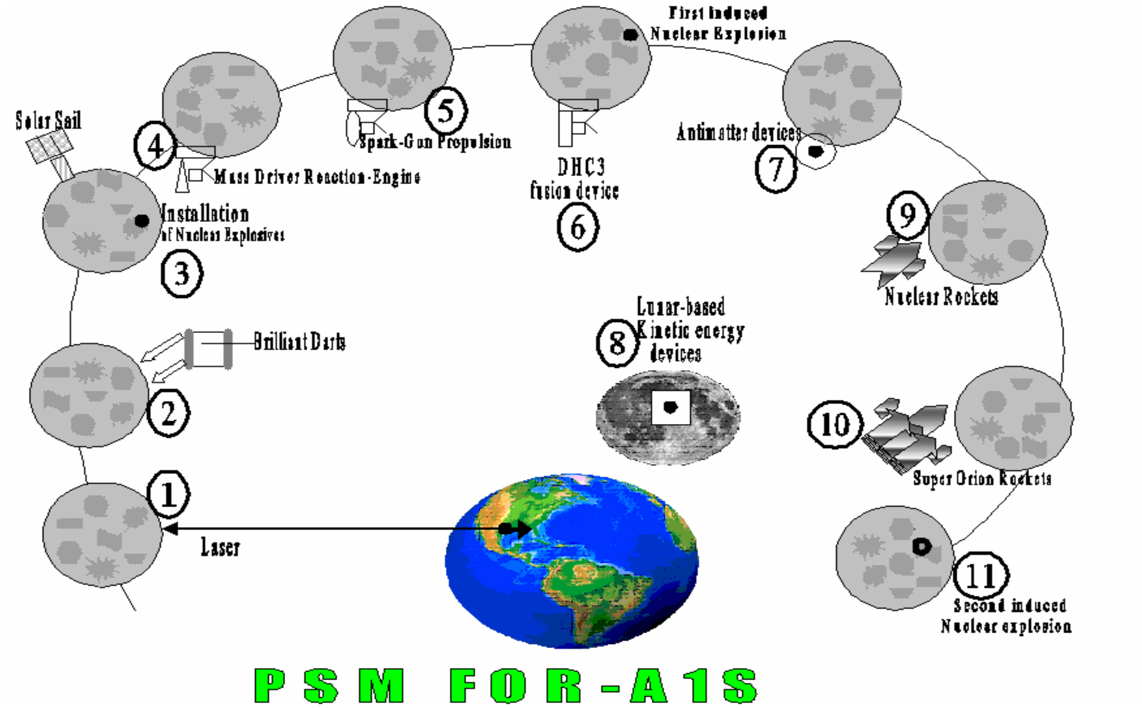


Figure 41: Prevention Sequence Mechanism for the A1S NEO group. Source: the author

Second, one would employ "Brilliant Darts," a kinetic energy weapon consisting of a cloud of 50 to 100 hypervelocity penetrators with "smart" terminal guidance. The third alternative would involve a two-pronged approach, installing a solar sail and nuclear explosives on the NEO. This involves anchoring a very large, low-weight, reflector sail to a NEO, which would slowly alter the NEOs orbit by solar radiation pressure. In addition, while installing the sail on the NEO, one would install two sets of nuclear explosives that may be necessary to use at a later phase in the PSM. Fourth, one would install the Mass Driver Reacting Engine (MDRE), which would use melted ice and lose surface materials on the NEO as a propellant to provide thrust for a reaction force, which would gradually, but significantly, alter the trajectory of the NEO. Fifth, one would try the similar technique of "spark gun" propulsion, which fires tiny bullets made of the NEOs surface material in order to alter the NEOs course. Sixth, like the MDRE, the DHC3 fusion driver would be a high specific impulse, low-thrust propulsion system attached to the NEO that uses an electric current and fusion to generate protons that will propel the NEO off its course. In addition, one would detonate the first set of nuclear explosives on the NEO. Seventh, an Antimatter Energy Source could be used to create mass quantities of antiprotons for a small Orion-type device, or for initiating a low-weight, high-yield nuclear device for deflecting or destroying an NEO.

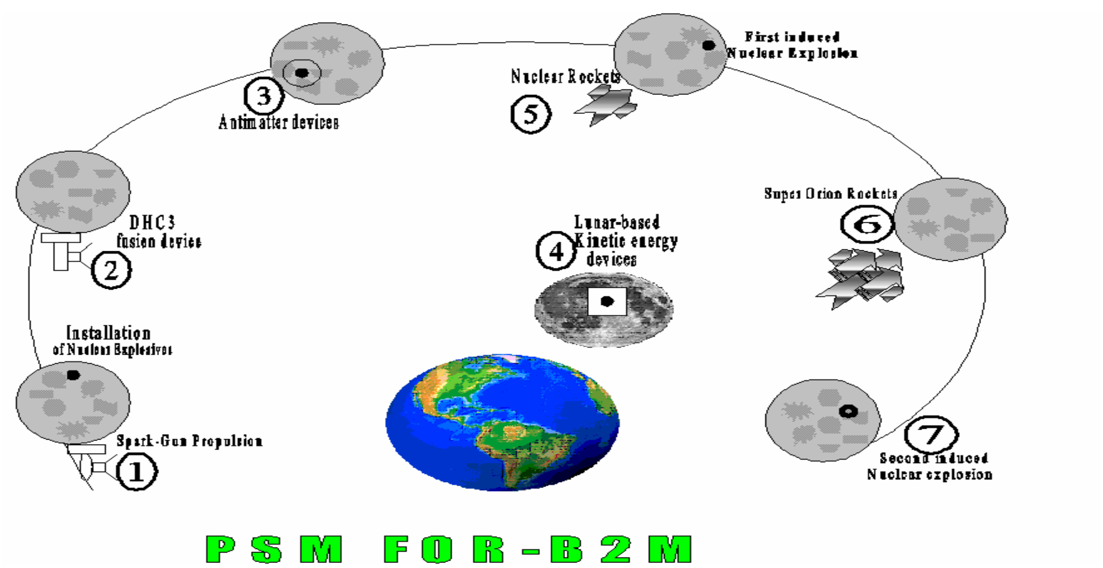


Figure 42: Prevention Sequence Mechanism for the B2M NEO group. Source: the author

Eighth, as the NEO gets closer to the Earth-moon orbit, one could use lunar-based kinetic energy devices to deflect the NEO. Ninth, one could use nuclear rockets with hydrogen propellants to destroy or deflect the NEO. Tenth, one could use Super Orion Rockets that create low-yield nuclear explosions with a shock absorber system interposed between the nuclear devices and the payload vehicle. Finally, if all else fails, one would detonate the second set of nuclear explosives that had been installed on the NEO, and hope for the best. Given the vast number of options, it is likely that, at least in concert, these eleven options would successfully deflect or destroy an NEO of the A1S class.

In Figure 42, a slightly more ominous class- the B2M class, is the threat case scenario. Notice, that given its larger size and shorter time to impact, there are fewer options for deflecting or destroying a B2M class NEO. In addition, the options utilized are the more drastic and more expensive options taken from the A1S PSM. For example, the first option would be to use the Spark Gun Propulsion while simultaneously planting nuclear explosives on the NEO. Second, one would deploy the DHC3 fusion device, and, third, one would use antimatter devices that generate antiprotons. Fourth, lunar-based kinetic energy devices would be employed due to the B2M's closer proximity to the earth. Fifth, the nuclear rockets would be utilized along with the first nuclear explosion. Together, these would exert a formidable force on the NEO, but if unsuccessful, one would still have the Super Orion rockets and the second nuclear explosion in reserve. Note that as the size and time to impact increases, the nature of the force used changes. Here, one would use more drastic measures to knock the NEO off its original course, and if unsuccessful, one would use heavier explosive methods early on. Figure 43 details the PSM for an even more pressing threat, the C3 class, regardless of composition. Basically, even though the C3 only uses one less method than the B2M, the six methods employed are some of the most drastic of those possible. One would begin with the most drastic course-altering methods, such as the kinetic-energy billiards shot and the antimatter devices, while simultaneous installing nuclear explosives for the last-resort moves. Next, as the NEO nears the Earth-moon orbit, one would employ lunar-based kinetic energy devices. Finally, the last three steps would consist of a variety of explosions from nuclear rockets to nuclear explosions to Super Orion rockets. As you can see, as the NEO draws closer to Earth and the situation becomes more desperate, one must resort more to explosive techniques in order to make a larger impact on the NEO over a shorter period of time.

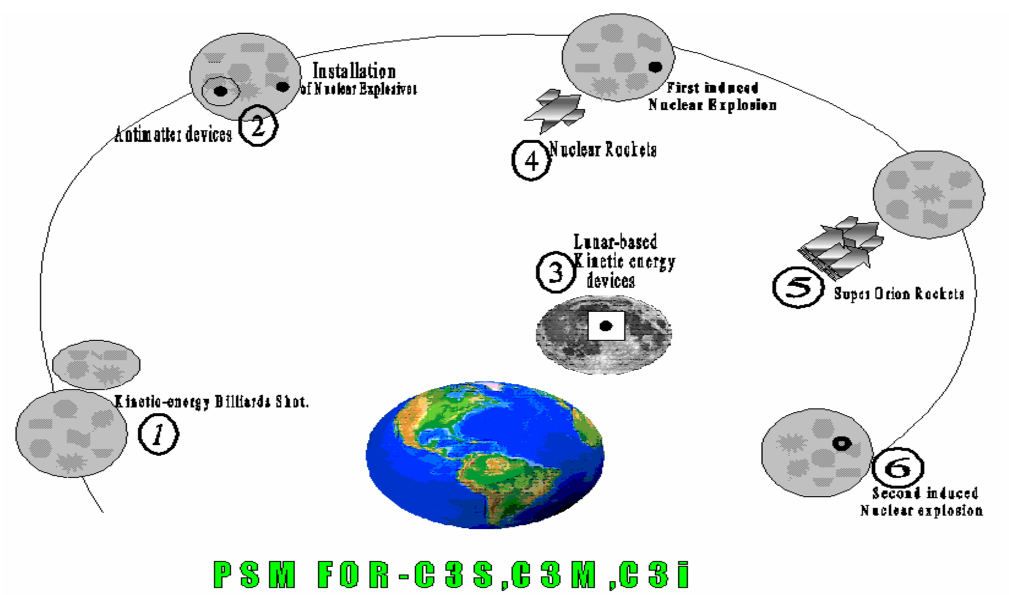


Figure 43: Prevention Sequence Mechanisms for the C3S, C3M and C31 groups. Source: the author

Finally, the fourth PSM diagram illustrates the PSMs for the deadliest class of NEOs, the D4 class, regardless of composition. Since, these are the largest and most rapidly approaching

NEOS, the number of options is reduced to merely five. Given the time to impact of the NEO, one can harvest the power of the lunar-based kinetic energy devices much earlier on the PSM process. The next three options involve some form of explosion. The final option involves the

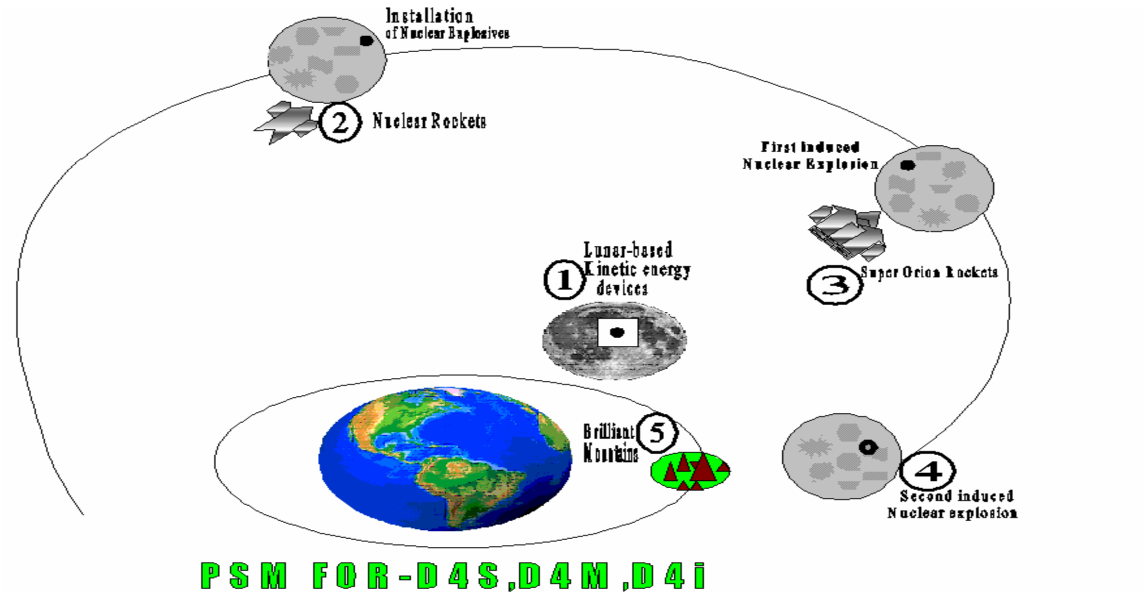


Figure 44: Prevention Sequence Mechanism for the D4S, D4M and D4i NEO groups. Source: the author

use of "Brilliant Mountains," which involves using nuclear rockets to return large quantities of cometary or asteroidal material from NEOs to Earth's orbit (much before the D4 threat is being dealt with), where these masses (1000 to 10,000 metric tons) could be deployed to provide close-in intercepts of NEOs in Earth-orbit. Essentially, this would be like creating a small "asteroid belt" around Earth as a shield and hoping that the numerous impediments would slow down or deflect the NEO. In summary, these four PSM diagrams illustrate the differences in how one would design PSMs for NEOs based on their classifications. There are actually twenty-six PSM diagrams for forty-eight classes in our classification scheme, given the parameters for size, time to impact and composition, but these four diagrams exemplify the four main types of PSM that would be generated by the system. The greatest factors for the differences in the PSM diagrams would be the size and time to impact, while the composition is slightly less determinative of the PSM that would be employed. The number of options is proportional to the time of impact (i.e. less time means less options) and inversely proportional to the size of the NEO (i.e. the larger the object the fewer the options). Thus, one could easily predict that a B3 class NEO will probably have more options than a D3 class NEO, and that an A2 class NEO probably will have more options than an A4 class NEO. There are a total of 26 PSM diagrams for the 48 NEO groups, and all have been generated by the three-parameter based classification scheme. Representations of these diagrams can be found in Appendix-1 of this thesis.

The method used to measure results for the PSMs was to identify the best possible "solution-ordering" for a particular NEO group through trial and error. For example, while laser technology would not be useful for deflecting Metallic NEOs (such as the C1M group), it would be very useful for deflecting or destroying NEOs in the Icy Group (such as the A1I group), because the heat generated from a very powerful laser beam will erode the surface structure of the NEO causing it to deviate from its original path, or perhaps even destroying it. Through trial and error within the PDTS 1.0 System, one can identify viable methods in a controlled artificial environment, rather than testing these methods for the first time when there is a real threat.

Chapter 8: Conclusions

In spite of the discovery of several NEOs, such as XP142004, 69239 Hermes and 4581 Asclepius, the world's population does not take the prospect of cosmic collisions seriously. We all must realize that this hazard from space is indeed a subject of deadly concern to humanity. The NEO problem is a complex socio-technical problem, and it is necessary that we approach this problem from a multi-disciplinary point of view in order to arrive at effective solutions. It is for this reason that this thesis has used the CLIOS Process to characterize this problem and analyze the subsystems that are necessary to deal with this problem. The three-parameter based classification scheme and the PSM framework form the foundation of the PDTS 1.0 System, which plays a significant role in generating various alternatives and customized solutions for different NEOs.

Throughout the thesis it was evident how the CLIOS Process helped us to effectively design and construct the system-level representation required to deal with this problem. We conceived a three-parameter based classification scheme which enabled us to classify any NEO into one of the NEO groups of the classification scheme. We then conceived a concept call the PSM (Prevention Sequence Mechanisms) framework. Each PSM showed how the best possible sequence in which a set of prevention mechanisms (applicable to a certain NEO group of our classification scheme) must be implemented. A software-package called PDTS 1.0 was designed for tracking and cataloging potentially hazardous NEOs based on the PSM framework and the three-parameter based classification scheme. Through mutual collaboration and segmentation of PSM modules the mitigation effort was optimized. Therefore, in the future, if an NEO on collision course with the Earth is detected then the group name of that NEO is found from our classification scheme and the corresponding PSM for that group is implemented to deflect or destroy the NEO.

We worked our way through the NEO problem by constructing a thorough definition of the NEO problem. It is well known that problem definition is more crucial than problem analysis. The CLIOS Process provided an excellent framework to define the actor groups and subsystems in this problem. This set the tone for carrying out further analysis. By examining the interaction between the physical domain and the institutional sphere we gained a deeper understanding of the system behavior. Four specialized tools were designed in Chapter 4: (i) *Institution-specific Segmentation* tool, (ii) *Value-based CLIOS System* tool, (iii) *Strategic Impact Measurement* tool, (iv) *Strategy System Structure Matching* tool. The *Strategic Impact Measurement* tool was applied extensively throughout Chapter 6, and provided us key insights into what could be the best strategic alternative in the detection, prevention and planning subsystems.

In Chapter 3 we examined the details of the CLIOS Process where we explored how it helps us analyze complex socio-technical systems through tools that aid its proper function, like ornaments on a Christmas tree. The CLIOS Process is extremely useful because it breaks down the physical domain into various subsystems, and then individually analyzes each subsystem. By enabling the separation of the institutional sphere and the physical domain we were able to analyze various interactions that otherwise would have gone unnoticed. The resulting analysis helped us devise a comprehensive emergency response plan, which clearly outlined the chain of command and various steps that needed to be executed by different entities in the system.

In Chapter 4 new tools were designed to enhance the CLIOS Process. These specialized tools helped populate the "Christmas Tree" of the CLIOS Process, and gave it a more vibrant enhanced look. The institution specific segmentation tool helped us demonstrate how each prospective player could be deemed a mismatch (to our CLIOS System structure) or considered the right fit within the institutional sphere. The player was not filtered out in the representation-stage of the CLIOS Process as long as the player had a role within the system, even if the role was ineffectual in nature. For example, while identifying players in the institutional sphere for the NEO problem we will realize that the EPA does not belong in the institutional sphere after the design, evaluation and selection stage of the CLIOS Process. Once the institution-specific segmentation tool helped us populate the institutional sphere, we used the value-based segmentation tool to separate and classify the various players based on the value they brought to the CLIOS System. The strategic impact measurement tool was a crucial tool for helping us decide how the evaluative metrics of the institution-specific segments can help us choose between various strategic alternatives. The segments in this case are a set of players based on their level of importance within the CLIOS System. Finally, we used the strategy system-structure matching tool to help us align the right strategy based on the architecture and levels of competency in the system which we described in Figure 19 of this thesis.

In chapters 5 and 6 we applied the CLIOS Process to the NEO problem. In Chapter 5 we created the characteristics, opportunities/issues/challenges, and system goals checklists. We described the various actor groups on the institutional sphere, and also described the emergency response system implementation in this Chapter. In Chapter 6, we analyzed the various subsystems in the NEO problem. The detection, prevention and social subsystems were explained in detail along with the CLIOS System Diagrams for each susbsytem. The *Strategic Impact Measurement* tool was also applied extensively throughout this chapter, and provided us key insights into what could be the best strategic alternative in the detection, prevention and planning subsystems.

The three-parameter scheme described in Chapter 7 helped us classify the potentially dangerous NEOs into various groups that were derived from three different classes based on certain NEO characteristics, such as size, time-to-impact and chemical composition. For each NEO group, we constructed a corresponding PSM. Each PSM showed the best possible sequence in which a set of mechanisms applicable to a certain NEO group (of our classification scheme) should be implemented. Therefore, in the future, if an NEO on collision course with the Earth is detected, then the group name of that NEO is found from the classification, and the corresponding PSM for that group should be implemented to deflect or destroy the NEO.

When viewed from a technical standpoint, there are several positive attributes to the PDTS 1.0 system. The fact that the system it is built on the Microsoft platform means that it provides excellent compatibility with a variety of military, defense and scientific systems. With several add-ins for changing the classification scheme, this system is certainly adaptable to future discoveries and improvements in NEO detection and PSM deployment technologies. The PDTS 1.0 provides ready-made solutions for every possible NEO that is discovered. Every possible threat scenario has been addressed through the PDTS 1.0 System by having preloaded PSMs. Moreover, each PSM contains several backup methods for dealing with a potential threat. If one mechanism fails, the next mechanism can be used. The first few mechanisms in the PSM diagram can be applied simultaneously to achieve the maximum possible deflection of the NEO. The earlier we apply the mechanisms, the greater the net effect on the deflected distance, which increases the chance of success. Therefore, the PDTS 1.0 system saves a lot of time in the planning efforts once an NEO is detected on collision course with Earth. By having a standardized set of procedures and line of command, as defined in the social subsystem, a lot of confusion is avoided during an emergency. Everyone has an opinion when it comes time to decide which deflection/destruction methods to use on an NEO heading toward Earth. The various PSMs provide a standardized set of methods with a specific sequence for each NEO, which helps to quiet the noise of the competing opinions and let the decision makers focus more on implementing the most effective response.

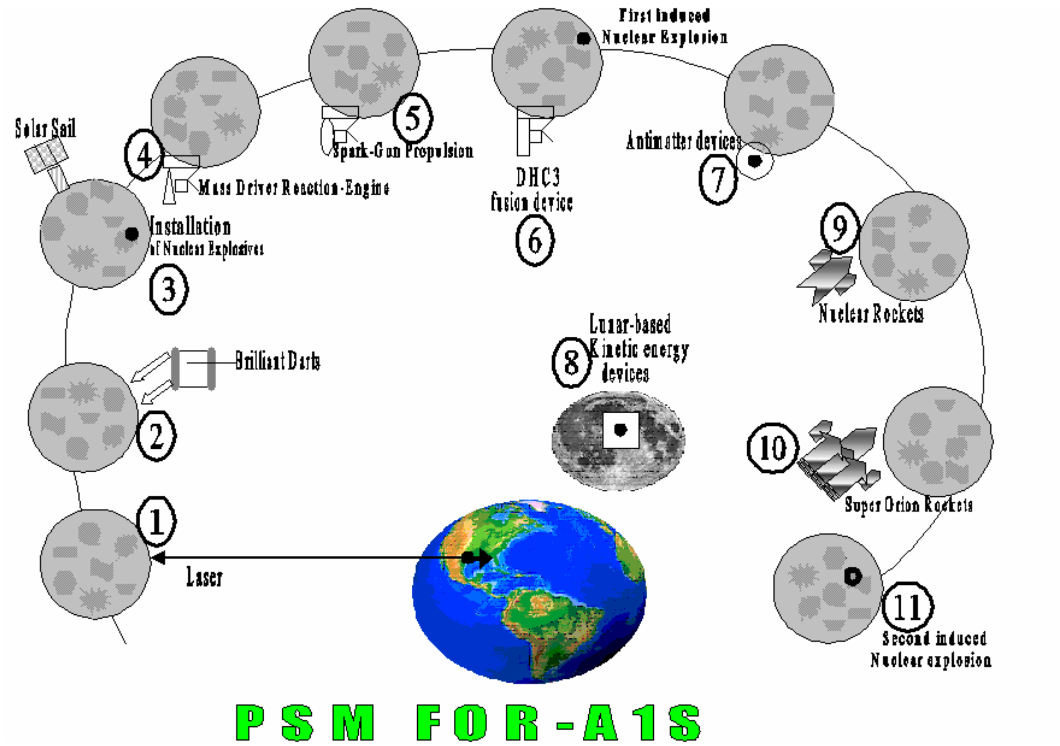
Future Research

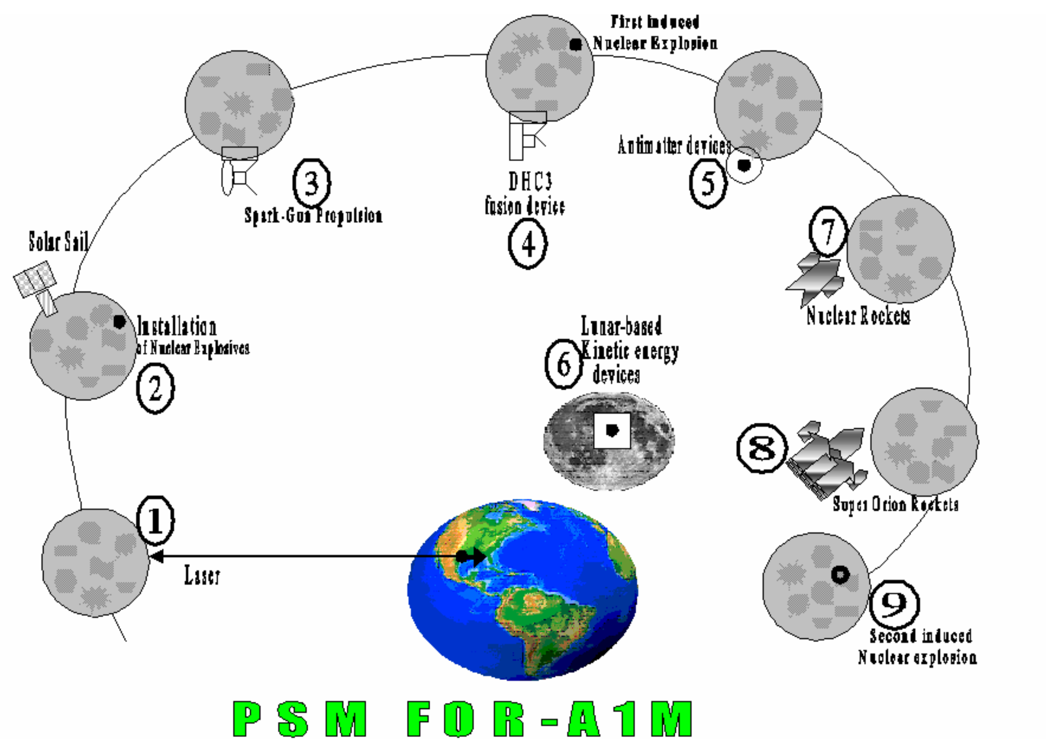
While much research was involved in creating the sequence in which various mechanisms should be applied to different NEOs, further research can be applied to determine the *optimal* sequence of methods needs to be applied. Thus, by inviting brainstorming and discussion between several researchers and organizations, all 26 PSMs can be standardized and accepted by all players. Applying the wrong mechanism early in the deflection process might complicate the problem. It is for this reason that we need future work to focus on carefully optimizing the sequence in the PSM diagrams and ensuring that the right evaluative metrics are used to analyze various strategic alternatives. We can use the strategic impact measurement tool described in Chapter 4 for this type of analysis. In our analysis we applied only one of the specialized tools (strategic impact measurement tool) described in Chapter 4 to the NEO problem. It will be interesting to see the changes in the system behavior when the remaining three tools are applied to the problem.

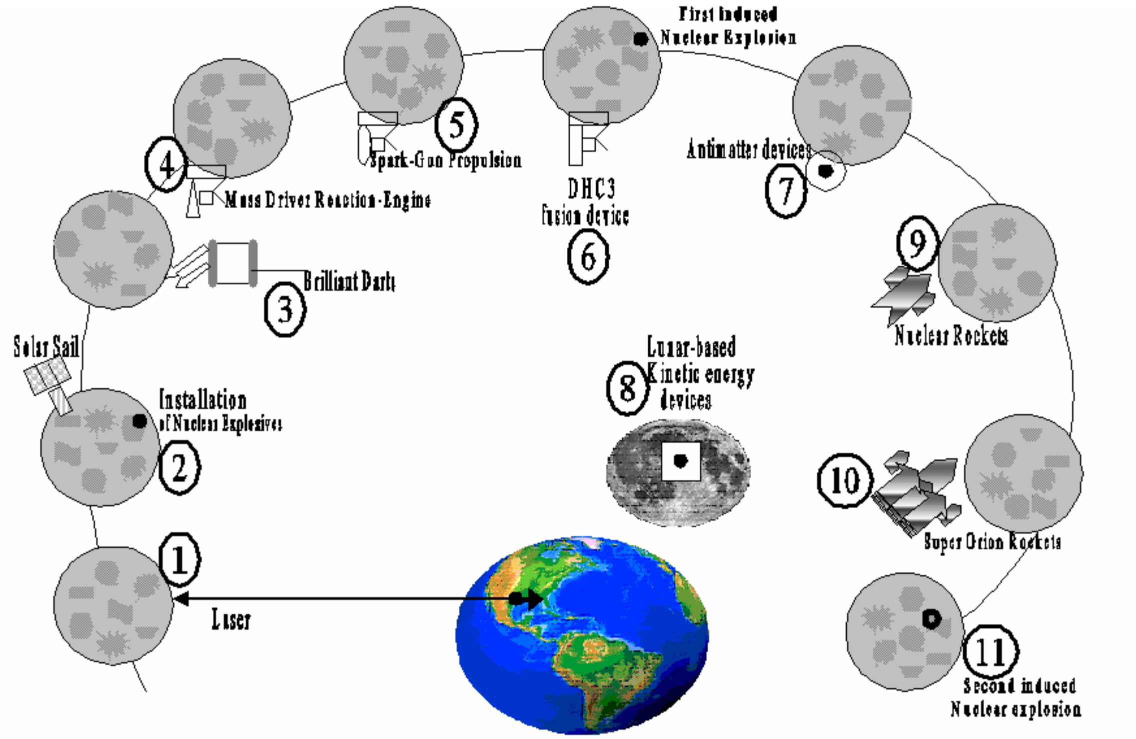
We have to understand that the stakes are simply too high for not arriving at practical solutions for the NEO problem. Indeed, the survival of humanity is at stake, which is why a cost-benefit analysis seemed antithetical to this thesis. “Now, is the first time in Earth’s history that a species has the knowledge and means to protect itself on a global scale (Taylor et al., 2006).” We must remember that dreams of an entire planet rest upon the ability of humanity to prevent such a disaster, and if we succeed in preventing such a disaster, it will by far be the biggest achievement in human history.

We must realize that the NEO problem is indeed a *real* and i*mportant* problem. We hope that the new classification scheme, the PSM framework and application of the CLIOS Process to the NEO problem has made some progress towards solving this problem. We also hope the ideas and information in this thesis are valuable to the reader.

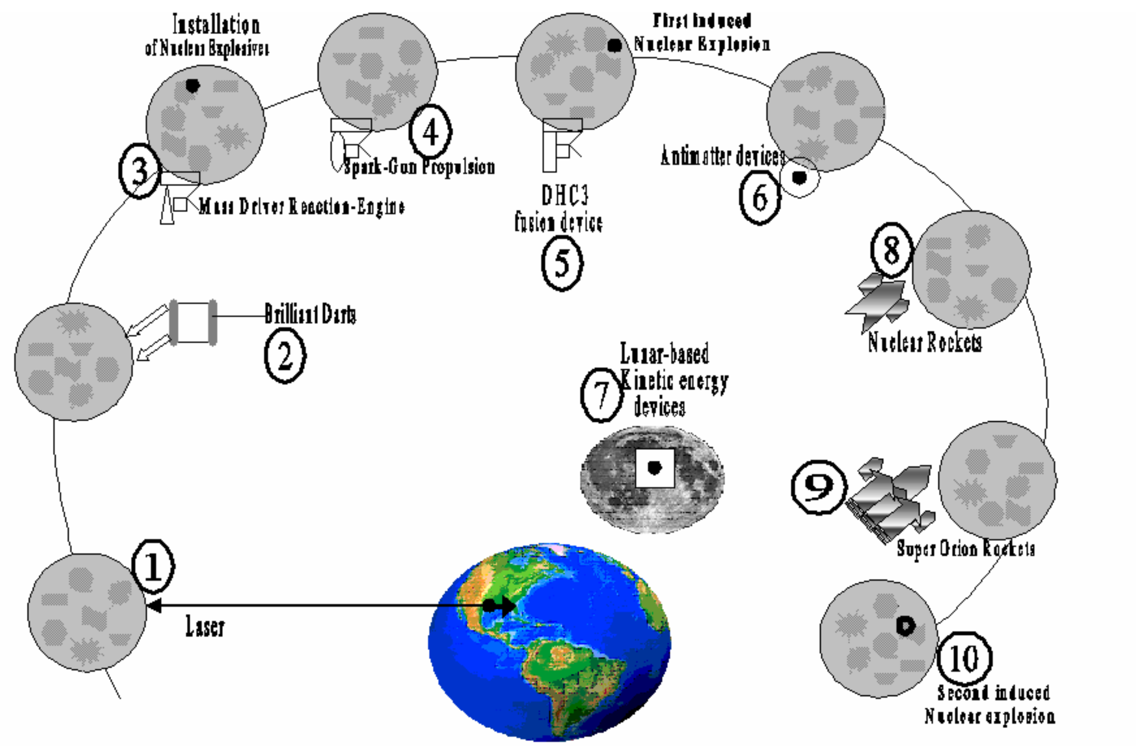
Appendix 1: PSM Diagrams



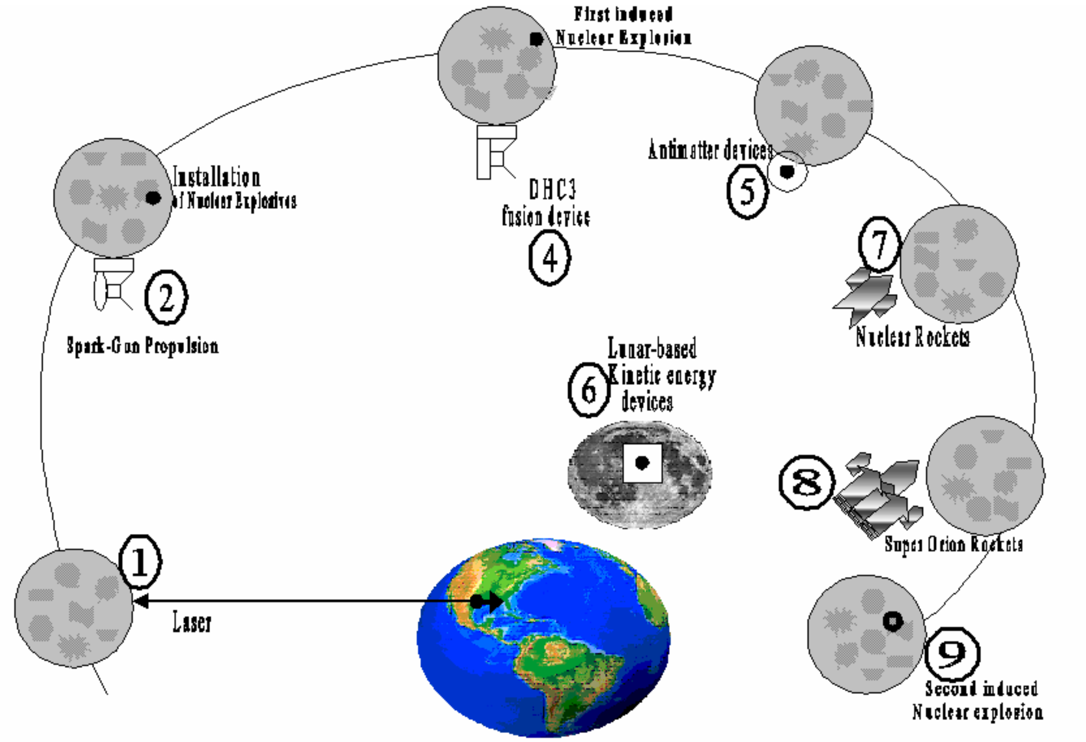




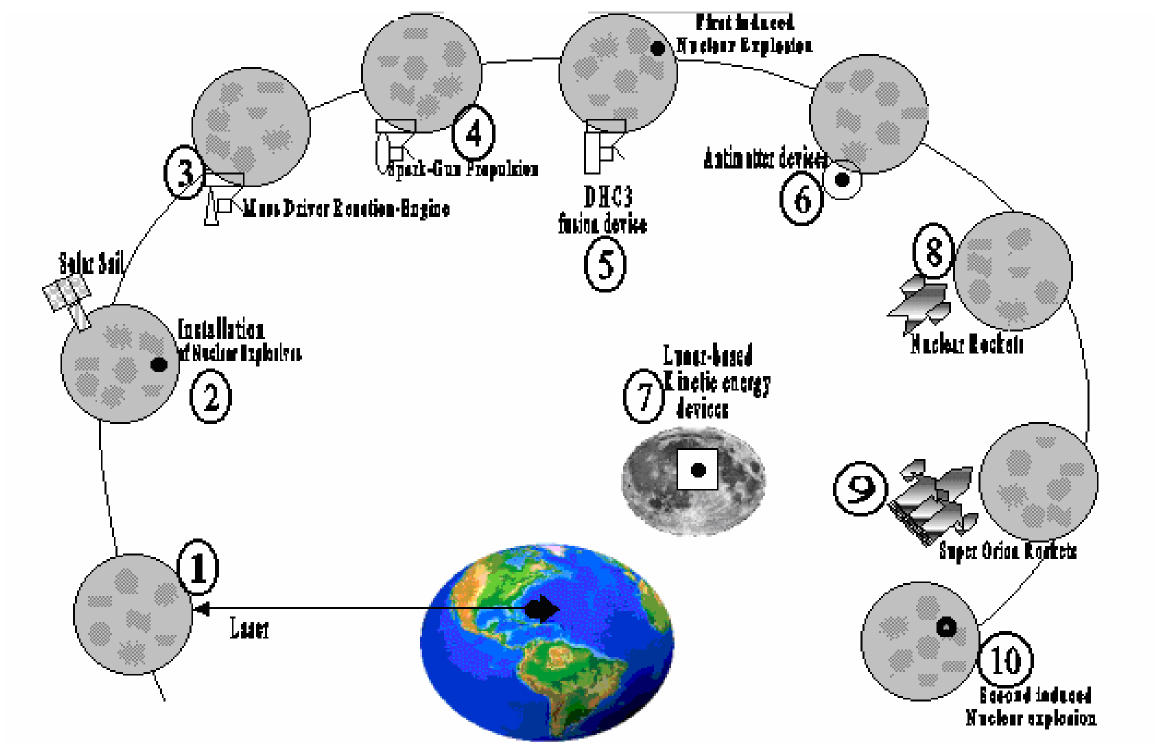
PSM FOR-A1i



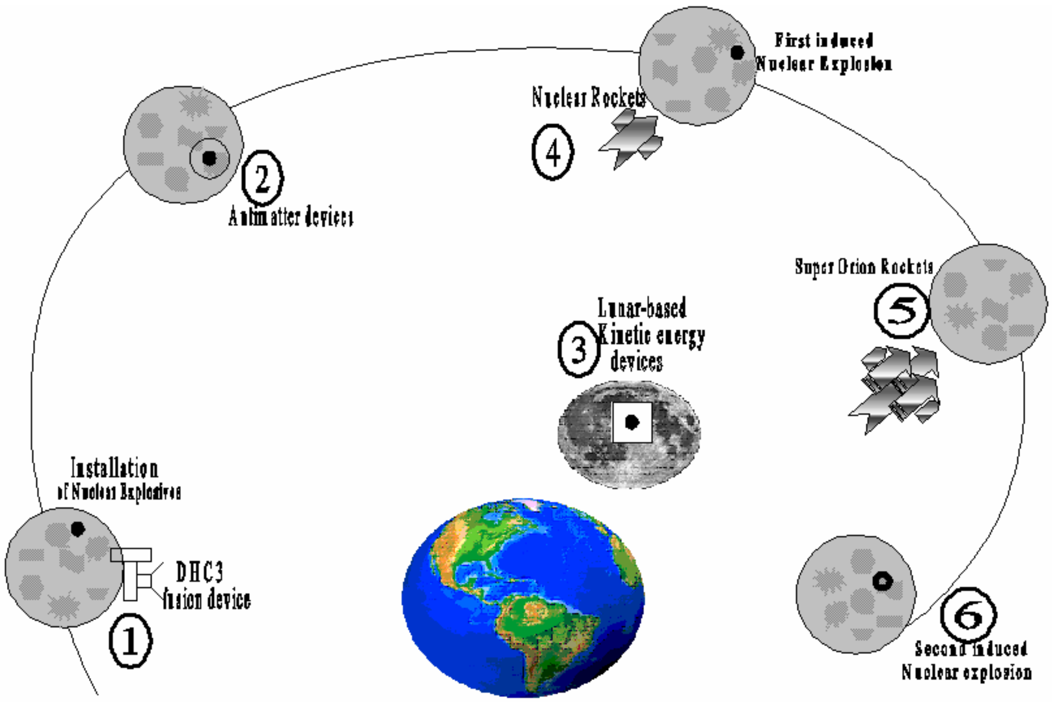
PSM FOR-A2S



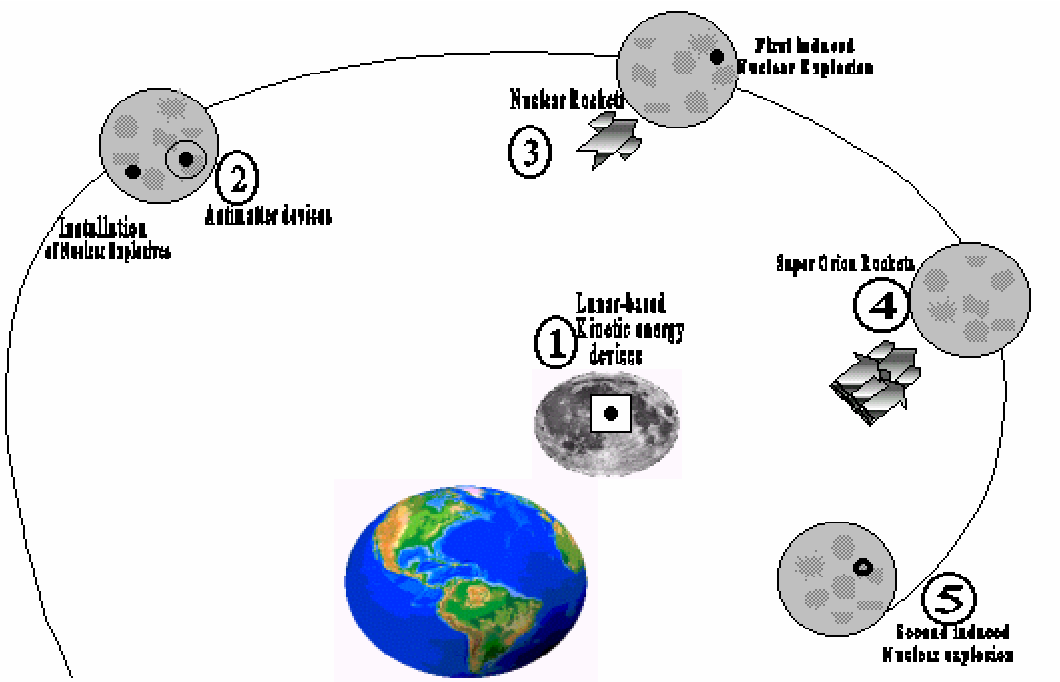
PSM FOR-A2M,B1M



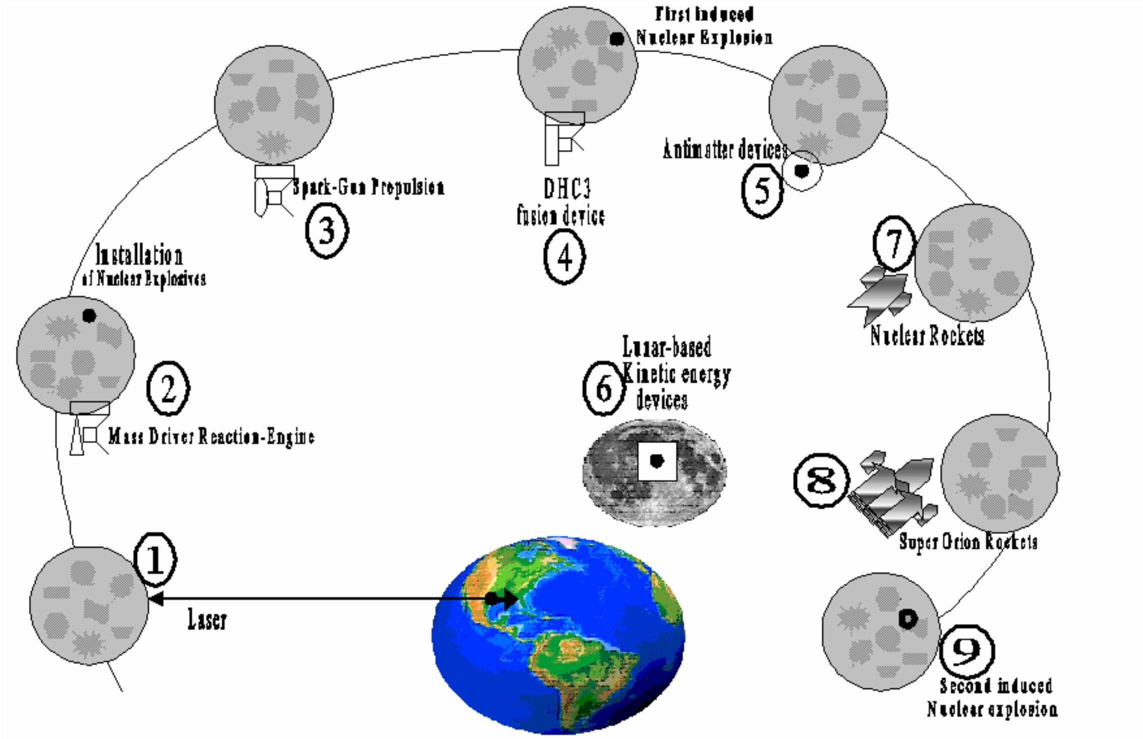
PSM FOR-A2I,B1I



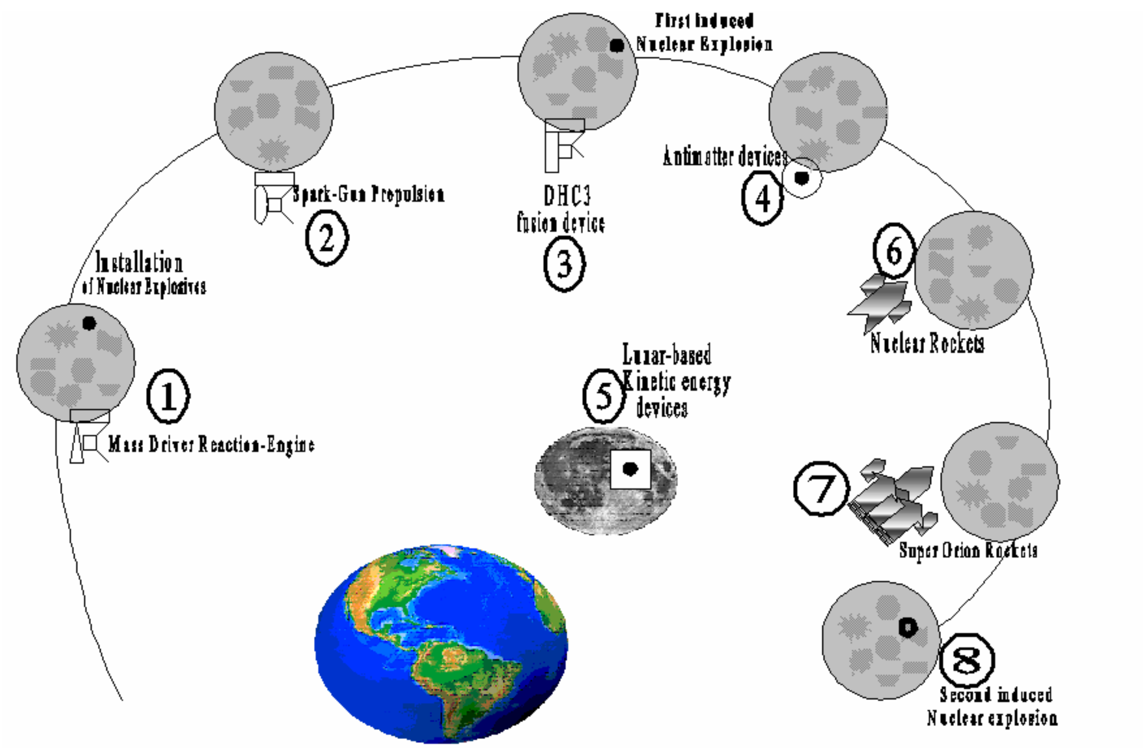
PSM FOR-A3S,A3M,A3i



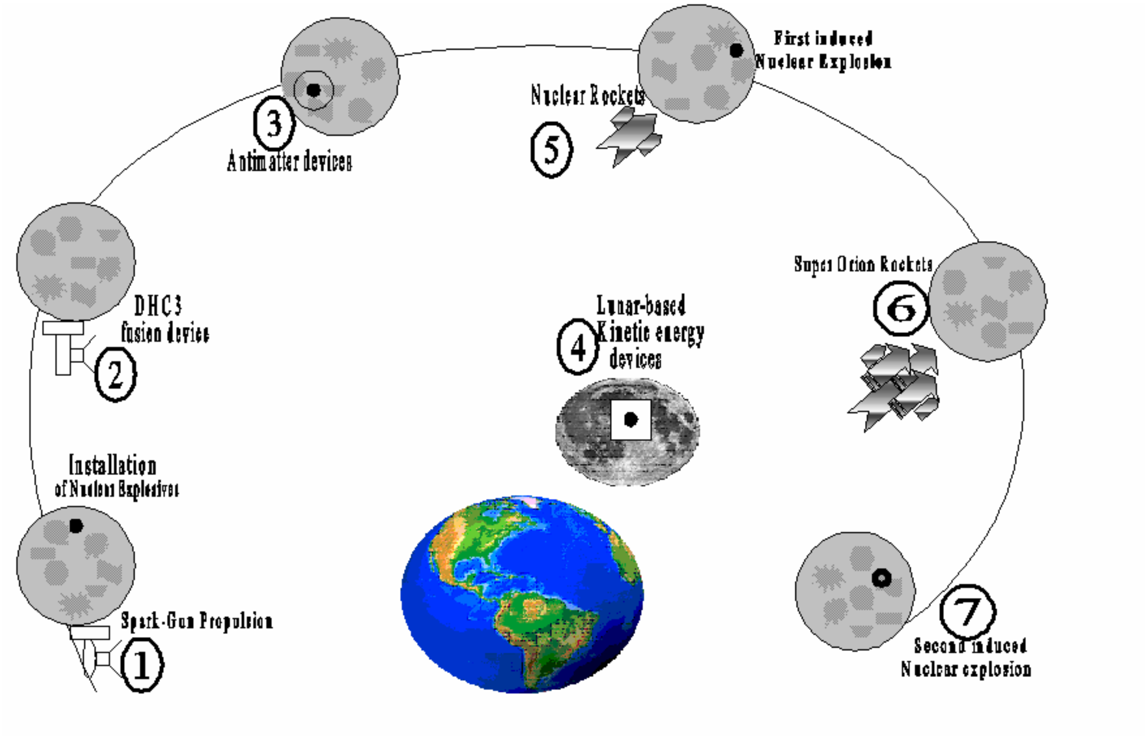
PSM FOR-A4S,A4M,A4I,B4S,B4M,B4I



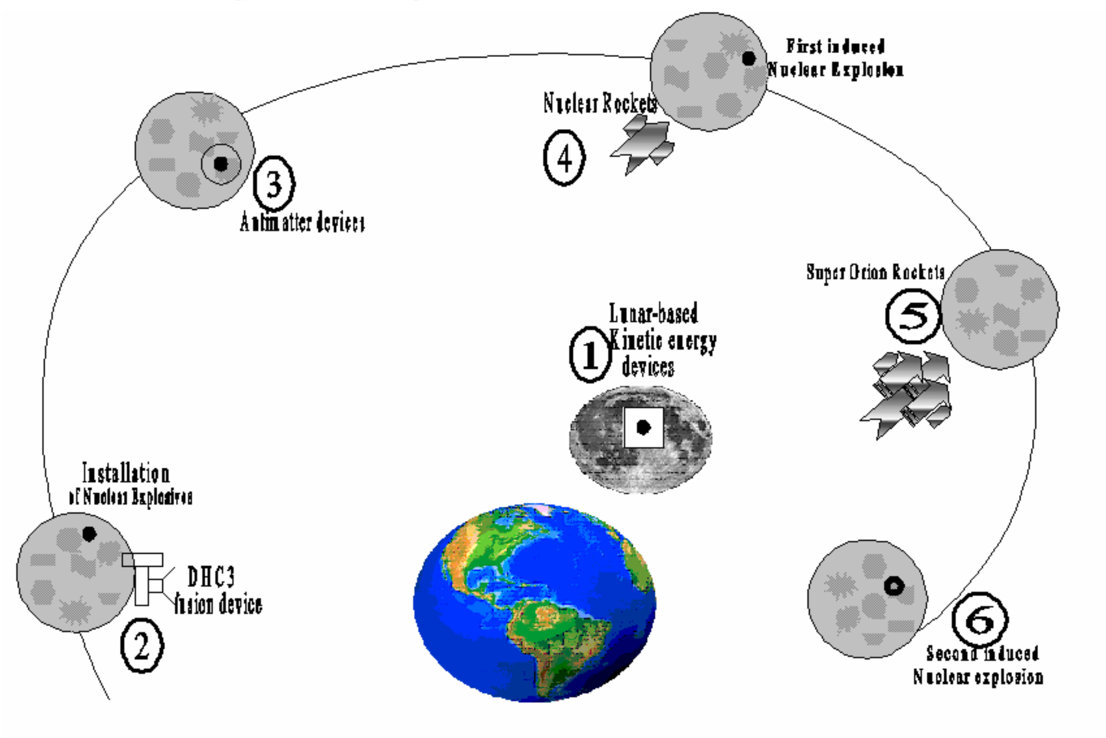
PSM FOR-B1S



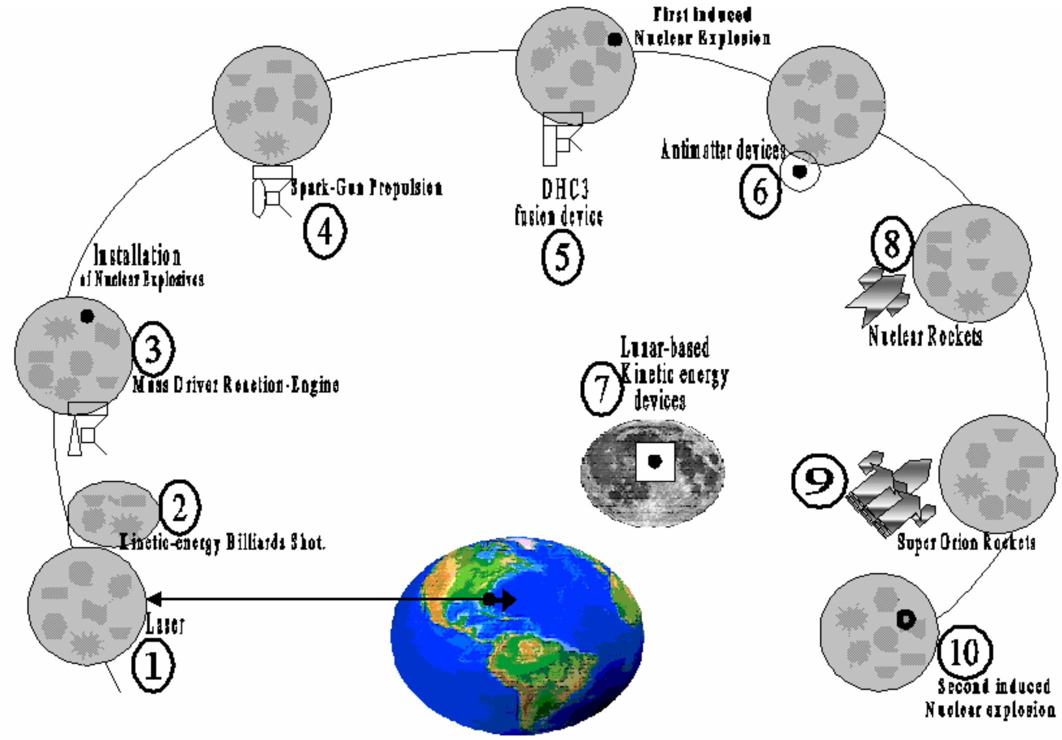
PSM FOR-B2S,B2i



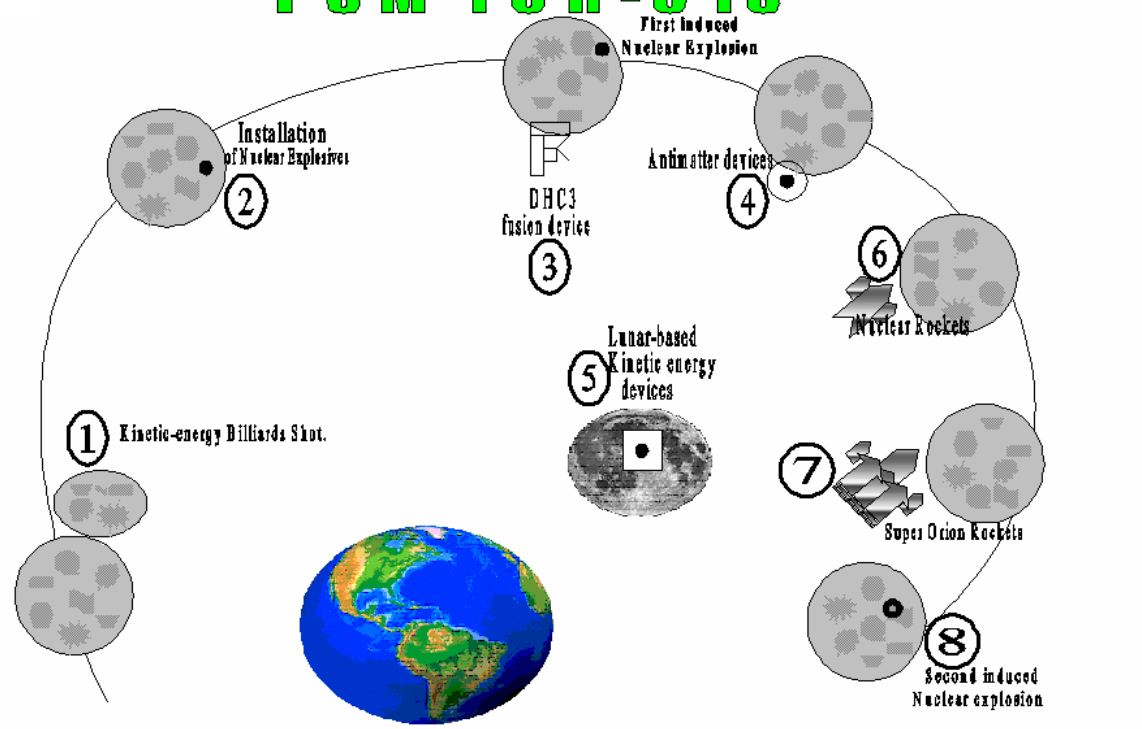
PSM FOR-B2M



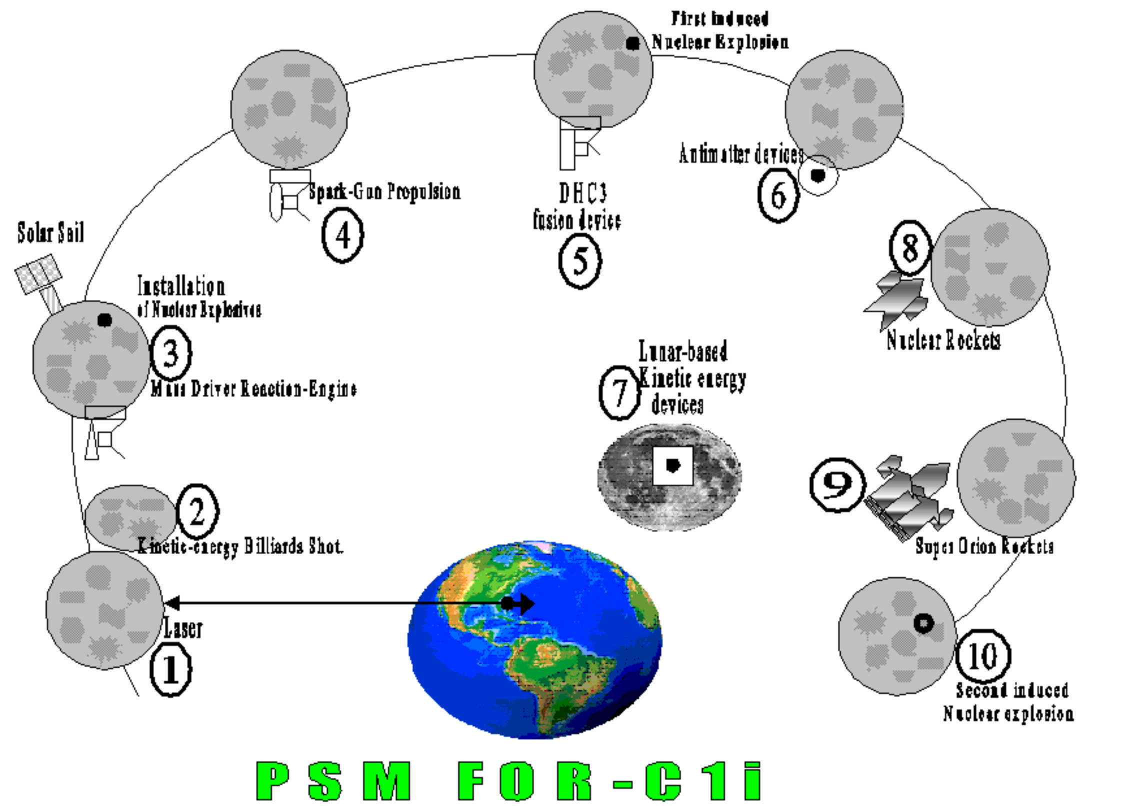
PSM FOR-B3S,B3M,B3i

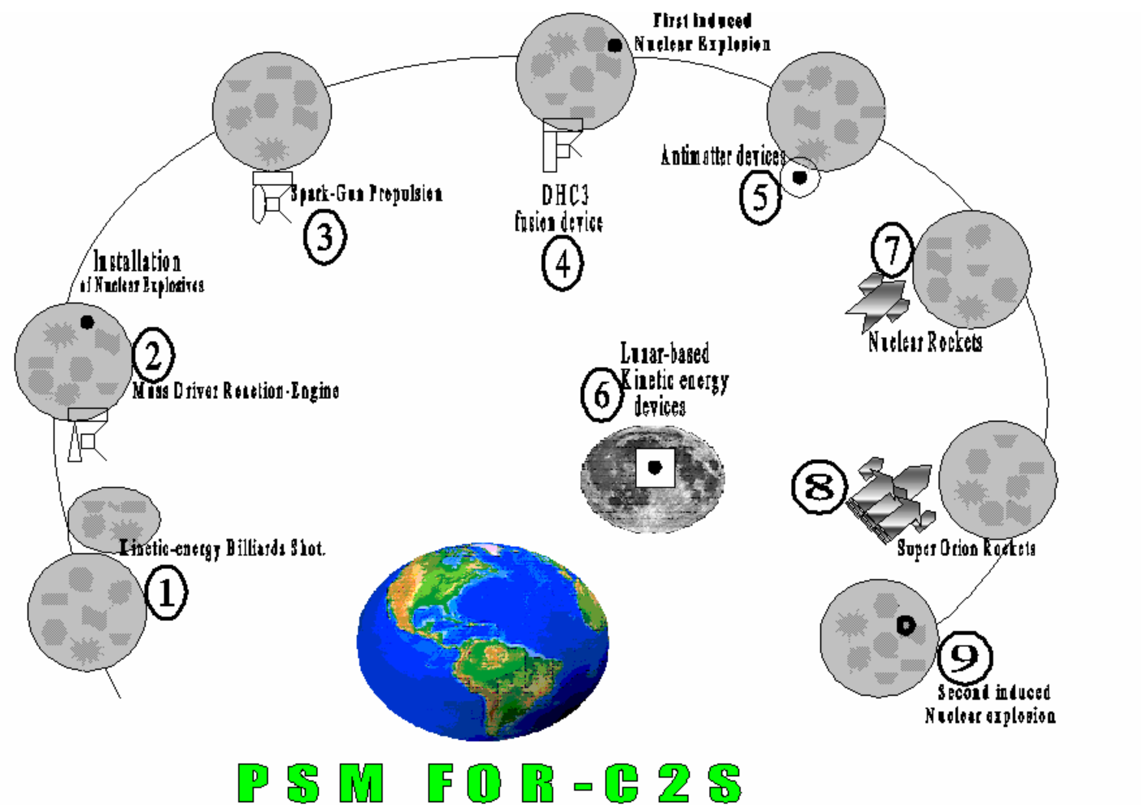


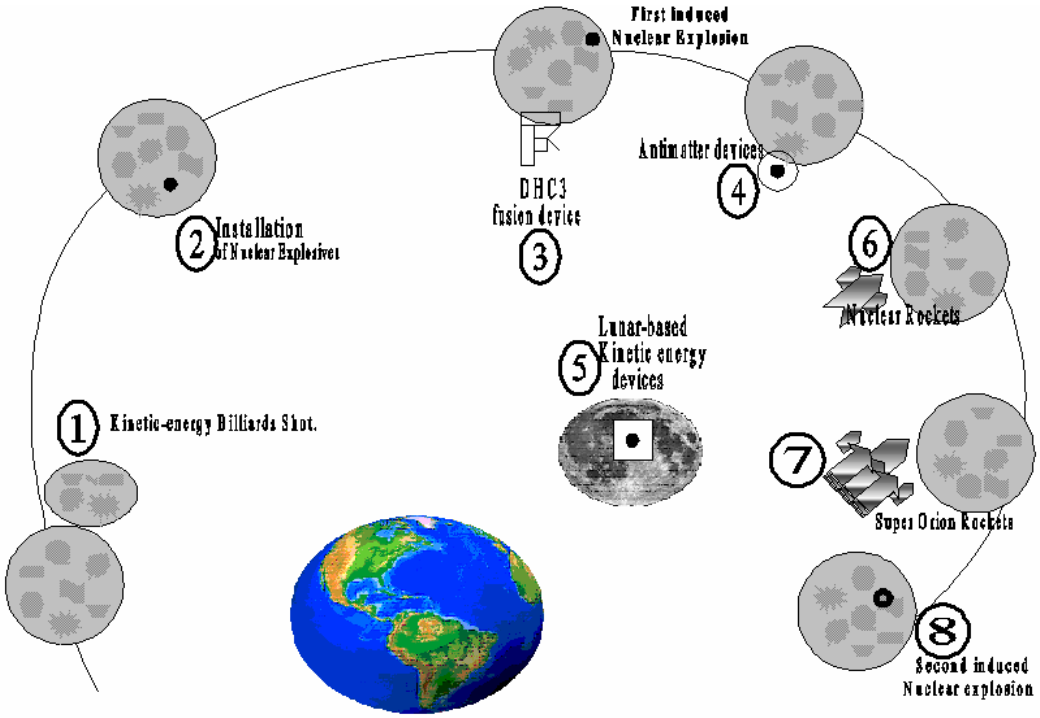
PSM FOR-C1S



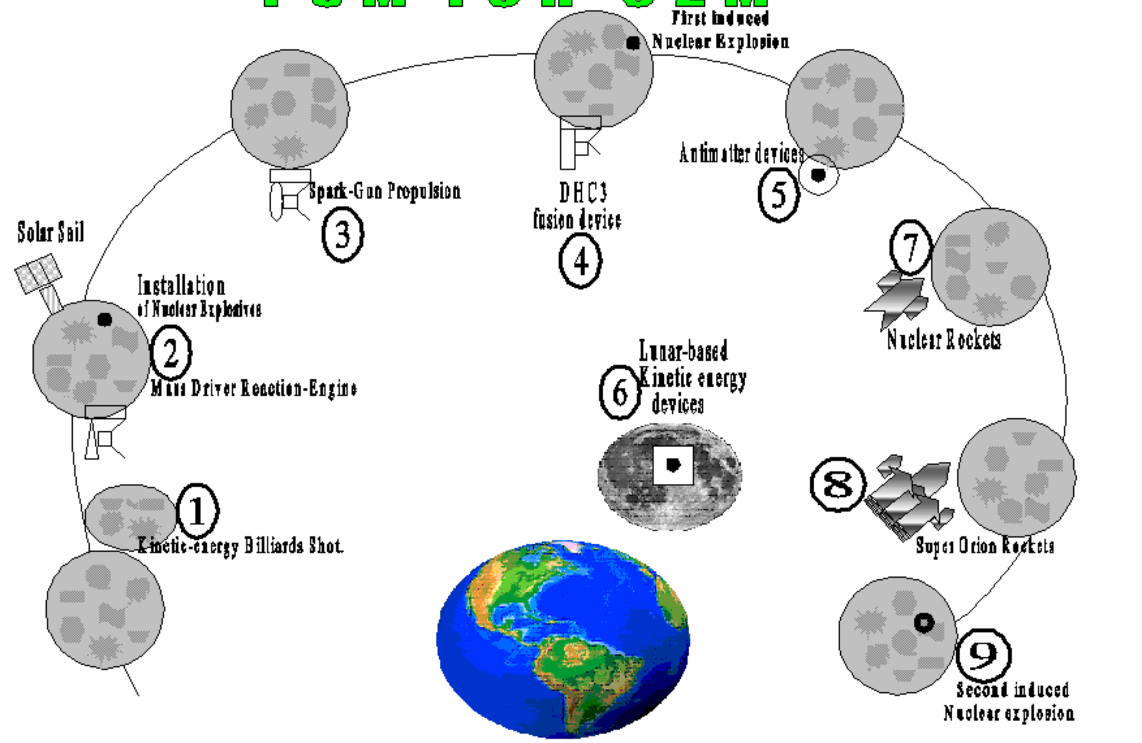
PSM FOR-C1M


First induced
Nuclear Explosion
Spark-Gun Propulsion
4
DHC3
fusion device
5
Antimatter devices
6
Solar Sail
Installation
of Nuclear Explosives
3
Mass Driver Reaction-Engine
8
Nuclear Rockets
Lunar-based
Kinetic energy
devices
7
2
Kinetic-energy Billiards Shot.
9
Super Orion Rockets
Laser
1
10
Second induced
Nuclear explosion
PSM FOR-C1i

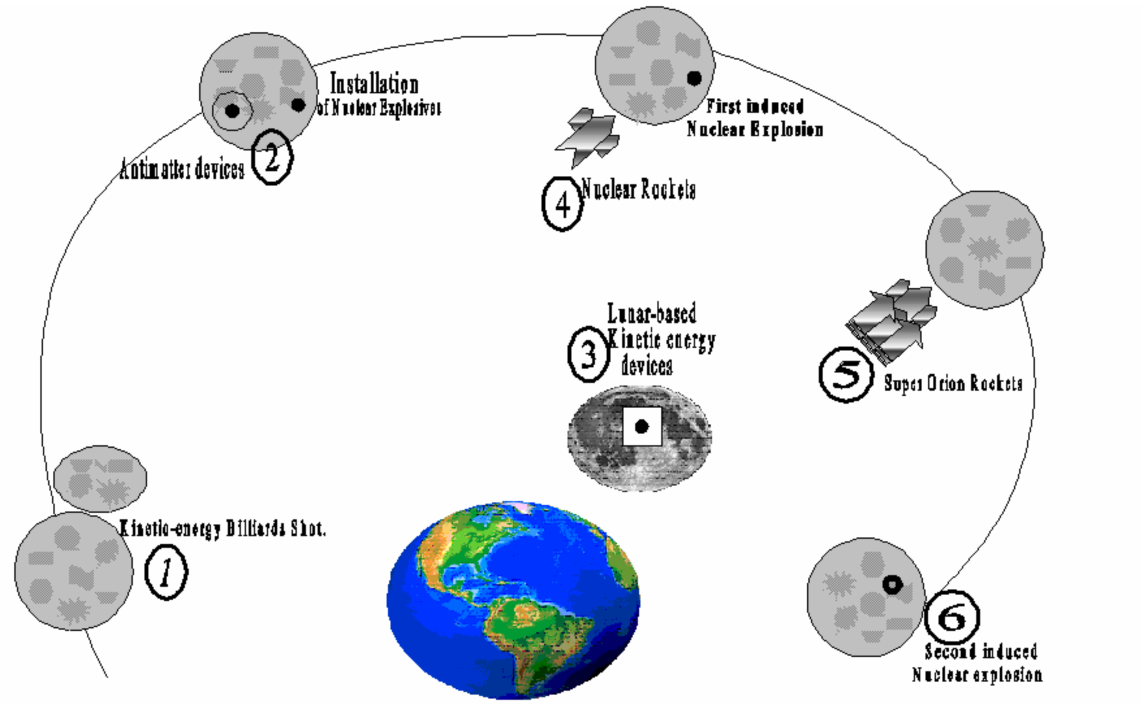

First induced
Nuclear Explosion
Spark-Gun Propulsion
3
DHC3
fusion device
4
Antimatter devices
5
Installation
of Nuclear Explosives
2
Mass Driver Reaction-Engine
7
Nuclear Rockets
Lunar-based
Kinetic energy
devices
6
8
Super Orion Rockets
Kinetic-energy Billiards Shot.
1
9
Second induced
Nuclear explosion
PSM FOR-C2S



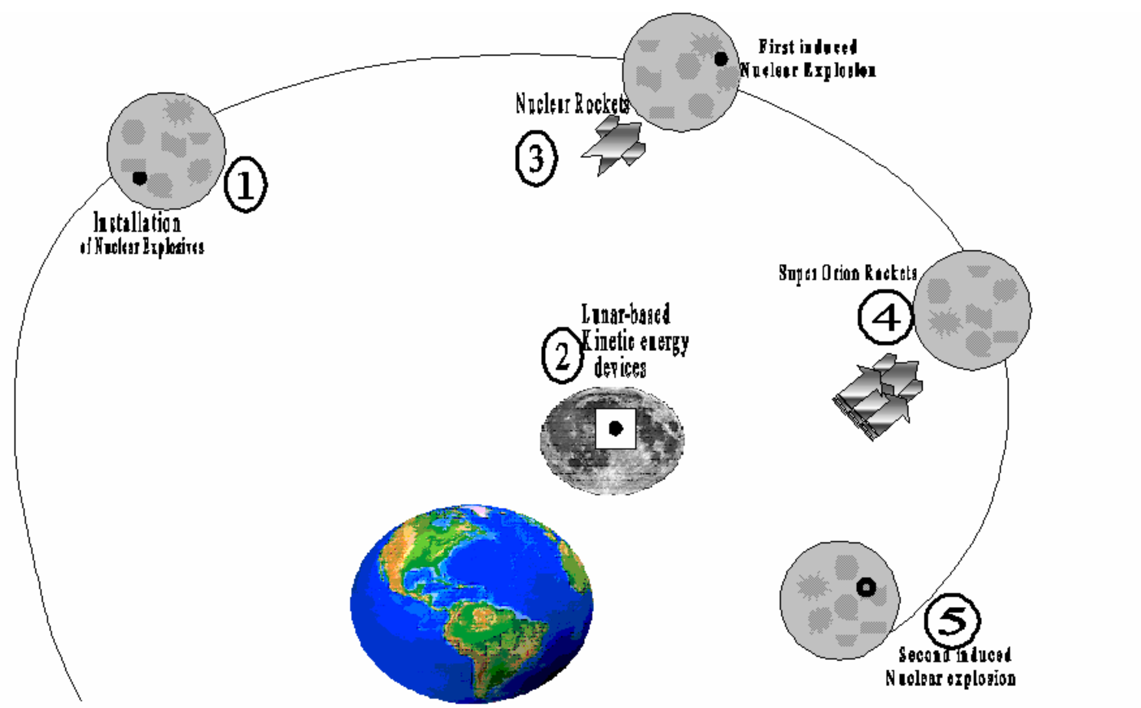
PSM FOR-C2M



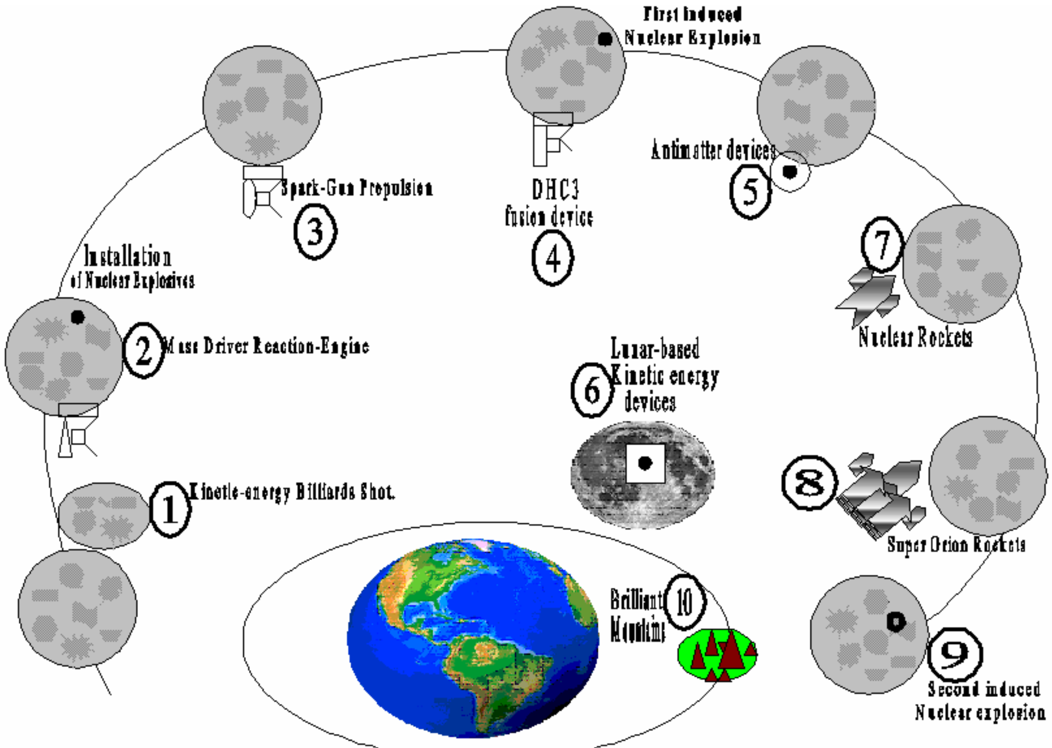
PSM FOR-C2i



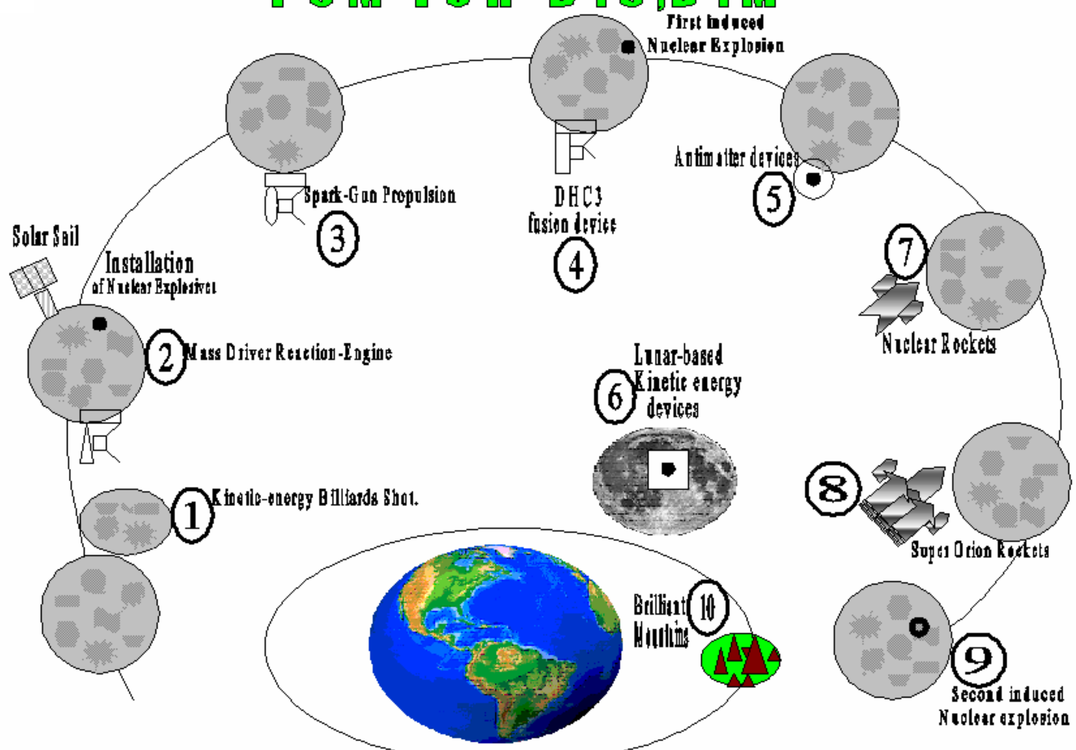
PSM FOR-C3S,C3M,C3i



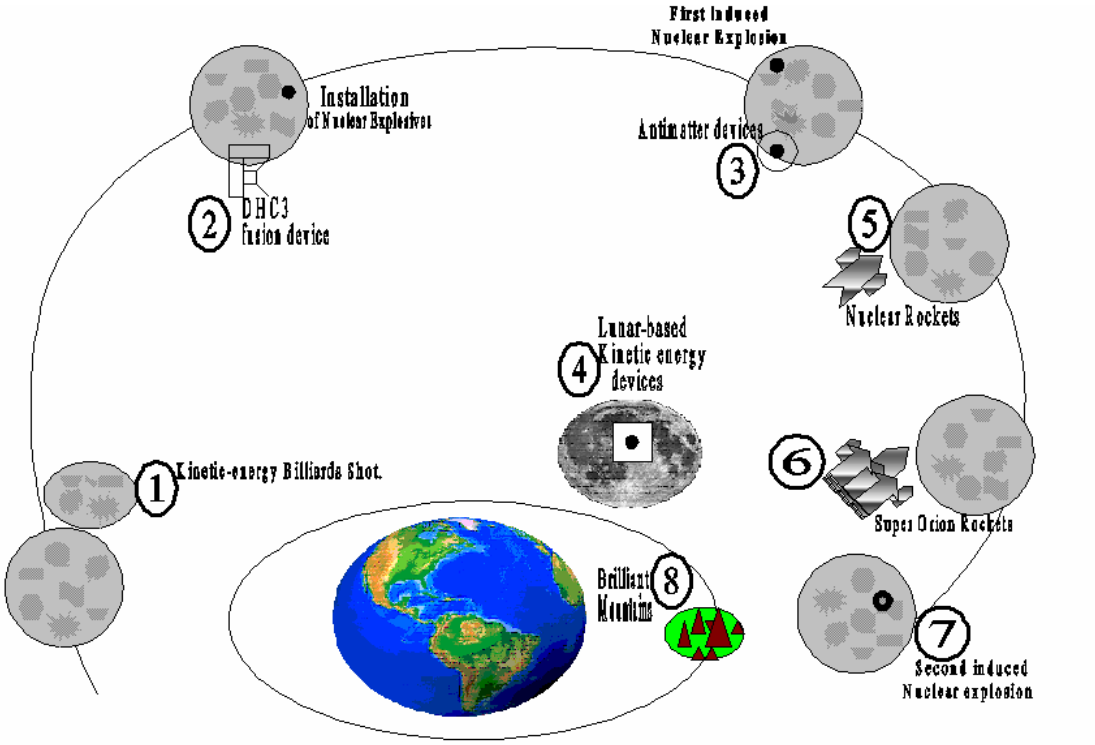
PSM FOR-C4S,C4M,C4i



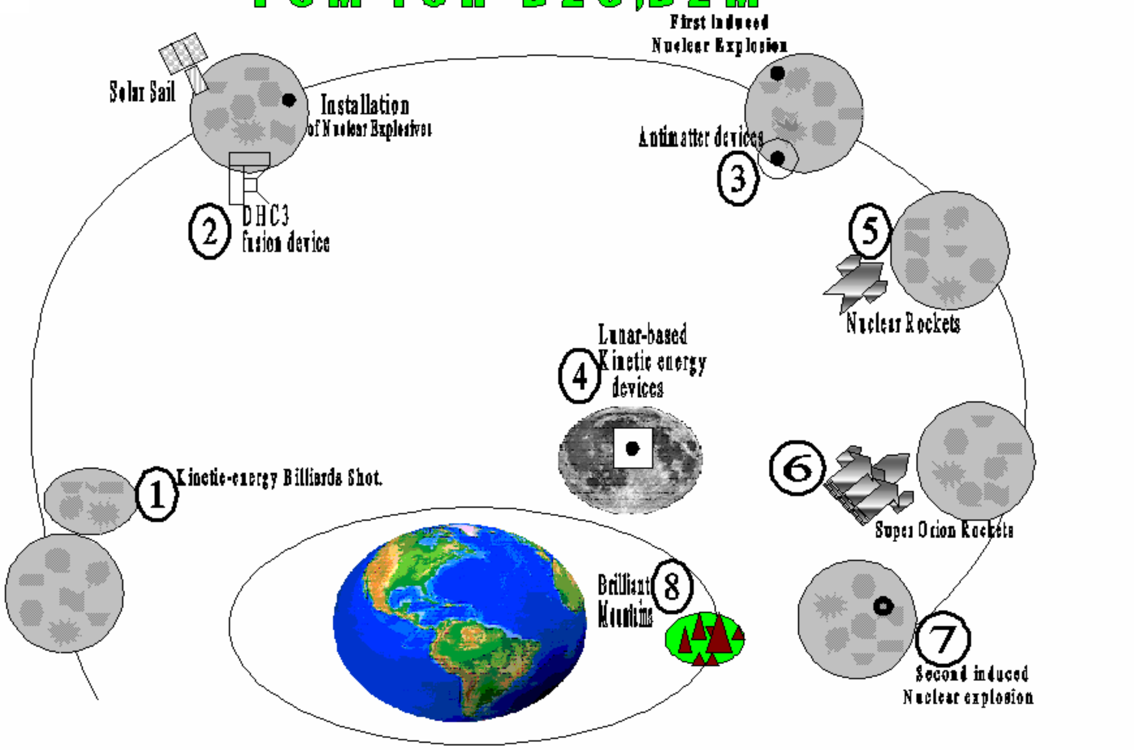
PSM FOR-D1S,D1M



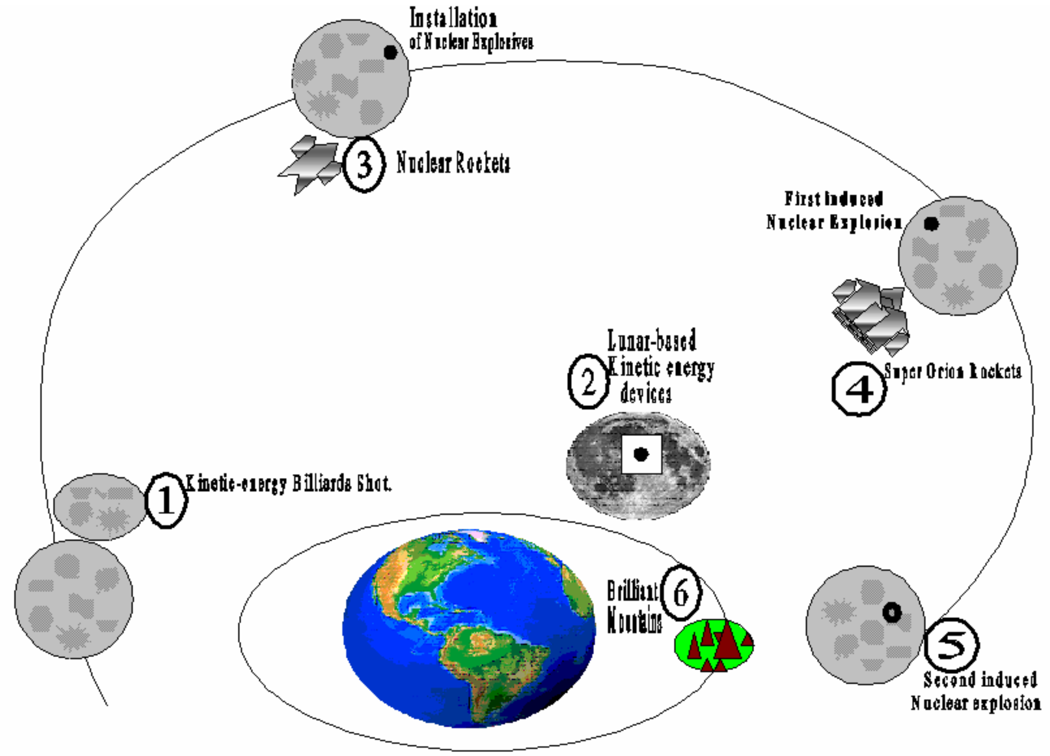
PSM FOR-D1i



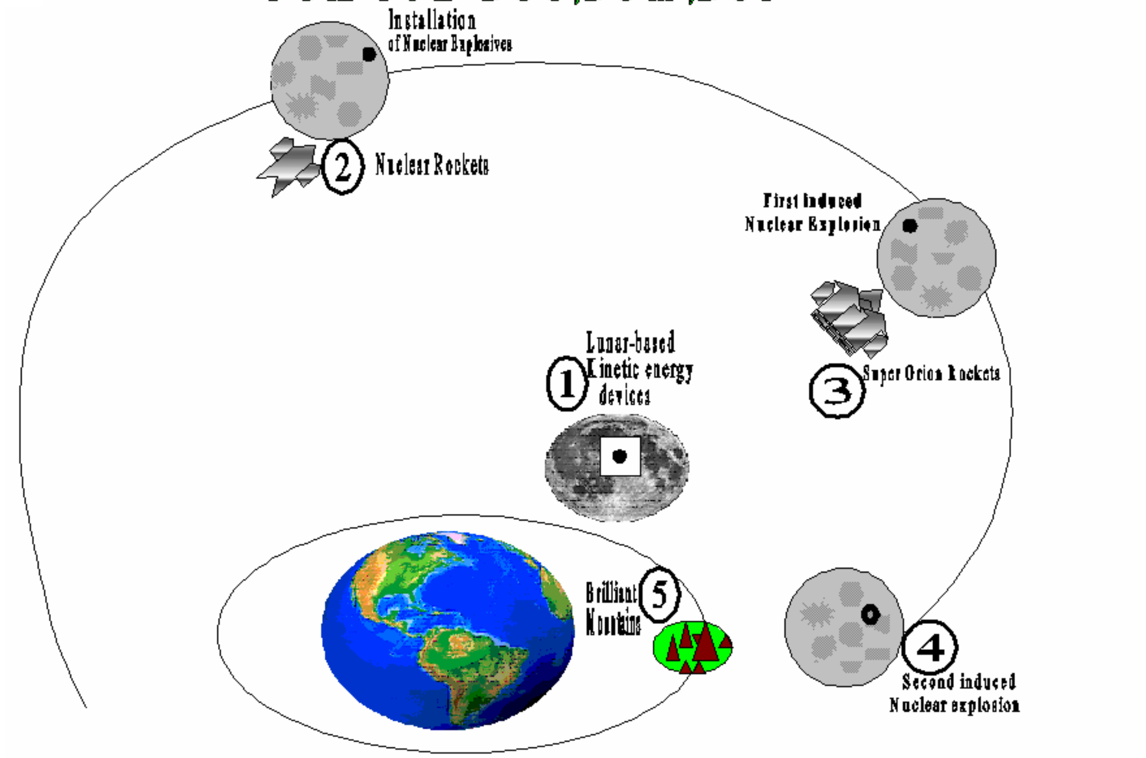
PSM FOR-D2S,D2M



PSM FOR-D2i



PSM FOR-D3S,D3M,D3i



PSM FOR-D4S,D4M,D4i

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Appendix 2: PDTS 1.0 Source Code

The source code for the forms within the different software modules has been described in this section of the thesis. This code was written in Visual Basic 6.0. The *login* and *administrator* forms are a part of the authentication module. The *classification master* form is a part of the classification module. This form allows us to change the parameters that are used to classify NEOs. The *employee master* form is exclusively used by the system administrator to store information regarding different users of the system. The *insert track* form is used to enter new NEO information into the tracking module. The *track search* form is used to retrieve existing NEO information within the tracking module. The *track* form is used to find out the NEO group that a particular asteroid or comet belongs to, based on its physical, optical, chemical and orbital parameters which were entered into the *insert track* form. When all this data is validated by the tracking module the corresponding PSM for the particular NEO group is generated by the PDTS 1.0 System.

Login form contains:

```
Private Sub connect()
Cn.Open "Driver={Microsoft Access Driver (*.MDB)};DBQ=" & App.Path & "\Space.Mdb" &
";UID = pradev;PWD = pradev;"
End Sub


Private Sub cmdOK_Click()
If OptProperietor.Value = True Then
   If txtadmin1.Text = "Admin" And Trim(txtAdminPass.Text) = "PDTS" Then
```

```
Unload Me
frmAdmin.Show 1
Exit Sub
End If
 If txtadmin1.Text <> "Admin" And Trim(txtAdminPass.Text) <> "PDTS" Then
  MsgBox "Invalid User Name & Password", vbOK, "Information required"
 txtadmin1.SetFocus
  Exit Sub
End If
If txtadmin1.Text = "Admin" And Trim(txtAdminPass.Text) <> "PDTS" Then
  MsgBox "Invalid Password", vbOK, "Information required"
 txtAdminPass.SetFocus
 Exit Sub
End If
If txtadmin1.Text <> "Admin" And Trim(txtAdminPass.Text) = "PDTS" Then
  MsgBox "Invalid UserName", vbOK, "Information required"
 txtadmin1.SetFocus
 Exit Sub
End If
If txtadmin1.Text = "" And Trim(txtAdminPass.Text) = "" Then
  MsgBox "UserName and Password cannot be blank", vbOK, "Information required"
 txtadmin1.SetFocus
 Exit Sub
End If
If txtadmin1.Text = "" And Trim(txtAdminPass.Text) = "PDTS" Then
```

```
  MsgBox "UserName cannot be blank", vbOK, "Information required"
 txtadmin1.SetFocus
 Exit Sub
End If
If txtadmin1.Text = "Admin" And Trim(txtAdminPass.Text) = "" Then
  MsgBox "Please enter the valid Password ", vbOK, "Information required"
 txtAdminPass.SetFocus
 Exit Sub
End If
Else
  If txtUser1.Text = "User" And Trim(txtUSerPass.Text) = "neotrack" Then
  Unload Me
  frmMain.Show
 Exit Sub
End If
If txtUser1.Text = "User" And Trim(txtUSerPass.Text) <> "neoTrack" Then
  MsgBox "Invalid Password", vbOK, "Information required"
 txtUser1.SetFocus
 Exit Sub
End If
If txtUser1.Text <> "Admin" And Trim(txtUSerPass.Text) = "neotrack" Then
  MsgBox "Invalid UserName", vbOK, "Information required"
 txtUser1.SetFocus
 Exit Sub
End If
```

```
   If txtUser1.Text = "" And Trim(txtUSerPass.Text) = "" Then
   MsgBox "UserName and Password cannot be blank", vbOK, "Information required"
    txtUser1.SetFocus
    Exit Sub
   End If
   If txtUser1.Text = "" And Trim(txtUSerPass.Text) = "neotrack" Then
     MsgBox "UserName cannot be blank", vbOK, "Information required"
    txtUser1.SetFocus
    Exit Sub
   End If
   If txtUser1.Text = "User" And Trim(txtUSerPass.Text) = "" Then
     MsgBox "Please enter the valid Password ", vbOK, "Information required"
    txtUSerPass.SetFocus
    Exit Sub
   End If
End If
End Sub

Private Sub Command1_Click()
Unload Me
Exit Sub
End Sub

Private Sub Form_KeyDown(KeyCode As Integer, Shift As Integer)
Select Case KeyCode
```

```
        Case vbKeyEscape:
                    Unload Me
            End Select
End Sub

Private Sub Form_KeyPress(KeyAscii As Integer)
If KeyAscii = 13 Then
SendKeys (vbTab)
End If
End Sub

Private Sub Form_Load()
'WINRUNNER: DO NOT DELETE THIS SECTION
   asr.Init Forms
'WINRUNNER: END
'Inet1.URL

'WebBrowser1.MenuBar = False
'WebBrowser1.Navigate "D:\gifs\aea021.gif"
connect
txtadmin1.Visible = False
txtAdminPass.Visible = False
txtUser1.Visible = False
txtUSerPass.Visible = False
End Sub
```

```
Private Sub Label2_Click()
End Sub

Private Sub OptEmployee_Click()
If OptEmployee.Value = True Then
txtadmin1.Visible = False
txtAdminPass.Visible = False
txtUser1.Visible = True
txtUSerPass.Visible = True
txtUser1.SetFocus
End If
End Sub

Private Sub OptProperietor_Click()
If OptProperietor.Value = True Then
txtUser1.Visible = False
txtUSerPass.Visible = False

txtadmin1.Visible = True
txtAdminPass.Visible = True
txtadmin1.SetFocus
End If
End Sub
```

Administrator form Contains:

```
Private Sub CmdBack_Click()

frmBackUp.Show 1

End Sub


Private Sub CmdManage_Click()

frmCustomer.Show 1

End Sub


Private Sub CmdTrack_Click()

frmTrack.Show 1

End Sub


Private Sub Command1_Click()

frmSplash.Show 1

End Sub


Private Sub Command2_Click()

frmClass.Show 1

End Sub

Private Sub Command3_Click()

frmNewtrack.Show 1

End Sub


Private Sub Command4_Click()
```

```
Unload Me
End Sub
```

Classification Master contains:

```
Private Function genCustCode() As String
   Dim rsCustCode As New ADODB.Recordset
   Sql = "Select Max(Val(ProdCode)) From Tbl_ClassMSt"
   rsCustCode.Open Sql, Cn, adOpenKeyset, adLockOptimistic
   If Not rsCustCode.EOF Then
      genCustCode = IIf(IsNull(rsCustCode(0)), 0, rsCustCode(0)) + 1
   Else
      genCustCode = 1
   End If
   rsCustCode.Close
End Function
Private Sub cmdClear_Click()
For Each ctl In Me
      If TypeOf ctl Is TextBox Then
         ctl.Text = ""
      End If
   Next
   For Each ctl In Me
   If TypeOf ctl Is ComboBox Then
         ctl.Text = ""
      End If
```

```
    Next
End Sub
Private Sub cmdDelete_Click()
Dim rsDel As New ADODB.Recordset
    If Trim(txtClass) = "" Then Exit Sub
    Sql = "Select * From Tbl_ClassMst Where ProdCode='" & Trim(txtClass) & "'"
    rsDel.Open Sql, Cn, adOpenKeyset, adLockPessimistic
    If Not rsDel.EOF Then
        If MsgBox("Are you sure you want to delete this Classification?", vbYesNo, "Confirmation") = vbYes Then
            Cn.Execute "Delete From Tbl_ClassMst Where ProdCode='" & Trim(txtClass) & "'"
            MsgBox "Record Deleted Successfully!", vbInformation, "Deleted"
            cmdClear_Click
        End If
    End If
End Sub

Private Sub cmdExit_Click()
Unload Me
End Sub

Private Sub cmdSave_Click()
Dim rsCust As New ADODB.Recordset
    If txtScheme = "" Then
        MsgBox "Enter Name to Save!", vbInformation, "Information Required"
        txtScheme.SetFocus
```

```
        Exit Sub
    End If
    Sql = "Select * From Tbl_ClassMst Where ProdCode='" & Trim(txtClass) & "'"
    rsCust.Open Sql, Cn, adOpenKeyset, adLockOptimistic
    If rsCust.EOF Then
        rsCust.AddNew
        rsCust!ProdCode = genCustCode
        txtClass = rsCust!ProdCode
    End If
    rsCust!SchemeName = txtScheme
    rsCust!Used = txtUsed
    rsCust.Update
    rsCust.Close
    MsgBox "Sucessfully Saved!"
End Sub

Private Sub Command1_Click()
End Sub

Private Sub cmdView_Click()
Dim Sql As String
    Dim rsCust As New ADODB.Recordset

    If Trim(txtScheme) = "" Then Exit Sub
    Sql = "Select * From Tbl_ClassMst Where SchemeName='" & Trim(txtScheme) & "'"
```

```
    rsCust.Open Sql, Cn, adOpenKeyset, adLockOptimistic
    If rsCust.EOF Then
        MsgBox "No Details Found in this Scheme Name!", vbInformation, "No Records"
        cmdClear_Click
    Else
        txtUsed = IIf(IsNull(rsCust!Used), "", rsCust!Used)
       txtClass = IIf(IsNull(rsCust!ProdCode), "", rsCust!ProdCode)
    End If
    rsCust.Close
End Sub

Private Sub Form_KeyDown(KeyCode As Integer, Shift As Integer)
Select Case KeyCode
        Case vbKeyEscape:
            Unload Me
  End Select
End Sub

Private Sub Form_KeyPress(KeyAscii As Integer)
End Sub

Private Sub Form_Load()
Dim rsProd As New ADODB.Recordset
    Sql = "Select * From Tbl_ClassMst Order By SchemeName"
    rsProd.Open Sql, Cn, adOpenKeyset, adLockOptimistic
```

```
    txtScheme.Clear
    While Not rsProd.EOF
        txtScheme.AddItem IIf(IsNull(rsProd!SchemeName), "", rsProd!SchemeName)
        rsProd.MoveNext
    Wend
    rsProd.Close
End Sub

Private Sub txtClass_LostFocus()
Dim Sql As String
    Dim rsCust As New ADODB.Recordset
    If Trim(txtClass) = "" Then Exit Sub
    Sql = "Select * From Tbl_ClassMst Where ProdCode='" & Trim(txtClass) & "'"
    rsCust.Open Sql, Cn, adOpenKeyset, adLockOptimistic
    If rsCust.EOF Then
        MsgBox "No Details Found in this Classification No!", vbInformation, "No Records"
        cmdClear_Click
    Else
        txtScheme = IIf(IsNull(rsCust("SchemeName")), "", rsCust("SchemeName"))
        txtUsed = IIf(IsNull(rsCust!Used), "", rsCust!Used)
   End If
End Sub



Private Sub txtScheme_Change()
```

```
Dim Sql As String
   Dim rsCust As New ADODB.Recordset
   If KeyAscii = 13 Then
   If Trim(txtScheme) = "" Then Exit Sub
   Sql = "Select * From Tbl_ClassMst Where SchemeName='" & Trim(txtScheme) & "'"
   rsCust.Open Sql, Cn, adOpenKeyset, adLockOptimistic
  If rsCust.EOF Then
      MsgBox "No Details Found in this Scheme Name!", vbInformation, "No Records"
      cmdClear_Click
   Else
      txtUsed = IIf(IsNull(rsCust!Used), "", rsCust!Used)
     txtClass = IIf(IsNull(rsCust!ProdCode), "", rsCust!ProdCode)
   End If
   rsCust.Close
   End If
End Sub

Private Sub txtScheme_KeyPress(KeyAscii As Integer)
Dim Sql As String
   Dim rsCust As New ADODB.Recordset
   If KeyAscii = 13 Then
   If Trim(txtScheme) = "" Then Exit Sub
   Sql = "Select * From Tbl_ClassMst Where SchemeName='" & Trim(txtScheme) & "'"
   rsCust.Open Sql, Cn, adOpenKeyset, adLockOptimistic
```

```
    If rsCust.EOF Then
        MsgBox "No Details Found in this Scheme Name!", vbInformation, "No Records"
        cmdClear_Click
    Else
      txtUsed = IIf(IsNull(rsCust!Used), "", rsCust!Used)
       txtClass = IIf(IsNull(rsCust!ProdCode), "", rsCust!ProdCode)
    End If
    rsCust.Close
  End If
End Sub

Private Sub txtScheme_LostFocus()
Dim Sql As String
    Dim rsCust As New ADODB.Recordset
  If Trim(txtName) = "" Then Exit Sub
    Sql = "Select * From Tbl_ClassMst Where SchemeName='" & Trim(txtScheme) & "'"
    rsCust.Open Sql, Cn, adOpenKeyset, adLockOptimistic
      txtScheme = IIf(IsNull(rsCust("SchemeName")), "", rsCust("SchemeName"))
        txtUsed = IIf(IsNull(rsCust!Used), "", rsCust!Used)
    rsCust.Close
End Sub
```

Employee Master Contains:

```
Private Function genCustCode() As String
    Dim rsCustCode As New ADODB.Recordset
```

```
  Sql = "Select Max(Val(CustCode)) From Tbl_CustomerMst"
  rsCustCode.Open Sql, Cn, adOpenKeyset, adLockOptimistic
  If Not rsCustCode.EOF Then
    genCustCode = IIf(IsNull(rsCustCode(0)), 0, rsCustCode(0)) + 1
  Else
    genCustCode = 1
  End If
  rsCustCode.Close
End Function
Private Sub Cmd_SellerDetail_Click()
frmSellerDetail.Show 1
End Sub

Private Sub cmdClear_Click()
For Each ctl In Me
    If TypeOf ctl Is TextBox Then
      ctl.Text = ""
    End If
  Next
  For Each ctl In Me
  If TypeOf ctl Is ComboBox Then
      ctl.Text = ""
    End If
  Next
```

```
    txtCustCode.SetFocus
End Sub
Private Sub cmdDelete_Click()
 Dim rsDel As New ADODB.Recordset
    If Trim(txtCustCode) = "" Then Exit Sub
    Sql = "Select * From Tbl_CustomerMst Where CustCode='" & Trim(txtCustCode) & "'"
    rsDel.Open Sql, Cn, adOpenKeyset, adLockPessimistic
    If Not rsDel.EOF Then
        If MsgBox("Are you sure to delete this Customer?", vbYesNo, "Confirmation") = vbYes
Then
            Cn.Execute "Delete From Tbl_CustomerMst Where CustCode='" & Trim(txtCustCode)
& "'"
            MsgBox "Record Deleted Successfully!", vbInformation, "Deleted"
            cmdClear_Click
        End If
    End If
End Sub

Private Sub cmdExit_Click()
 Unload Me
End Sub

Private Sub cmdSave_Click()
Dim rsCust As New ADODB.Recordset
    If txtName = "" Then
        MsgBox "Enter Name to Save!", vbInformation, "Information Required"
```

```
        txtName.SetFocus
        Exit Sub
    End If
    Sql = "Select * From Tbl_CustomerMst Where CustCode='" & Trim(txtCustCode) & "'"
    rsCust.Open Sql, Cn, adOpenKeyset, adLockOptimistic
    If rsCust.EOF Then
        rsCust.AddNew
        rsCust!CustCode = genCustCode
        txtCustCode = rsCust!CustCode
    End If
    rsCust("Name") = txtName
    rsCust!Address1 = txtAdd1
    rsCust!Address2 = txtAdd2
    rsCust!City = txtCity
    rsCust!PinCode = txtPin
    rsCust!Phone = txtPhone
    rsCust!ContactPerson = txtContactPerson
    rsCust!Designation = txtDesig
    rsCust!Department = txtDept
    rsCust.Update
    rsCust.Close
    MsgBox "Sucessfully Saved!"
End Sub

Private Sub CmdSearch_Click()
```

```
frmCustomerSearch1.Show 1
End Sub

Private Sub Form_KeyDown(KeyCode As Integer, Shift As Integer)
Select Case KeyCode
    Case vbKeyEscape:
        Unload Me
  End Select
End Sub

Private Sub Form_KeyPress(KeyAscii As Integer)
  If KeyAscii = 13 Then
    SendKeys (vbTab)
  End If
End Sub

Private Sub Form_Load()
Dim rsProd As New ADODB.Recordset
  Sql = "Select * From Tbl_CustomerMst Order By Name"
  rsProd.Open Sql, Cn, adOpenKeyset, adLockOptimistic
  txtName.Clear
  While Not rsProd.EOF
    txtName.AddItem IIf(IsNull(rsProd!Name), "", rsProd!Name)
    rsProd.MoveNext
  Wend
```

```
  rsProd.Close
 End Sub

Public Sub txtCustCode_LostFocus()
 Dim Sql As String
  Dim rsCust As New ADODB.Recordset
   Dim rsCust1 As New ADODB.Recordset
  If Trim(txtCustCode) = "" Then Exit Sub
  Sql = "Select * From Tbl_CustomerMst Where CustCode='" & Trim(txtCustCode) & "'"
 rsCust.Open Sql, Cn, adOpenKeyset, adLockOptimistic
  If rsCust.EOF Then
     MsgBox "No Details Found in this Customer ID!", vbInformation, "No Records"
     cmdClear_Click
  Else
     txtName = IIf(IsNull(rsCust("Name")), "", rsCust("Name"))
     txtAdd1 = IIf(IsNull(rsCust!Address1), "", rsCust!Address1)
     txtAdd2 = IIf(IsNull(rsCust!Address2), "", rsCust!Address2)
     txtCity = IIf(IsNull(rsCust!City), "", rsCust!City)
     txtPin = IIf(IsNull(rsCust!PinCode), "", rsCust!PinCode)
     txtPhone = IIf(IsNull(rsCust!Phone), "", rsCust!Phone)
     txtEMail = IIf(IsNull(rsCust!EMail), "", rsCust!EMail)
     txtDept = IIf(IsNull(rsCust!Department), "", rsCust!Department)
     txtDesig = IIf(IsNull(rsCust!Designation), "", rsCust!Designation)
     txtContactPerson = IIf(IsNull(rsCust!ContactPerson), "", rsCust!ContactPerson)
  End If
```

```
End Sub

Private Sub txtName_KeyPress(KeyAscii As Integer)
 Dim Sql As String
    Dim rsCust As New ADODB.Recordset
    If KeyAscii = 13 Then
    If Trim(txtName) = "" Then Exit Sub
    Sql = "Select * From Tbl_CustomerMst Where Name='" & Trim(txtName) & "'"
    rsCust.Open Sql, Cn, adOpenKeyset, adLockOptimistic
    If rsCust.EOF Then
        MsgBox "No Details Found in this Product Name!", vbInformation, "No Records"
        cmdClear_Click
    Else
        txtName = IIf(IsNull(rsCust("Name")), "", rsCust("Name"))
         txtCustCode = IIf(IsNull(rsCust!CustCode), "", rsCust!CustCode)
        txtAdd1 = IIf(IsNull(rsCust!Address1), "", rsCust!Address1)
        txtAdd2 = IIf(IsNull(rsCust!Address2), "", rsCust!Address2)
        txtCity = IIf(IsNull(rsCust!City), "", rsCust!City)
        txtPin = IIf(IsNull(rsCust!PinCode), "", rsCust!PinCode)
        txtPhone = IIf(IsNull(rsCust!Phone), "", rsCust!Phone)
       txtDept = IIf(IsNull(rsCust!Department), "", rsCust!Department)
        txtDesig = IIf(IsNull(rsCust!Designation), "", rsCust!Designation)
        txtContactPerson = IIf(IsNull(rsCust!ContactPerson), "", rsCust!ContactPerson)
    End If
    rsCust.Close
```

```
    End If
End Sub

Private Sub txtName_LostFocus()
Dim Sql As String
    Dim rsCust As New ADODB.Recordset
    If Trim(txtName) = "" Then Exit Sub
    Sql = "Select * From Tbl_CustomerMSt Where Name='" & Trim(txtName) & "'"
    rsCust.Open Sql, Cn, adOpenKeyset, adLockOptimistic
    If rsCust.EOF Then
      Exit Sub
    Else
        txtName = IIf(IsNull(rsCust("Name")), "", rsCust("Name"))
         txtCustCode = IIf(IsNull(rsCust!CustCode), "", rsCust!CustCode)
        txtAdd1 = IIf(IsNull(rsCust!Address1), "", rsCust!Address1)
        txtAdd2 = IIf(IsNull(rsCust!Address2), "", rsCust!Address2)
        txtCity = IIf(IsNull(rsCust!City), "", rsCust!City)
        txtPin = IIf(IsNull(rsCust!PinCode), "", rsCust!PinCode)
        txtPhone = IIf(IsNull(rsCust!Phone), "", rsCust!Phone)
        txtContactPerson = IIf(IsNull(rsCust!ContactPerson), "", rsCust!ContactPerson)
        txtDept = IIf(IsNull(rsCust!Department), "", rsCust!Department)
        txtDesig = IIf(IsNull(rsCust!Designation), "", rsCust!Designation)
    End If
    rsCust.Close
End Sub
```

Form Insert New Track Contains:

```
Private Function genCustCode() As String
  Dim rsCustCode As New ADODB.Recordset
  Sql = "Select Max(Val(TTCode)) From Tbl_Track1"
  rsCustCode.Open Sql, Cn, adOpenKeyset, adLockOptimistic

  If Not rsCustCode.EOF Then
    genCustCode = IIf(IsNull(rsCustCode(0)), 0, rsCustCode(0)) + 1
  Else
    genCustCode = 1000
  End If
  rsCustCode.Close
End Function
Private Sub result()
txtResult = Trim(txtName + CboMonth + txtYear)
End Sub

Private Sub cmdClear_Click()
For Each ctl In Me
    If TypeOf ctl Is TextBox Then
      ctl.Text = ""
    End If
  Next
  For Each ctl In Me
  If TypeOf ctl Is ComboBox Then
```

```
            ctl.Text = ""
        End If
    Next
End Sub

Private Sub cmdDelete_Click()
Dim rsDel As New ADODB.Recordset
    If Trim(txtTrackCode) = "" Then Exit Sub
    Sql = "Select * From Tbl_Track Where TCode='" & Trim(txtTCode) & "'"
    rsDel.Open Sql, Cn, adOpenKeyset, adLockPessimistic
    If Not rsDel.EOF Then
        If MsgBox("Are you sure to delete this Track Details?", vbYesNo, "Confirmation") =
vbYes Then
            Cn.Execute "Delete From Tbl_Track Where TCode='" & Trim(txtTCode) & "'"
            MsgBox "Record Deleted Successfully!", vbInformation, "Deleted"
            cmdClear_Click
        End If
    End If
End Sub

Private Sub cmdExit_Click()
Unload Me
End Sub

Private Sub cmdSave_Click()
Dim rsCust As New ADODB.Recordset
```

```
result
    If txtName = "" Then
        MsgBox "Enter Name to Save!", vbInformation, "Information Required"
        txtName.SetFocus
        Exit Sub
    End If
    Sql = "Select * From Tbl_Track1 Where TTCode='" & Trim(txtTCode) & "'"
    rsCust.Open Sql, Cn, adOpenKeyset, adLockOptimistic
    If rsCust.EOF Then
        rsCust.AddNew
        rsCust!TTcode = genCustCode
        txtTCode = rsCust!TTcode
    End If
    rsCust("Name") = txtName
    rsCust!Time = Val(txtTime.Text)
    rsCust!Date = DTPDate
    rsCust!Month = CboMonth
    rsCust!Year = txtYear
   rsCust!result = txtResult
    rsCust.Update
    rsCust.Close
    MsgBox "Sucessfully Saved!"
End Sub

Private Sub Form_KeyDown(KeyCode As Integer, Shift As Integer)
```

```
Select Case KeyCode
        Case vbKeyEscape:
                Unload Me
                End Select
End Sub

Private Sub Form_KeyPress(KeyAscii As Integer)
If KeyAscii = 13 Then
SendKeys (vbTab)
End If
End Sub

Private Sub Form_Load()
Dim rsProd As New ADODB.Recordset
    Sql = "Select * From Tbl_Track Order By Name"
    rsProd.Open Sql, Cn, adOpenKeyset, adLockOptimistic
    DTPDate = Format(Now, "d/m/yy")
    rsProd.Close
  txtTCode.Enabled = True
End Sub
```

Form Track Contains:

```
Private Function genProdCode() As String
    Dim rsProdCode As New ADODB.Recordset
    Sql = "Select Max(Val(TCode)) From Tbl_Track"
```

```
   rsProdCode.Open Sql, Cn, adOpenKeyset, adLockOptimistic
   If Not rsProdCode.EOF Then
      genProdCode = IIf(IsNull(rsProdCode(0)), 0, rsProdCode(0)) + 1
   Else
      genProdCode = 1
   End If
   rsProdCode.Close
End Function

Private Sub cmdClear_Click()
 For Each ctl In Me
      If TypeOf ctl Is TextBox Then
         ctl.Text = ""
      End If
      If TypeOf ctl Is ComboBox Then
         ctl.Text = ""
      End If
   Next
End Sub

Private Sub cmdDelete_Click()
Dim rsDel As New ADODB.Recordset
   If Trim(txtTCode) = "" Then Exit Sub
   Sql = "Select * From Tbl_Track Where TCode='" & Trim(txtTCode) & "'"
   rsDel.Open Sql, Cn, adOpenKeyset, adLockPessimistic
```

```
  If Not rsDel.EOF Then
    If MsgBox("Are you sure to delete this item?", vbYesNo, "Confirmation") = vbYes Then
      Cn.Execute "Delete From Tbl_Track Where TCode='" & Trim(txtTCode) & "'"
      MsgBox "Record Deleted Successfully!", vbInformation, "Deleted"
      cmdClear_Click
    End If
  End If
End Sub
Private Sub cmdExit_Click()
Unload Me
End Sub

Private Sub cmdProdSearch_Click()
frmTrackSearch.Show 1
End Sub

Private Sub cmdSave_Click()
Dim rsProd As New ADODB.Recordset
  Sql = "Select * From Tbl_Track Where TCode='" & Trim(txtTCode) & "'"
  rsProd.Open Sql, Cn, adOpenKeyset, adLockOptimistic
  If rsProd.EOF Then
    rsProd.AddNew
    rsProd!Tcode = genProdCode
    txtTCode = rsProd!Tcode
  End If
```

```
rsProd!GM = Val(txtGM.Text)
rsProd!Name = (txtName.Text)
rsProd!Radius = Val(txtRadius.Text)
rsProd!Rotation = Val(txtRotation.Text)
rsProd!Eccentricity = Val(txtEccen.Text)
rsProd!Inclination = Val(txtInclination.Text)
rsProd!Perihelion = Val(txtPerihelion.Text)
rsProd!Periarg = Val(txtPeriarg.Text)
rsProd!Axis = Val(txtAxis.Text)
rsProd!Longitude = Val(txtLong.Text)
rsProd!Aphelion = Val(txtAphelion.Text)
rsProd!Magnitude = Val(txtMag.Text)
rsProd!MagSlope = Val(txtMagslope.Text)
rsProd!Color = Trim(txtColor.Text)
rsProd!Geometric = Val(txtGeometric.Text)
rsProd!Spectral = Val(txtSpectral.Text)
rsProd!Observation = Trim(txtObservation)
rsProd!Robitual = Val(txtRobitual.Text)
rsProd!Orbital = Val(txtOrbital.Text)
rsProd!Period = Val(txtPeriod.Text)
rsProd!Velocity = Val(txtVelocity.Text)
rsProd!Composition = txtCompostion.Text
rsProd!result = (txtResult.Text)
rsProd!Month = txtMonth.Text
rsProd!Year = (TxtYear.Text)
```

```
    rsProd!Time = Val(TxtTime.Text)
    rsProd.Update
    rsProd.Close
If Trim(txtPerihelion.Text) = "" And Trim(txtAphelion.Text) = "" Then
    frmPopUp1.Show vbModal
    frmPopUp2.Show vbModal
    frmPopUp3.Show vbModal
End If
End Sub

Private Sub cmdView_Click()
frmSam.Show 1
End Sub

Private Sub Command1_Click()
frmTrackSearch.Show 1
End Sub

Private Sub Form_KeyDown(KeyCode As Integer, Shift As Integer)
Select Case KeyCode
        Case vbKeyEscape:
                Unload Me
                End
    End Select
End Sub
```

```
Private Sub Form_KeyPress(KeyAscii As Integer)
If KeyAscii = 13 Then
    SendKeys (vbTab)
  End If
End Sub

Private Sub Form_Load()
Dim rsProd As New ADODB.Recordset
  Sql = "Select * From Tbl_Track1 Order By TTCode"
  rsProd.Open Sql, Cn, adOpenKeyset, adLockOptimistic

  While Not rsProd.EOF
    txtName.AddItem IIf(IsNull(rsProd!result), "", rsProd!result)
    rsProd.MoveNext
 Wend
  rsProd.Close
End Sub
Private Sub txtName_KeyPress(KeyAscii As Integer)
Dim rsCustName As New ADODB.Recordset
Sql = "Select * from Tbl_Track1 Where Name='" & Trim(txtName.Text) & "'"
  rsCustName.Open Sql, Cn, adOpenForwardOnly, adLockOptimistic
  If rsCustName.EOF Then
    Exit Sub
  Else
```

```
        txtTCode.Text = IIf(IsNull(rsCustName("TTCode")), "", rsCustName("TTCode"))
    End If
    rsCustName.Close
End Sub

Private Sub txtName_LostFocus()
Dim Sql As String
    Dim rsCust As New ADODB.Recordset
   If Trim(txtName) = "" Then Exit Sub
    Sql = "Select * From Tbl_Track1 Where Result ='" & Trim(txtName) & "'"
    rsCust.Open Sql, Cn, adOpenKeyset, adLockOptimistic

    If rsCust.EOF Then
        MsgBox "No Details Found in this Track Name!", vbInformation, "No Records"
    Else
        txtResult = IIf(IsNull(rsCust("result")), "", rsCust("result"))
        TxtYear = IIf(IsNull(rsCust!Year), "", rsCust!Year)
        txtMonth = IIf(IsNull(rsCust!Month), "", rsCust!Month)
        TxtTime = IIf(IsNull(rsCust!Time), "", rsCust!Time)
    End If
    rsCust.Close
End Sub

Public Sub txtTCode_LostFocus()
    Dim Sql As String
```

```
Dim rsProd As New ADODB.Recordset
Dim rsProd1 As New ADODB.Recordset
 If Trim(txtTCode) = "" Then Exit Sub
Sql = "Select * From Tbl_Track Where TCode='" & Trim(txtTCode) & "'"
rsProd.Open Sql, Cn, adOpenKeyset, adLockOptimistic
If rsProd.EOF Then
   MsgBox "No Details Found in this Track Code!", vbInformation, "No Records"
   cmdClear_Click
Else
    txtGM = IIf(IsNull(rsProd!GM), "", rsProd!GM)
   txtRadius = IIf(IsNull(rsProd!Radius), "", rsProd!Radius)
   txtRotation = IIf(IsNull(rsProd!Rotation), "", rsProd!Rotation)
   txtEccen = IIf(IsNull(rsProd!Eccentricity), "", rsProd!Eccentricity)
   txtInclination = IIf(IsNull(rsProd!Inclination), "", rsProd!Inclination)
   txtPerihelion = IIf(IsNull(rsProd!Perihelion), 0, rsProd!Perihelion)
   txtPeriarg = IIf(IsNull(rsProd!Periarg), 0, rsProd!Periarg)
   txtAxis = IIf(IsNull(rsProd!Axis), 0, rsProd!Axis)
   txtLong = IIf(IsNull(rsProd!Longitude), 0, rsProd!Longitude)
   txtAphelion = IIf(IsNull(rsProd!Aphelion), "", rsProd!Aphelion)
   txtMag = IIf(IsNull(rsProd!Magnitude), 0, rsProd!Magnitude)
   txtColor = IIf(IsNull(rsProd!Color), 0, rsProd!Color)
   txtGeometric = IIf(IsNull(rsProd!Geometric), 0, rsProd!Geometric)
   txtCompostion.Text = IIf(IsNull(rsProd!Composition), "", rsProd!Composition)
   txtSpectral = IIf(IsNull(rsProd!Spectral), "", rsProd!Spectral)
   txtObservation = IIf(IsNull(rsProd!Observation), 0, rsProd!Observation)
```

```
    txtRobitual = IIf(IsNull(rsProd!Robitual), 0, rsProd!Robitual)
    txtOrbital = IIf(IsNull(rsProd!Orbital), 0, rsProd!Orbital)
    txtPeriod = IIf(IsNull(rsProd!Period), 0, rsProd!Period)
    txtVelocity = IIf(IsNull(rsProd!Velocity), 0, rsProd!Velocity)
    txtResult = IIf(IsNull(rsProd!result), "", rsProd!result)
    TxtYear = IIf(IsNull(rsProd!Year), "", rsProd!Year)
    txtMonth.Text = IIf(IsNull(rsProd!Month), "", rsProd!Month)
End If
txtName.Text = txtResult.Text
End Sub
```

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