Master’s Thesis

Risk-Based Fire Research Decision Methodology

By

Richard L. Hansen

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Prof. Frank Noonan

Thesis Advisor

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Prof. David Lucht

Director, Center for Firesafety Studies

ABSTRACT

A risk-based decision methodology is presented to support United States Coast Guard regulators' determinations of the most appropriate fire safety areas for allocating research and development resources. The methodology consists of risk-based analysis of previous shipboard fire and explosion incidents to establish historical problem areas and trends. The analysis results were then presented to a panel of experts in shipboard fire safety regulations. An analytical hierarchical process was used to encode these experts' opinions on subjective attributes of the decision. Nineteen attributes were selected by the panel and used to rate eighteen potential research and development alternatives. The series of eighteen alternative areas for possible research and development efforts were ranked using a scoring model. A sensitivity analysis was performed on the top five alternatives to assess the relative influence the attributes have on the decision.

Information from two marine casualty databases were analyzed to establish the historical problem areas and trends. Fire and explosion incidents were taken from the United States Coast Guard's Marine Safety Information System (MSIS) database and Lloyd's Maritime Information Service Ltd.'s Casualty System (CASMAN). Following the methodology presented, the top five areas for possible allocation of research and development resources are: egress of passengers and crew, development of international design & approval standards for fire protection systems, hazard analysis review of fire safety regulations, development of alternative design assessment methodology, and investigation of lagging requirements for fire protection.

ACKNOWLEDGEMENTS

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INTRODUCTION

The United States Coast Guard (Coast Guard) is charged, under law, with promoting and protecting safety, security, and the environment through the regulation of marine commerce in the United States. The Coast Guard carries out this assignment through its Office of Marine Safety and Environmental Protection (G-M). The Marine Safety and Marine Environmental Protection programs within this office have responsibilities to establish federal policies/standards, negotiate international maritime safety/environmental protection standards, assure U.S. vessel compliance, port state control, provide security for U.S. ports, and direct response activities to mitigate the effects of maritime casualties and pollution.

The program's standards making functions are performed by the Director of Standards (G-MS) and his staff located in headquarters. The compliance and response functions are carried out primarily by field personnel at other Coast Guard locations including Marine Safety Offices, Marine Inspection Offices, Nation Strike Team locations, and Vessel Traffic Services locations.

The development of the Federal government's marine polices and standards as well as the participation in international maritime safety standards are handled by the Standards Directorate (G-MS). Individual divisions within the directorate are responsible for different areas. For example, shipboard fire safety issues fall under the responsibility of the Lifesaving and Fire Safety Division (G-MSE-4).

To support their regulatory functions and rule interpretations, G-MSE-4 submits requests for support to the Coast Guard's Research and Development Program (G-SIR). The Research and Development Program is a separate program within the Coast Guards Systems (G-S) office. G-SIR has a separate line of funding established by Congress (RDT&E funds) and these funds cannot be used for other than appropriate research and development efforts. Each of the other programs within Coast Guard must submit their requests for research and development support to the R&D Program.

For each request for R&D support, a project proposal is developed along with an estimate of the amount of time and resources required to complete the requested effort. All of the Requests are then combined with their project proposals and ranked by a multi-attribute rating system.

This high level Rating system is performed by R&D program (G-SIR) personnel with some input from the individual program offices. The rating system is a scoring model with attributes of guidance linkages, benefit-to-cost measures, and investment measures. The guidance linkages are broken down into scores for linkages to planning documents (Department of Transportation's, Commandant's Executive Business Plan, and the individual Program's Business Plan), mandates (whether direct or indirect support of a mandate), and other guidances (e.g., Commandant's Determinations, and the DOT Strategic Agenda). Benefit-to-Cost measures consist of a Life-Cycle Cost, a Life-Cycle Benefit, and Figure of Merit scores (the quotient of Life-Cycle Benefit score divided by the Life-Cycle Cost score). The Investment Measures' attribute consists of scores on probability of success, project size verses the R&D program funds, affordability measures, capital investment impact, and Coast Guard operating expenses impact. These scores are then used in the multicriteria decision tool known as ELECTRE to weight the different attributes. A final ranked list of projects is then created. The available RDT&E funds are then distributed to the highest-ranking projects until the resources are expended. The individual programs are given an opportunity for reclamas to the ranking. A final list of projects to fund, given the projected funding level, is established. This process begins two-years before the government budget is set by Congress and the President. Any budget cuts or increases are accounted for by the elimination or addition of the projects in the ranking.

For an individual office's R&D need to be addressed by the limited R&D resources, the request must compete within its own program's list of needs. The request must then compete against projects from the other programs for funding in the high level ranking process described above. Therefore, the likelihood of a need being addressed by the R&D Program is very much dependent on the strength of the supporting information of the request, and the ability to be highly ranked in G-SIR's process.

A decision support methodology implemented at a this initial level can help support these needs and assist the requesting offices in selecting the most important areas to be researched. By tailoring their own internal ranking process to reflect the goals of the high level ranking process, their R&D needs will likely be better ranked and potentially funded. For the purposes of this effort, the needs of the Lifesaving and Fire Safety Division (G-MSE-4) will be examined.

CURRENT DECISION PROCESS

The current decision-making process for this initial selection of fire research areas and the proposed decision support methodology, share several attributes. Both include some historical incident perspective, and encoding of the decision-maker's "expert opinion." The difference between the current and proposed methodologies lies in the structuring and documenting of the process. The greatest benefit will be that the selection process reflects the higher level ranking process.

Currently the decision-makers receive some information on fire and explosion incidents. This might be in the form of an official Coast Guard incident investigation report or as part of a Commandant's Review of an accident investigation. The decision-maker can request casualty data be extracted from the Coast Guard's casualty database. They also receive information through various industry trade magazines and newsletters. The decision-makers are occasionally asked to assist in an accident investigation. Sometimes they hear of an incident from a broadcast news program or in a newspaper.

There is a weakness in the current method for receiving information on incidents. The largest or highest profile incidents get most of the attention. Very few people in America were unaware of the fire on the cruise Ecstasy. "It was a cruise marketer's worst nightmare. Hours of continuous live coverage of pillars of smoke billowing from the stern of the sleek white cruise liner, complete with captions flashing "Cruise Ship Terror" and the like." (Blenkey, 1998) was stated in the cover story of a trade magazine.

This incident was broadcast live over many national news programs and was reported on in most newspapers. These high profile incidents often sway the decision-making process due to public opinion, which can lead to congressional inquiry. The result is that smaller incidents that occur more frequently may be overlooked.

A second weakness in the current methodology is the general lack of documentation of all the factors that went into the decision process. If the decision-maker's perception is that there seem to have been many fires on Offshore Support Vessels (OSV) recently, the decision might be swayed by that availability heuristic. The availability heuristic is defined as the readily available information in a person's memory (Tversky, 1973). Had there been a structured decision-making process, the increase in frequency for OSV's would have been captured and available for later review if needed.

The final weakness in the current process is the inability to justify the request in the selection process. There are new requirements that make this an important aspect. The Government Performance and Results Act (Public Law 103-62, August 1993) requires that all government programs measure their performance and demonstrate the possible results of the regulation or action. Regulatory actions must demonstrate that the benefits of the regulation outweigh the cost of implementing it. This has resulted in the investigation of the goal of eventual results much earlier in the process. This has never been included in the R&D decision making process. A structured decision support tool can include this attribute as well as document the need, which supports the benefits analysis.

PROPOSED DECISION METHODOLOGY

The goal of the decision methodology is to improve upon the strengths of the current process while providing structure and documentation. It is not the intent of this effort to fix a broken process, but improve it to better meet the changing requirements.

The proposed decision methodology consists of a risk-based analysis of historical maritime fire and explosion accidents. The goal of this analysis is to determine where the most significant fire and explosion problems are occurring. Significant fires and explosions, as used here refer to the type of incidents with the highest product of probability of occurring times the consequence of it occurring. The analysis will try to identify the types of vessels, the locations of the incidents on the vessel, and the sources of ignition that are responsible for the most significant fires and explosions. The analyses should be performed on the best available information, and information should represent the regulated population.

The next step is the presentation of the data to the decision-makers. The goal here is to present the data most useful and in a form that will allow the decision-maker to use the information as well as document this portion of the decision process.

Once the decision-maker has reviewed the data, the next part of the process is for the decision-makers to establish the attributes for rating alternatives. Alternatives as used here, refer to possible areas for a research and development effort. Attributes are the criteria by which to rate those alternatives. The method presented here is that of a brainstorming process. This method encourages the consideration of a wide range of attributes and then the selection of the most appropriate ones. In subsequent decision processes, this stage may be reconfigured to the brainstorming of potential new attributes not previously used followed by the selection of the best from existing and new attributes.

After the attributes are established, they must be ranked according to the relative importance to each other. The method selected here was that of the Analytical Hierarchy Process (AHP). AHP is a multi-criteria decision analysis methodology that allows subjective as well as objective factors to be considered in the process (Mustafa, 1991). Thomas L. Saaty of the Wharton School at the University of Pennsylvania developed AHP in the early 1970s to help decision-makers deal with the complexity inherent in multi-criteria based decisions. AHP allows decision-makers to capture their expert knowledge of the problem while incorporating both subjective and objective data into a logical, hierarchic framework. Above all, AHP provides decision-makers with an intuitive and common sense approach to evaluating the importance of each attribute through a pairwise comparison process.

In this process, the ranking of the various attributes is broken down into easier to analyze pairwise comparisons. These comparisons allow the attributes to be compared individually to each other with respect to the goal. The goal is the decision that is being modeled. The attributes are represented as individual nodes in the decision model. Global nodes are made up from local nodes. This grouping of like attributes into global attributes forms the decision model. The individual comparisons are then rolled up into a complete ranking of the attributes.

The decision-makers can then establish a list of alternative research areas to be considered based on the analyzed data presented, as well as their opinions based on their experiences. The alternatives can be developed using the same brainstorming process used for establishing the attributes. The goal here is to capture all possibilities and allow the AHP to determine the relative merits of each. Subsequent decision-making processes might consider starting with the alternatives of previous efforts that were not chosen and a reassessment of the attributes.

The final input to the AHP is the rating of the alternatives against the ranked attributes. This can be done by the same pairwise comparison process; however, as the number of alternatives increase, the number of individual decisions can become unmanageable. A usual cut-off point is at eight or nine alternatives. This is also dependent on the number of attributes. A simpler process can be selected for rating the alternatives. This is simply a two point scale or three point scale established for each of the lowest level attributes. In this process, a standard scale is created for each attribute and the alternative is rated against that scale. A simple "yes" or "no" two-point scale for example, is established to rate if an alternative affects the attribute or not.

The ratings from the scaled alternatives and the ranked attributes are then synthesized. Synthesis is the process of weighting and combining the inputted priorities through the decision model to yield the result. Global weights are obtained for nodes throughout the decision model by applying each node's local priority by its parent's global weight. The global weights are then summed to yield the overall or synthesized weights. The preferred alternative is the one with the highest weight.

The decision-makers then have a list of alternatives, in order of their weighted priorities. The decision-makers can then select from this list the alternatives they want to submit for allocation of R&D resources.

HISTORICAL INFORMATION

Information on the types of fires and explosions that typically occur reside in historical incident records. For shipboard fire and explosion incidents, records are typically found in casualty databases and are maintained by various organizations. The type of information maintained is usually determined by that organization's informational needs. Insurance related organizations, such as the classification societies, collect a range of data to help in the establishment of insurance rates. Governmental organizations collect data to help determine the need for, as well as tracking the effectiveness of regulations. Some large shipping companies collect data to assess their companies' performance. This information is usually proprietary.

An ideal historical fire and explosion database would consist of a complete listing of all casualties and significant near misses. Near misses being described as hazardous situations where all precursor events happen, that, but for some corrective action in the chain of events, did not result in the casualty. The database would provide detailed information on the casualty and its root causes, and list information regarding the events and operations leading up to the accident. Information on repair costs or its constructive lost value would also be included. The database would also list consequential losses, such as an oil spill that resulted from the incident.

With such a detailed casualty record on incidents and near misses, trends leading up to problem areas could be identified and possibly avoided. Problems associated with changes in technology, ship designs, and types of cargo carried can be identified earlier and intervention actions taken, such as new regulations or operating procedures.

GOAL OF DATABASES ANALYSES

Two databases were selected to be analyzed to establish the historical incident rates and trends. Their selection was based on the uniqueness of each. The first is the United States Coast Guard's Marine Safety Information System (MSIS) database. The second is Lloyd's Maritime Information Services Ltd's Casualty System (CASMAN) database. Both databases were queried for casualties/incidents that involved fire or explosions on vessels greater than 100 gross tons (g.t.). The vessel's size cut-off was established by the common regulatory size determination for commercial vessels. The following is a description of the individual databases.

MSIS DATABASE DESCRIPTION

The United States Coast Guard's Marine Safety field units have been populating this database since 1985. They input incident activity data for a range of safety related incidents. The incidents include fires, explosions, collisions, allisions, sinkings, loss of propulsion, loss of steering and marine pollution occurrences. The incidents included in this database are those in which the USCG has conducted an investigation for cause. These incidents meet the requirements of a reportable casualty criterion as defined in Title 46 of the Code of Federal Regulations (CFR).

The MSIS database was chosen for its coverage of US flagged vessels and all vessels in US territorial waters that require an investigation for cause. It includes incidents on vessels of any flag that occur within US waters. It includes incidents of US flagged vessels that occur outside US waters. The database covers all US navigable waterways, including lakes, rivers, bays, harbors, sounds, and the oceans out to the territorial limits.

Relevant attributes of the database are summarized in Table 1, which compares both databases (MSIS and Lloyd's) to an ideal data source. The MSIS database is very good at identifying a primary cause for each of the incidents listed. Very few of the records list "unknown" or have blank fields in the source column. However, it should be noted that the cause listed is generally not a root cause. The investigators generally do not have the time or possibly the expertise to analyze the incident to that degree of detail.

The MSIS database also includes a data field for documenting the location of the incident on the vessel. This aids greatly in the resolution of the causal analysis performed. It generally lists specific locations on the ship, i.e., engine room, bridge, and crew's cabin. It does not include detail location information, e.g., on top of no. 6 main engine cylinder head on starboard main engine. The level of detail in the information is generally sufficient for a coarse analysis of incident types and trends.

The MSIS database contains information about the amount of damage incurred and sometimes a dollar value estimate of the incident. If the damage to the vessel exceeds the value of the vessel, it is reported as a total constructive loss. While this reporting has an implied dollar value, there is insufficient information within the database to determine an actual dollar value of the loss.

Table 1 - Database Comparison

Attribute Included	Ideal Source	USCG MSIS	Lloyd’s
US flagged vessels	All	All	Some
Foreign flagged vessels	All	Some	Some
Incident’s primary clause	Always	Most	Some
Incident’s root cause	Always	Few	Very Few
Location of origin of incident	Always	Most	Most
Equipment or component involved	Always	Few	Few
Damage costs	Always	Most	None
Related consequences	Always	Few	Very Few
Deaths or missing persons	Always	Always	Always
Injuries	Always	Few	None
Vessel’s name	Always	Always	Always
Vessel’s flag of registry	Always	Always	Always
Vessel’s classification society	Always	Always	Always
Vessel’s registered gross tonnage	Always	Always	Always
Operational status at time of incident	Always	Most	Some

Deaths, missing persons, and injuries are also reported in the database. The number of deaths and missing persons is probably fairly accurate accounting. However, the reported injuries are probably a reporting of significant injuries that required external medical care. There is no quantification of the seriousness of the injuries. These could range from permanent disability to treatment of minor smoke inhalation.

The database contains information on the vessel itself. It contains the vessel's name, flag of registry, classification society, and its gross tonnage. Gross tonnage is a derived sizing of a vessel for registry and regulatory purposes. It is derived from a calculation of the available space to carry cargo or passengers and does not include propulsion or crew spaces. It does not directly correlate to deadweight tonnage, which is a measure of the weight of seawater it displaces. Analysis based on gross tonnage is appropriate for this analysis, as the potential end use of the decision will generally be a regulatory action.

LLOYD'S DATABASE DESCRIPTION

This database is maintained by Lloyd's Maritime Information Services Limited (LMIS). LMIS is a private limited company jointly owned by Lloyd's Register of Shipping, the world's oldest and largest classification society, and Lloyd's of London Press Limited, the wholly owned publishing and intelligence subsidiary of the Corporation of Lloyd's (Lloyd's of London). The database contains records of reported serious casualties to all propelled sea-going merchant ships in the world of 100 gross tons and above. The database contains incidents from 1 January 1978 for all vessel types and serious and non-serious incidents to tankers since 1 January 1975. The database is populated primarily from reports received daily from Lloyd's Agents and Lloyd's Register Surveyors who are situated in over 130 countries.

The database is considered by the maritime industry to be a good accounting of incidents on seagoing merchant ships of the world. It covers all the world's oceans and seas. It does not include military, recreational, and other non-merchant ships. It does not include ships on non-international, coastal or inland waterways. Table 1 summarizes the relevant database attributes that it contains.

As with the MSIS database, Lloyd's database contains information about the vessel (vessel name, flag, classification society, gross tonnage, and deadweight tonnage), propulsion type, as well as information about the vessel's owner. It contains information on the geographic location of the incident, vessel's status (moored, underway, etc.), and vessel's disposition (scrapped, returned to service, etc.). Also included is information on the number of persons killed or missing, but the database does not contain any information on injuries. The database also contains multiple text fields into which the incident can be described in more detail.

The incident records contained in the database are far from complete. Important data fields of some records were found blank. Individual fields may also be lacking adequate detail. For example, an incident description might contain no more detail information than "fire and sank." Therefore, analysis as to the causes of the incidents was not attempted. Despite shortcomings in some of its data, Lloyd's database is the most comprehensive compilation of the world fleet's casualties.

DATABASE ANALYSIS

The analysis approach described herein, attempted to use the strengths of the two databases and minimize the effects of their weaknesses. Since the Lloyd's database is believed to capture the types of incidents and types of vessels occurring worldwide, it will be used to help establish the historical analysis for the Coast Guard's efforts relating to international regulations. It is important to establish this type of information for the decision-makers because 90% of the port calls made in the US are made by foreign flagged vessels (Gilbreath, 1997). One of the Coast Guard's primary business areas is to maintain effective port state control.

For the Coast Guard's efforts affecting regulations on U.S. flagged vessels, the data contained in the MSIS database is more appropriate. These data as a whole cover all the types of vessels subject to the regulations. The database's percentage of incidents by vessel type differs significantly from the Lloyd's data. This is due to the differences in the incidents recorded in the databases. Lloyd's does not gather information on vessels making only coastal or inland waterway voyages. Lloyd's also looks only at merchant vessels, while the MSIS also includes recreational vessels of applicable size.

In the past ten years, there have been a number of significant changes to the international fire safety requirements, Safety of Life At Sea (SOLAS) regulations. These changes include the requirements for sprinkler systems in passenger vessel's accommodations and assembly spaces, adoption of the International Safety Management (ISM) code, and other changes. The full compliance dates for these changes vary, and some are not required for the next 5 to 10 years. Yet, these changes are already appearing in some vessels. Therefore, the database's time frame originally selected for this analysis was the last five complete years (1993 to 1997). Upon receiving the databases, it was found that three quarters of 1998 existed in the data from Lloyd's database. Almost the complete year of 1998 existed in the data from the MSIS database (except for potentially some incidents post-dated in early in 1999. The additional time was included in the analysis as it provided the most up to date and relevant information. This should increase the likelihood that improvements in vessels, due to implemented regulatory changes, will be evident.

Where information is available on the population of a type of vessel, the probability values for an incident have been calculated. Analysis of most of the Lloyd's database information includes probability values where appropriate. Given the uncertainty with population values for the 'fleet' that the MSIS database covers, no probability values have been determined.

Where appropriate, a Pareto analysis of the data has been performed to identify the categories with the highest probabilities of casualties. This analysis is displayed as Pareto diagrams. Pareto analysis is a prioritization technique that identifies the most significant items among many. The analysis employs the "80-20" rule, which states that 20% of the causes produce 80% of the effects. The technique can be used in both a system-level analysis as well as a component level analysis. The analysis technique is named for a 19th century Italian economist, Vilfredo Pareto. He observed that 80% of Italy's wealth was owned by 20% of the population.

The vessel types used for this analysis are tank, fishing, freight, passenger/ferry, tug/OSV, recreational, and another category for miscellaneous types. The tank vessel category consists of all bulk liquid carrying vessels. This includes crude and product oil tankers. It also includes chemical carriers. The fishing vessel category comprises of all types of vessels associated with harvesting food products from the sea. This includes trawlers, factory, processing, and freezer vessels. The freight category includes dry bulk cargo, general cargo, container, roll-on roll-off (RoRo) and refrigerated cargo. The passenger/ferry category includes all vessels whose primary function includes the transport of passengers across the water, including ferries which transport passengers with some cargo and vehicles. The tug/OSV category includes all vessels whose primary function is to transport other vessel types or offshore support vessels. Offshore support vessels include crew, supply, anchor handling, standby safety vessel, and other vessels associated with the offshore exploration and production of oil and gas. Recreational vessels are large privately owned vessels. Their size makes them fall within certain regulatory requirements. The MSIS database contains information on vessels in this category; Lloyd's database does not include this type of vessel.

LLOYD'S INCIDENTS ANALYSIS

The Lloyd's Casualty System (CASMAN) database query resulted in 782 fire and explosion incidents for the five and three quarters (5 ¾) of a year time frame. In 1993 the world fleet size was estimated to be 80,655 vessels as published in Lloyd's Register of Shipping World Fleet Statistics, 1997 (Lloyd's, 1997). The world fleet size was estimated to be 85,494 vessels for 1997. World fleet data for 1998 was not available during this analysis. The average increase in world fleet size per year was 1.4%. The median number of registered ships in the seagoing merchant world fleet for those years was 82,890 vessels. This results in a fire and explosion incident rate for the world fleet of 0.94 %. The breakdown of the incidents by type of vessel and the world fleet population can be seen in Figure 1. The incident rate per year and frequency of occurrence (incidents per week) is shown in Figure 2. It shows that there is an average frequency of a fire or explosion occurrence of 2.6 times per week for those years. There is no established increasing or decreasing trend evident during this period.

Figure 3 shows the cumulative incidents and frequency of occurrence for the seven vessel types used in this analysis. There are no data for recreational vessels in the Lloyd’s database, so none is shown in the figure. The frequency of occurrence is displayed as the number of days between incidents. Freight, tank, and fishing vessels clearly have the lowest number of days between occurrences. These high occurrence rates for these vessel types clearly identify them for further analysis.

Another method of assessing the fire and explosion incident rate is to calculate the percentage of vessels disposed of due to fires and explosions from the total number of vessels that have been disposed. Another way of saying this is, how many of the vessels removed from service were due to fires or explosions? Figure 4 shows the percentage of vessels disposal of by fires and explosions from the total number of vessels disposed of by type of vessel. The figure shows that passenger/ferry vessels and the “other” category of vessel types have larger percentages (12% and 10% respectively) of disposals from

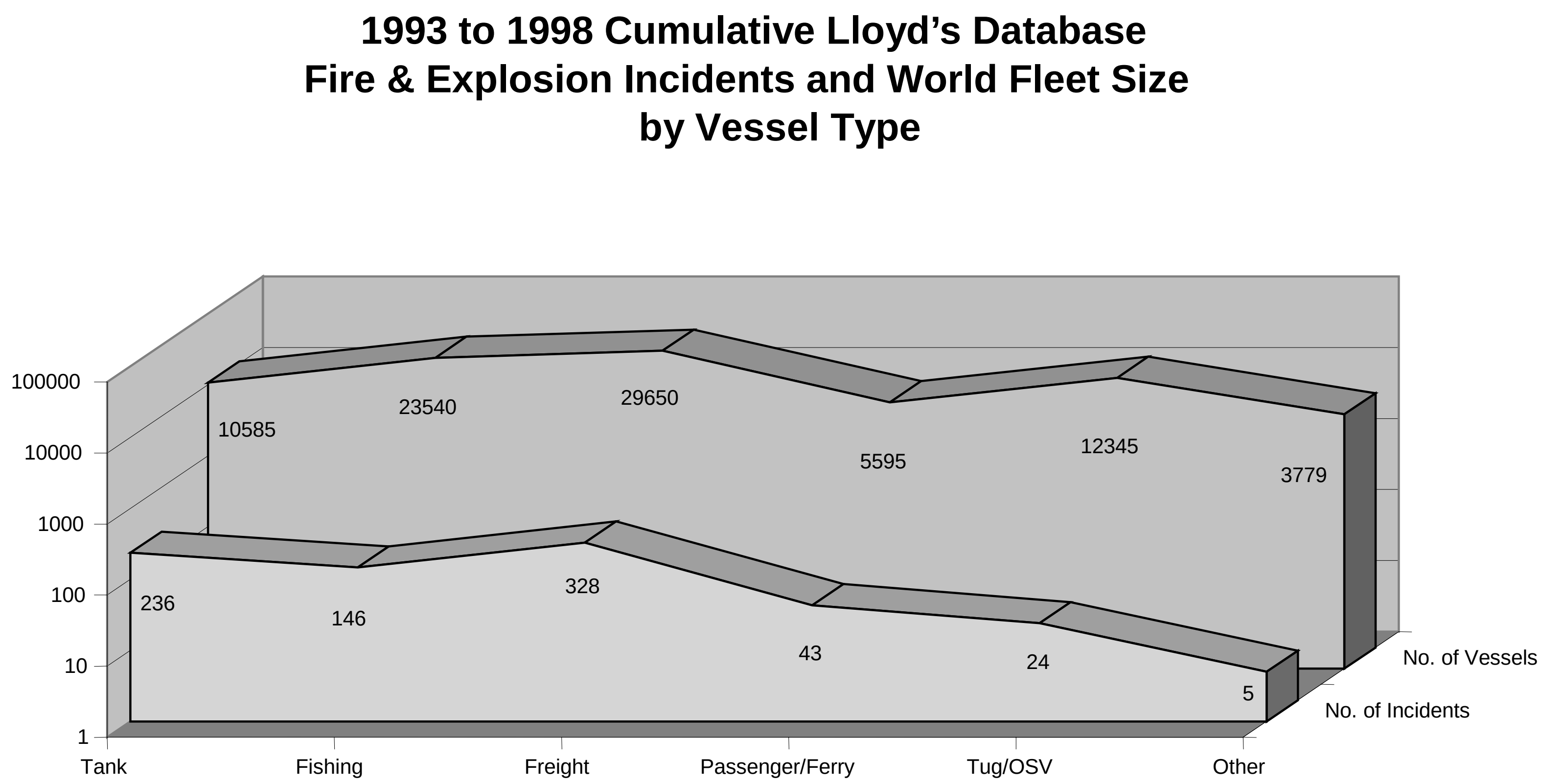


Figure 1– Lloyd's Database & World Fleet

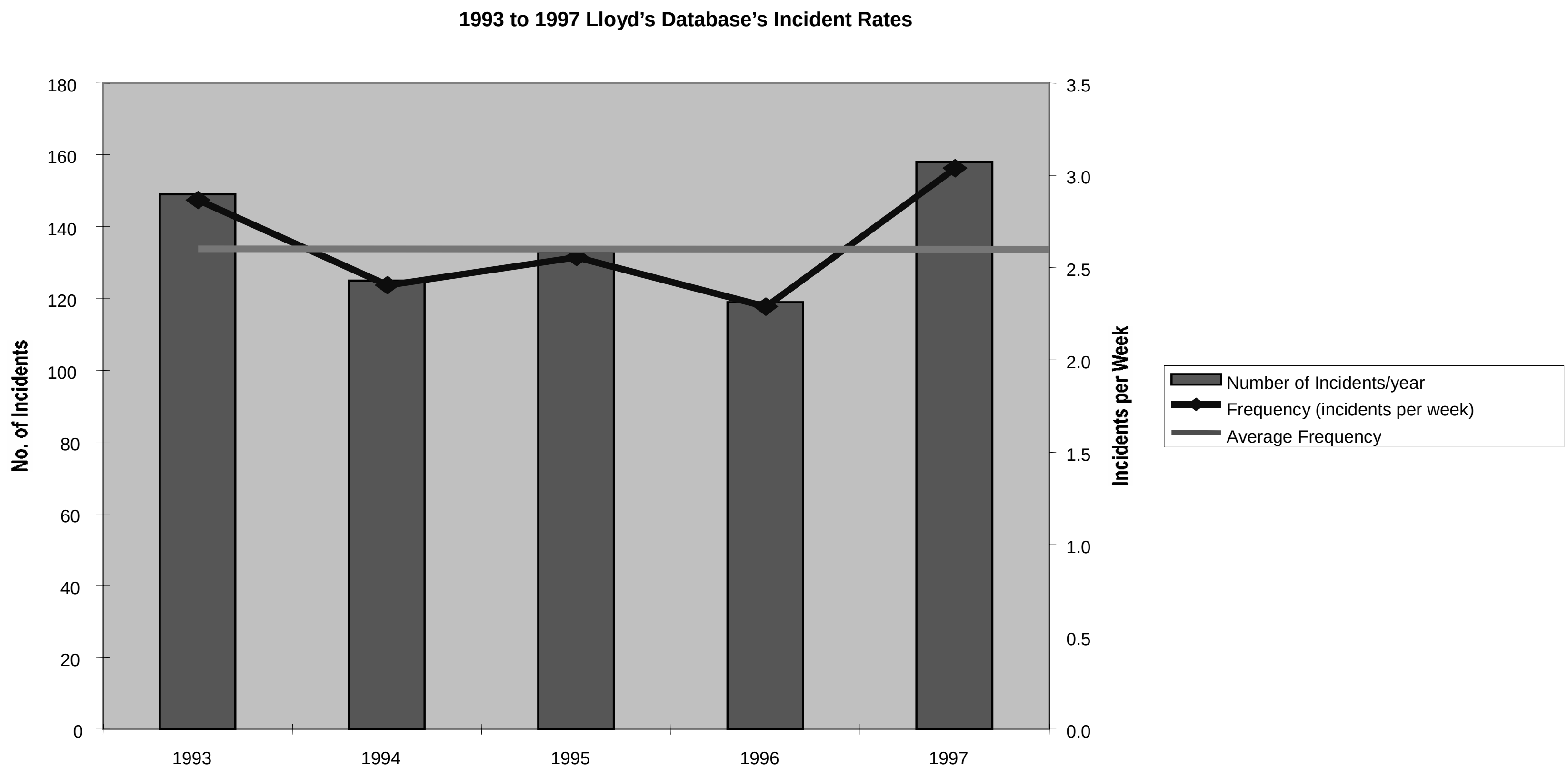


Figure 2 - Lloyd's Incident rates

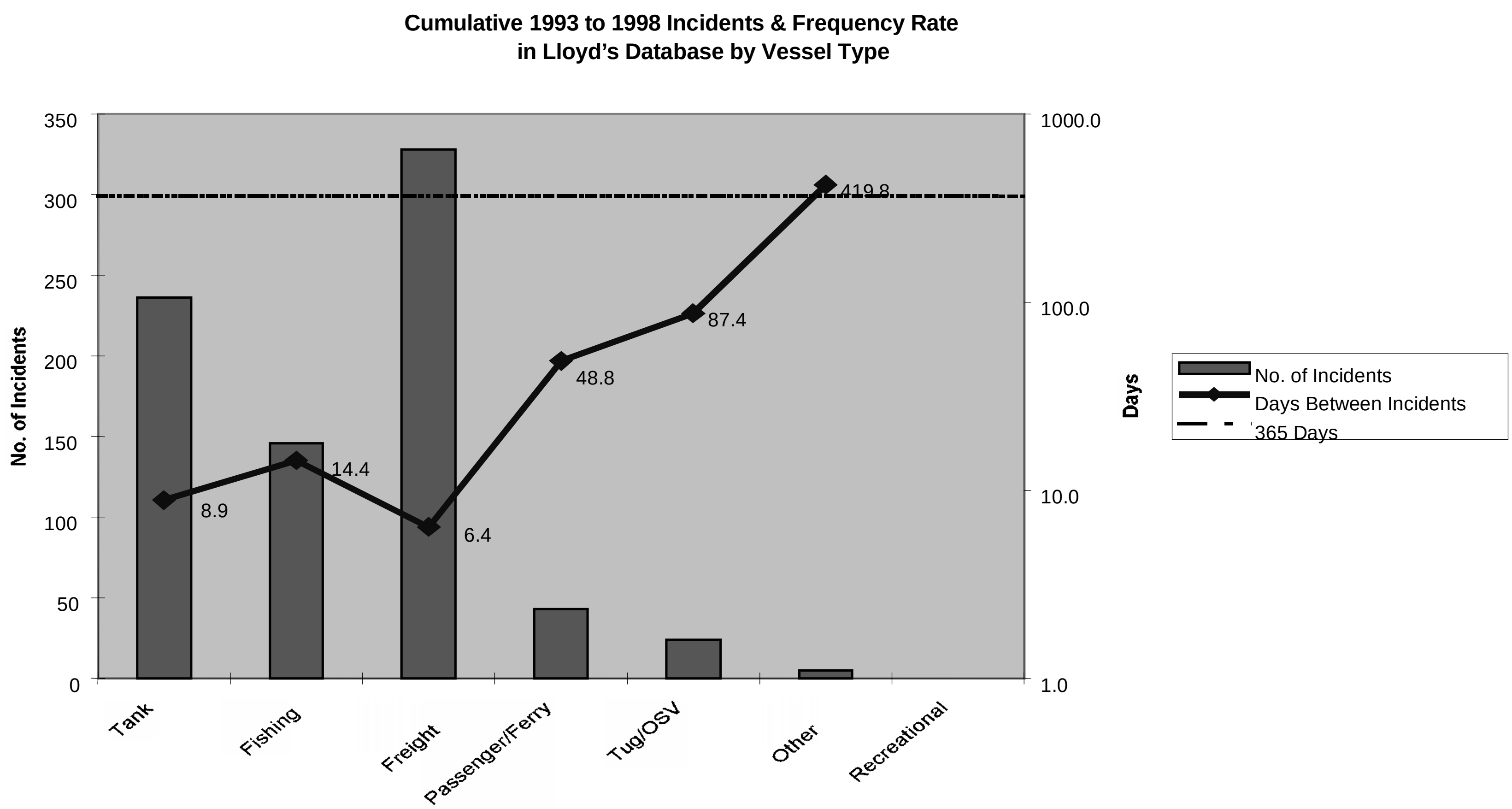
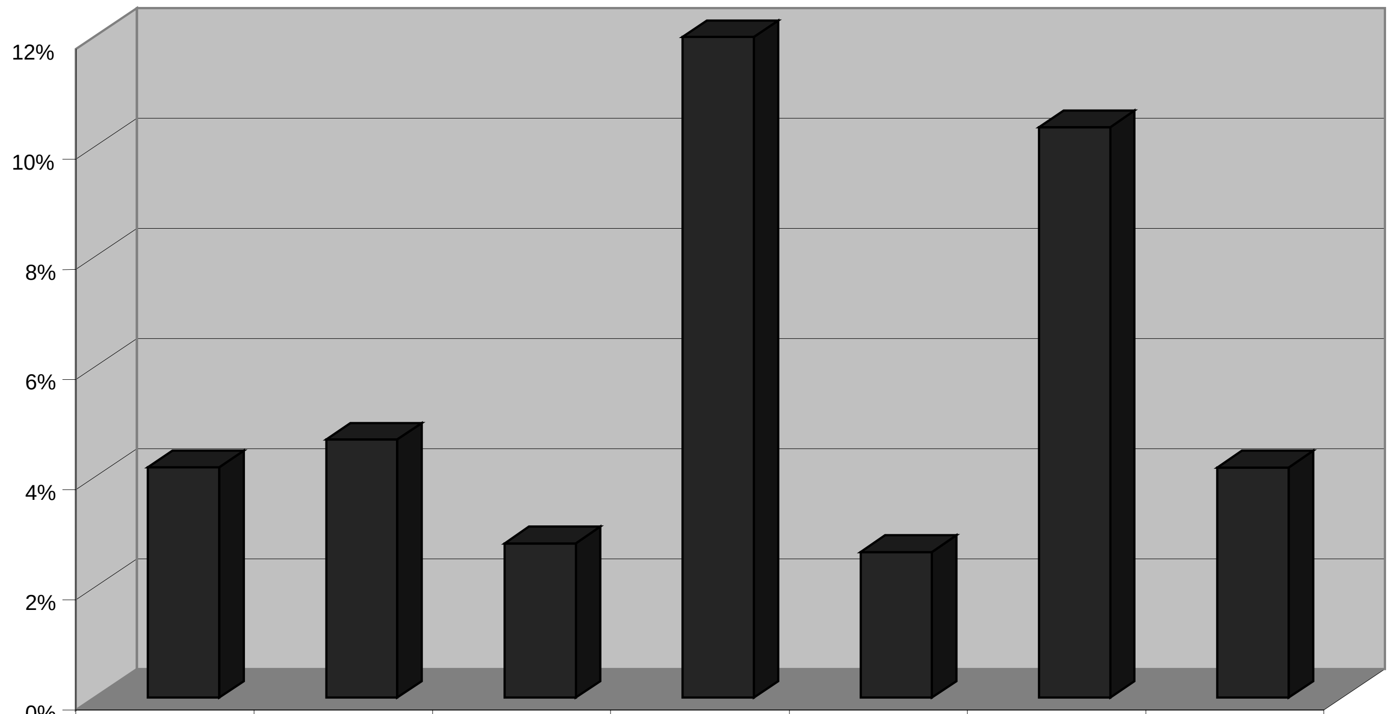


Figure 3 - Lloyd's Incident and Frequency Rates

Percentage of World Fleet's Vessel Disposals Caused by Fire or Explosion from Lloyd's Database by Vessel Type in 1997



	Tank	Fishing	Freight	Passenger/Ferry	Tug/OSV	Other	Total
Percentage of Disposal	4%	5%	3%	12%	3%	10%	4%

Figure 4 - Disposals by Fire & Explosions

fires and explosions. This area might warrant further investigation because the exact cause cannot be determined from the data.

The higher fire/explosion disposal to total disposal ratio for these vessel types cannot just be attributed to the lower overall population of these types vessels. It could be related to an actual higher fire and explosion incident rate these types of vessels are experiencing. Alternatively, it could be attributed to a higher demand for these types of vessels, which is causing a decreased disposal rate, as their service life is extended. Lloyd's Register of Shipping World Fleet Statistics, 1997, lists "25 years old and greater" category as having the largest number of vessels. This does lead to some credibility to the latter possibility. However, this data is only a one-year summary and doesn't reflect an actual trend. This issue will be brought out before the panel and their interpretation will be sought.

MSIS INCIDENTS ANALYSIS

The Coast Guard's Marine Safety Information System (MSIS) database query resulted in 1250 fire and explosion incidents for the full 6-year time frame, 1993 through 1998. The incident rate per year is shown in Figure 5. There appears to be a slight downward trend in the number of incidents per year. The trend, however, does not consistently decline, as can be seen by the small increase of six incidents in 1997. This is less than a three percent increase from the prior year.

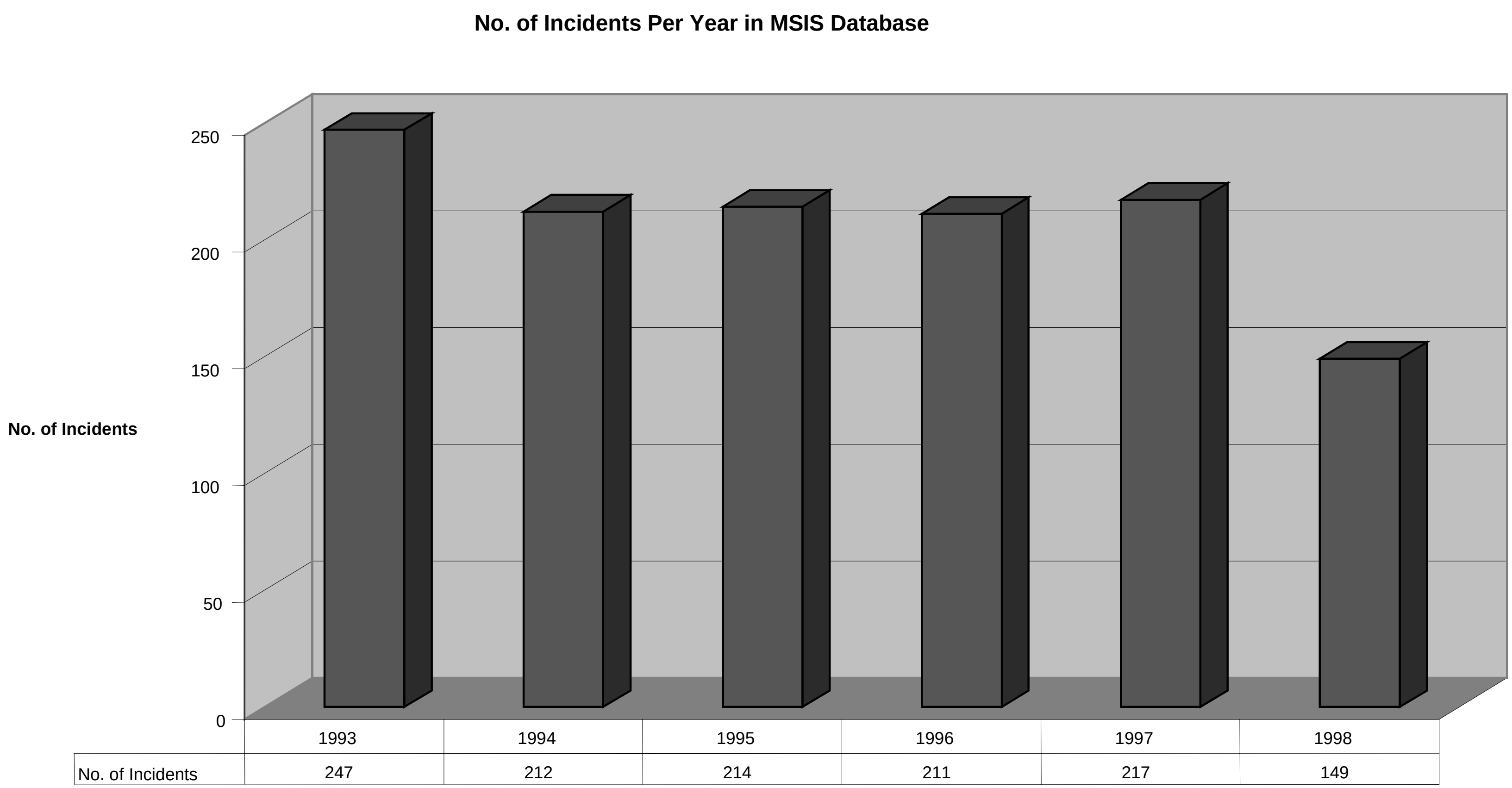


Figure 5 – Incidents per Year in MSIS Database

Due to the range of vessels, multiple flags and vessel registry requirements included in the MSIS database, there is no accurate way to estimate the size of the fleet of vessels from which these incidents result. A breakdown of the number of vessels by vessel type can be seen in Figure 6. It also shows a Pareto analysis graphic display of the incident types. The vessel type categories of Fishing, Tug/Tow, Passenger, and Freight make up nearly 80% of the reported incidents, with fishing vessels accounting for the largest percentage, 33.6%. Note the MSIS database does contain information on recreational vessels, not included in the Lloyd's database.

A comparison by the vessel types in the two databases cannot be easily made. A breakdown by vessel type as a percentage of each of the databases' incidents can be seen in Figure 7. In addition to the recreational vessel category, there are significant differences in all other vessel type categories. At first appearance, it would seem that the two databases are incompatible for analysis. However, despite the inherent difference in the kinds of vessels for which information is collected on in the two databases, comparisons can be made.

From the descriptions of the databases above, the differences in Figure 7 can be justified by the fact that the MSIS database includes a vessel type not in Lloyd's, as well as vessels making voyages explicitly excluded by Lloyd's. The inclusion of non-ocean going fishing vessels, passenger vessels, freight vessels, and tow vessels in the MSIS database certainly explains the differences for those vessel types. These non-ocean going vessels would include barges and the associated tow/push vessels, whose voyages are predominately on inland waterways and coastal routes.

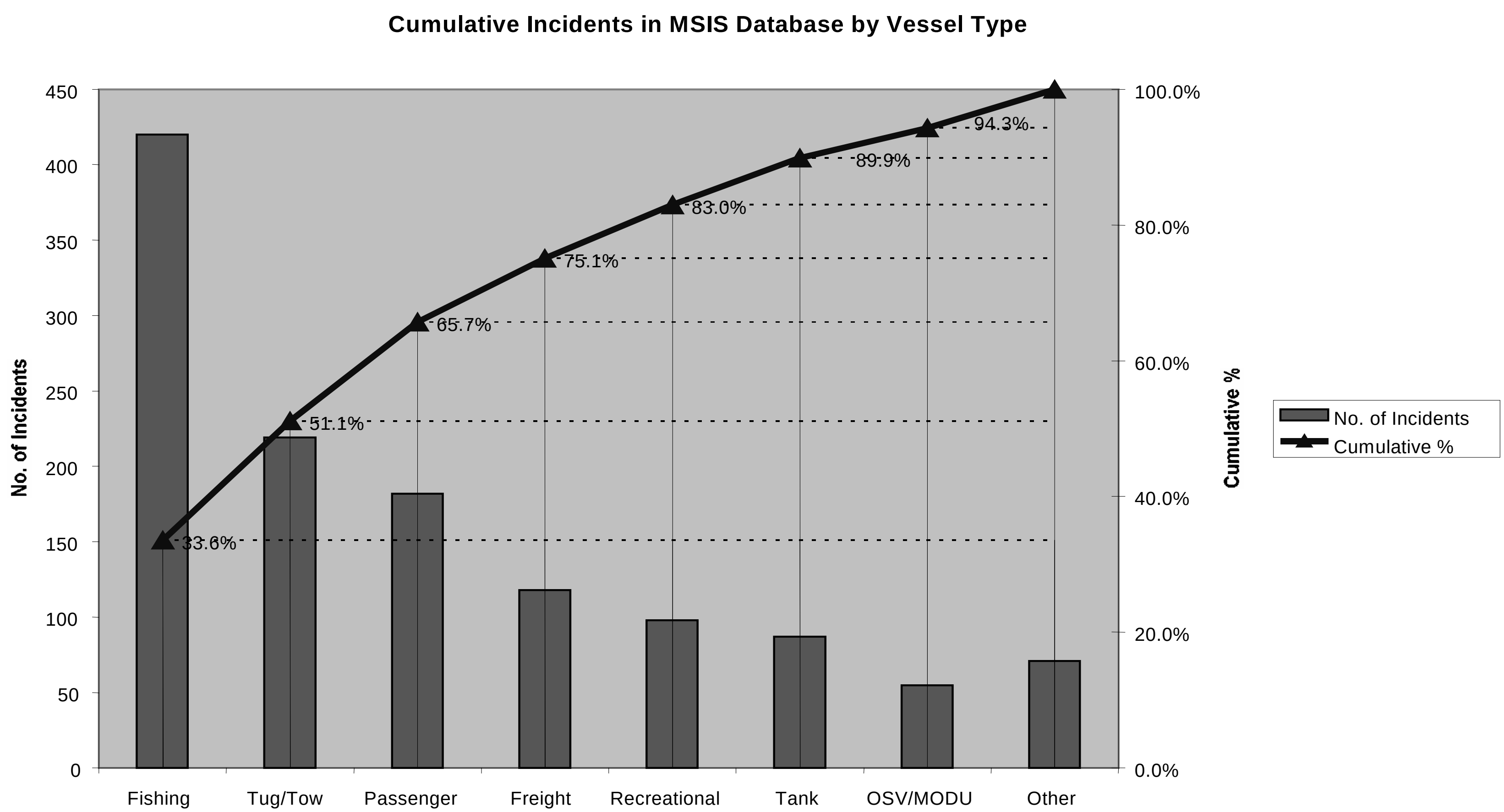
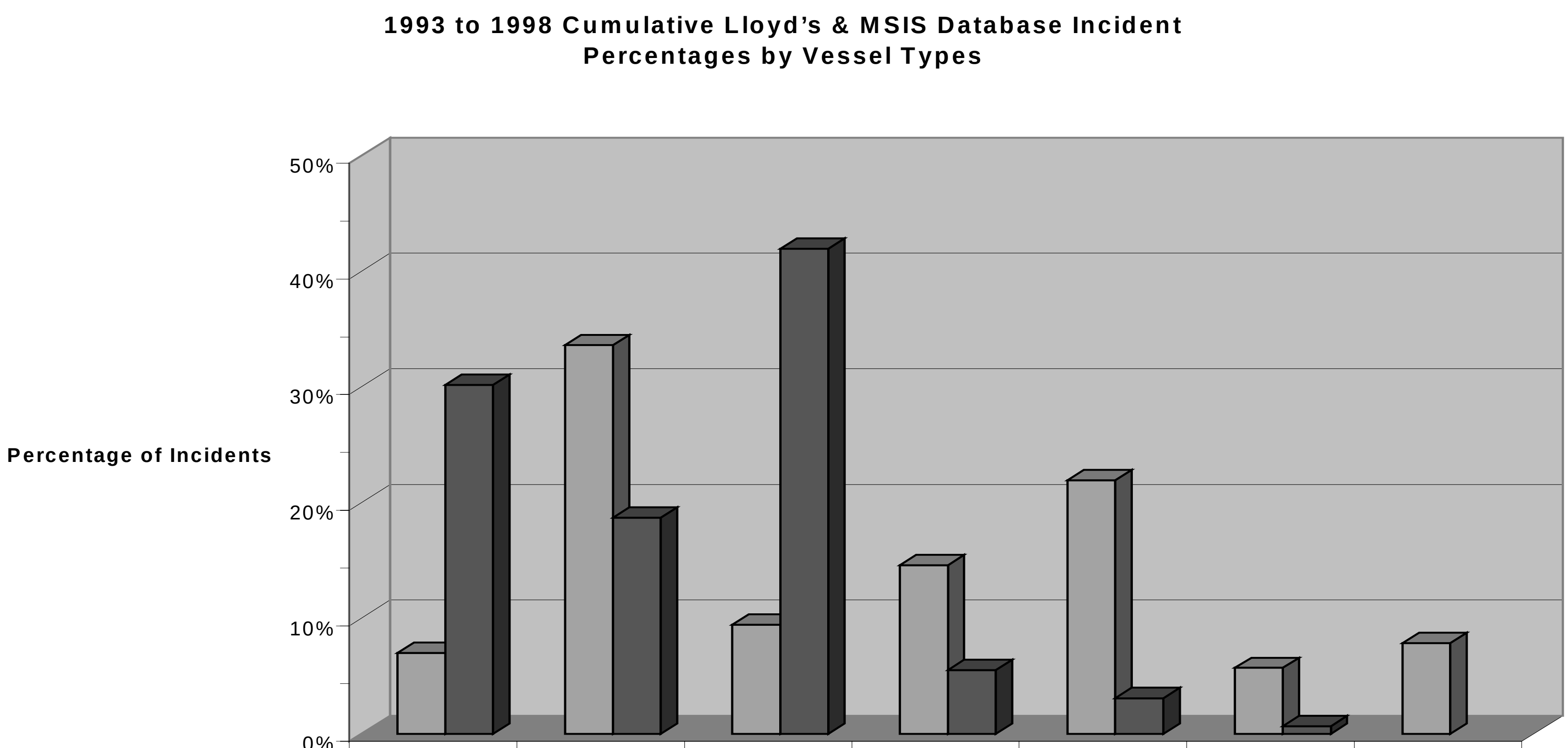


Figure 6 - MSIS Cumulative Incidents by Vessel Type



	Tank	Fishing	Freight	Passenger	Tug/OSV	Other	Recreational
MSIS Percentage	7%	34%	9%	15%	22%	6%	8%
Lloyd’s Percentage	30%	19%	42%	5%	3%	1%	

Figure 7 - MSIS & Lloyd’s Vessel Types by Percentage

The MSIS database includes a large population of passenger vessels that Lloyds does not include. This includes ferries, coastal excursion (e.g., cruises along the coast, and whale watching), and large dinner cruise or gaming vessels. The inclusion of these additional vessels in other vessel types changes the overall population, which affects the remaining types (e.g. tank vessels).

INCIDENT LOCATION ANALYSIS

The concurrence between the two databases becomes apparent when analyzing them for the locations of the initiation of the fire or explosion incident. Figure 8 shows the percentage of incidents by location in a Pareto diagram for the Lloyd's database. Pareto analysis shows that incidents in machinery spaces, cargo areas, and the undefined areas are the location of 86 % of the incidents. The largest majority of these, 51 % of the incidents, occurred in machinery spaces onboard the vessels.

Figure 9 shows the percentage of incidents by location in a Pareto diagram for the MSIS database. The Pareto analysis identifies machinery spaces and cargo areas as accounting for almost 75 % of the incidents' locations. Again, a majority of these, 57 % of incidents, occurred in machinery spaces.

For direct comparison of both databases, Figure 10 shows the percentages for each side by side. There is good agreement between the two databases for the initiating locations found. The percentage of unknown locations is higher in the Lloyds database due to the nature of the reporting method being less structured than that of the MSIS.

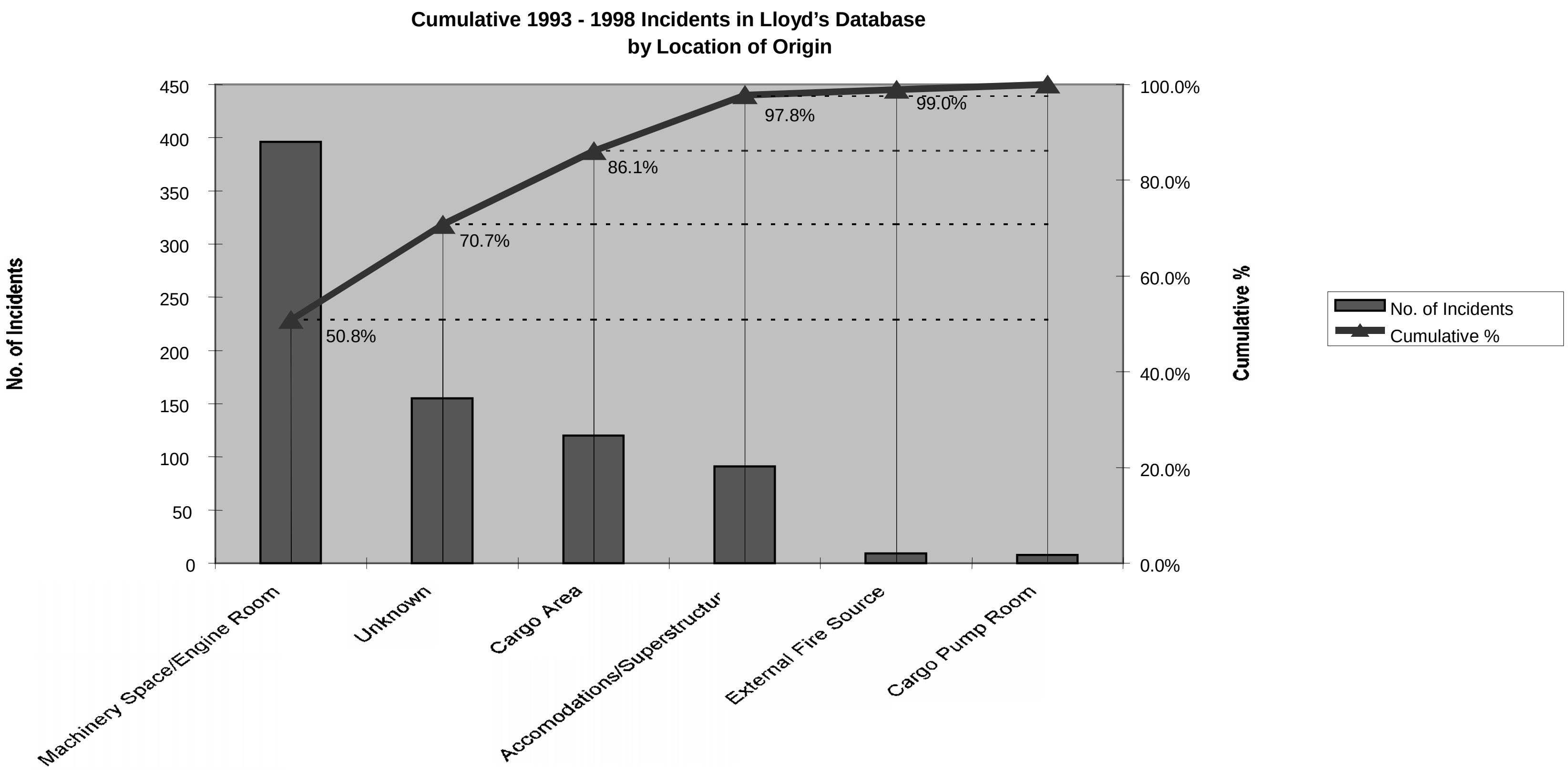


Figure 8 - Cumulative Lloyd's Database by Location of Origin

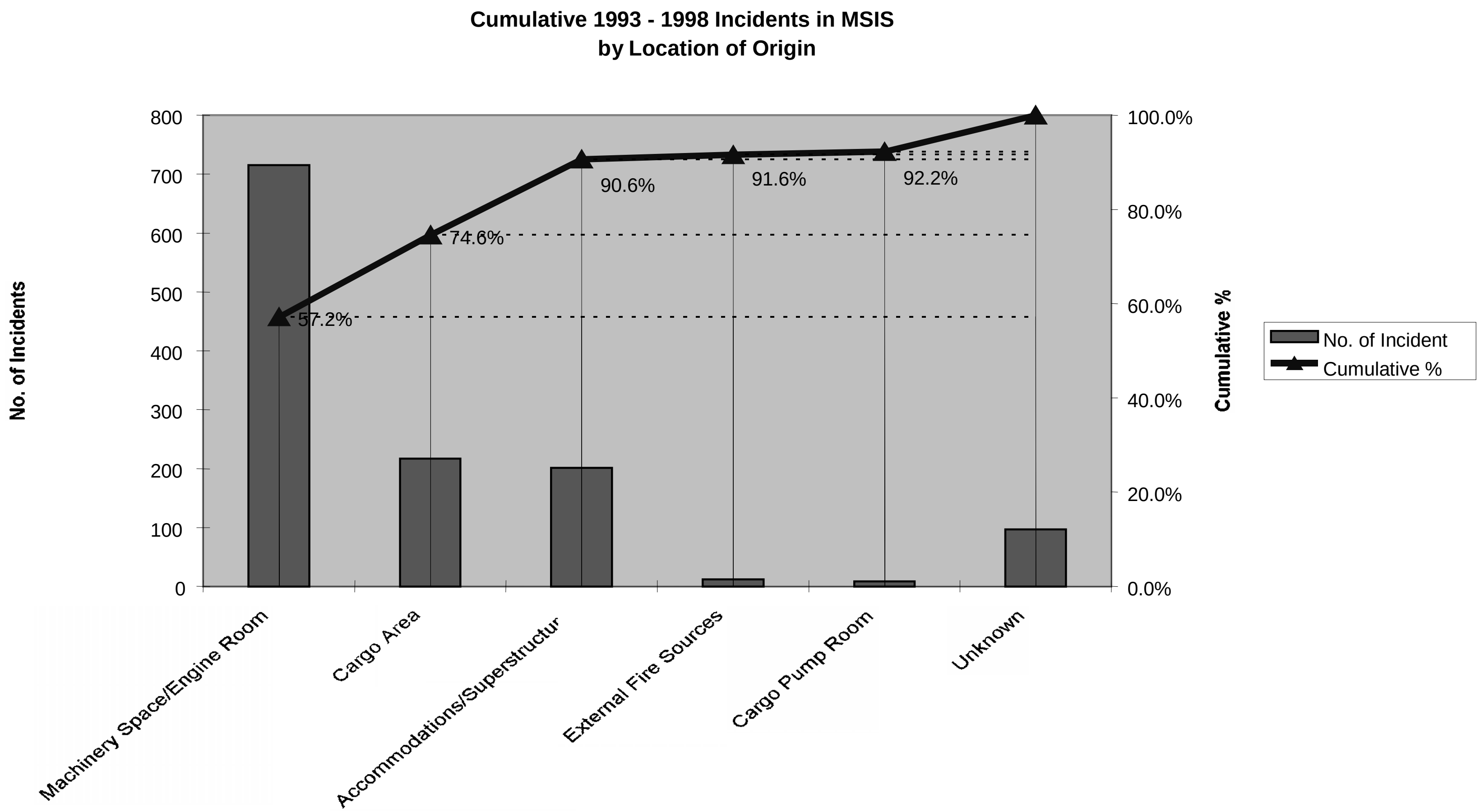
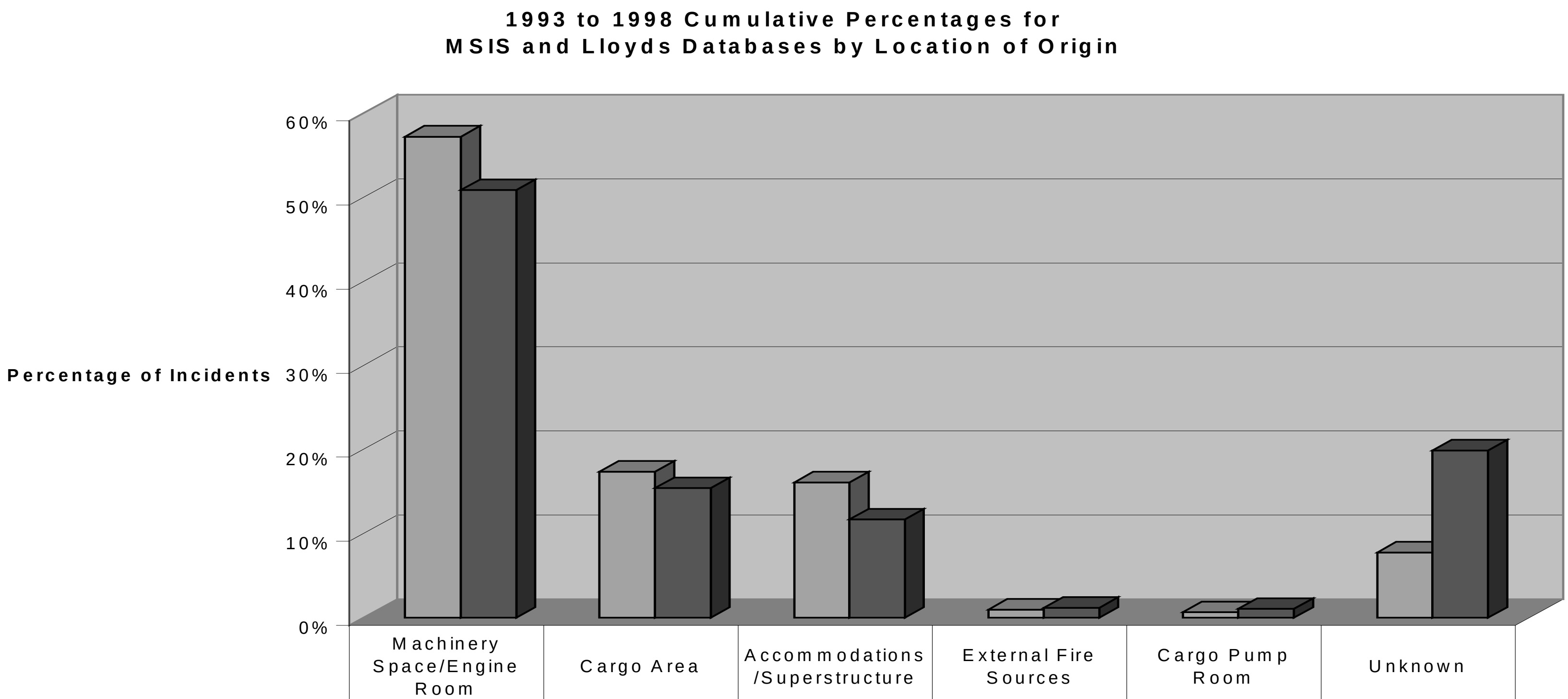


Figure 9 - Cumulative MSIS Incidents by Location of Origin



	Machinery Space/Engine Room	Cargo Area	Accommodations /Superstructure	External Fire Sources	Cargo Pump Room	Unknown
MSIS	57%	17%	16%	1%	1%	8%
Lloyds	51%	15%	12%	1%	1%	20%

Figure 10 - MSIS and Lloyd's Location Percentages

From this analysis, it is clear that a more detailed investigation into the causes of the incidents in machinery spaces, cargo areas, and accommodation areas is needed. Identification of ignition sources in each of these areas should identify any common causes.

INCIDENT IGNITION SOURCE ANALYSIS

The analysis of ignition sources for each of the three shipboard areas was only performed on the MSIS database. This database's level of detail into the causal factors facilitates this analysis. Therefore, the following discussion will be based upon the data in the MSIS database. Due to the concurrence of the data from the Lloyd's database with regard to location of origin, the findings from the MSIS analysis should be applicable to both.

Machinery Space Sources

Analysis shows that the location on all the vessels where a majority of the incidents of fires or explosions initiated is the machinery spaces. Analysis for the specific ignition source types in the machinery spaces revealed they can be broken down into five categories. They are heated/hot surfaces, electrical, internal to machinery, welding/hot work, or unknown. The percentages of these categories can be seen in Figure 11.

Heated and hot surfaces account for 45% of the ignition sources. These typically involve a spray or spill of flammable liquid onto a heated or hot surface where the surface's temperature is high enough to support auto-ignition of the liquid (typically

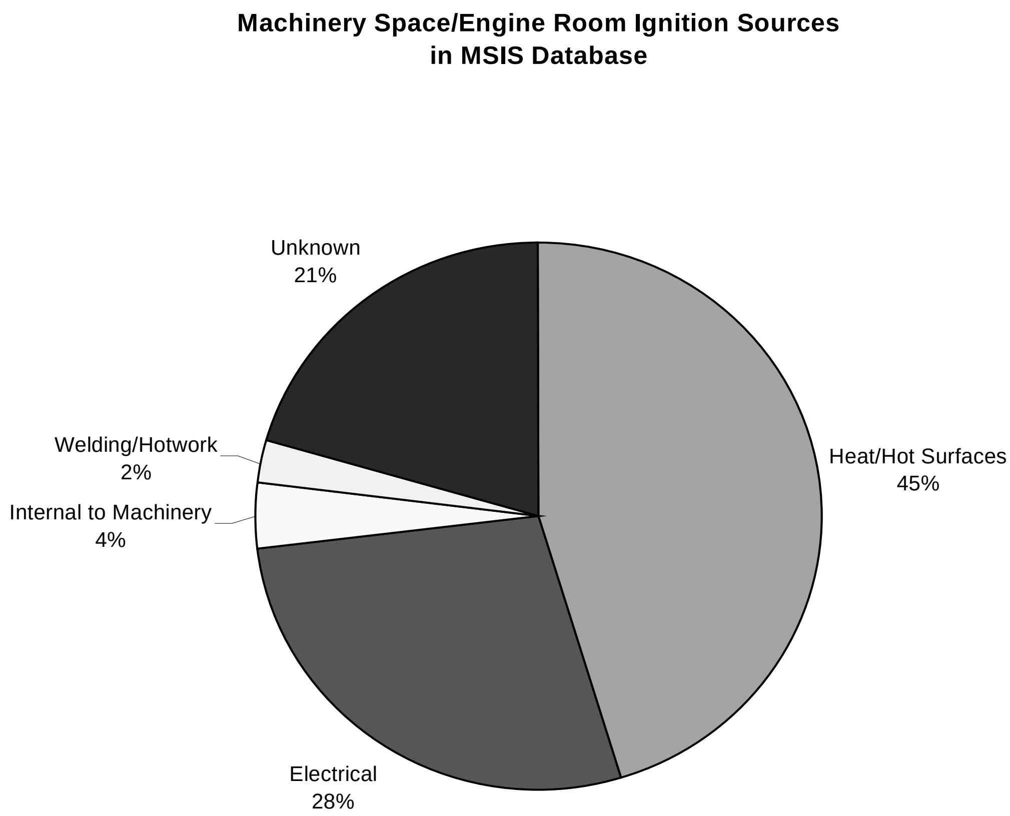


Figure 11 - Machinery Space Ignition Sources

450^{o}C for most liquid hydrocarbons). Figure 12 shows the breakdown of the different types of hot surfaces found in the incidents. The surfaces are engine casings or the engines' exhaust manifolds, at 62%. Hot exhaust piping and/or exhaust stack gases account for 27%. Another 10% are friction-heated surfaces, such as clutches or brake pads. One percent does not fit into any of these three source types.

Electrical accounted for 28% of the sources as seen in Figure 11. There are two primary ignition mechanisms under the electrical category. They are shorts/overheating of electrical components and ignition of a flammable or combustible liquid/vapors by an electrical component. The ignition of the liquid or vapors is usually from a spark, e.g., from a motor's brushes or relay contact shutting, and not from the heat of the item. The percentages of each of these can be seen in Figure 13. Shorts and overheating account for over two thirds (67%) of these electrical sources.

Cargo Area Sources

Incidents originating in cargo areas were the second highest location found in the MSIS database. They accounted for 17.4 % of the incidents. An analysis of the sources of ignition for cargo area incidents found eight common sources and a group of unknown incidents. Figure 14 shows the result of that analysis. Electrical shorts and/or sparks accounted for 21% of the sources, followed closely by hot work and/or welding at 20%. Unknown sources accounted for 21% of the incidents. Hot surfaces or sparks from an exhaust were attributed to 13%. Arson or crew attributed (cigarettes, etc.), static electricity/lightening, cargo explosion/fireworks, chemical reaction, and an external

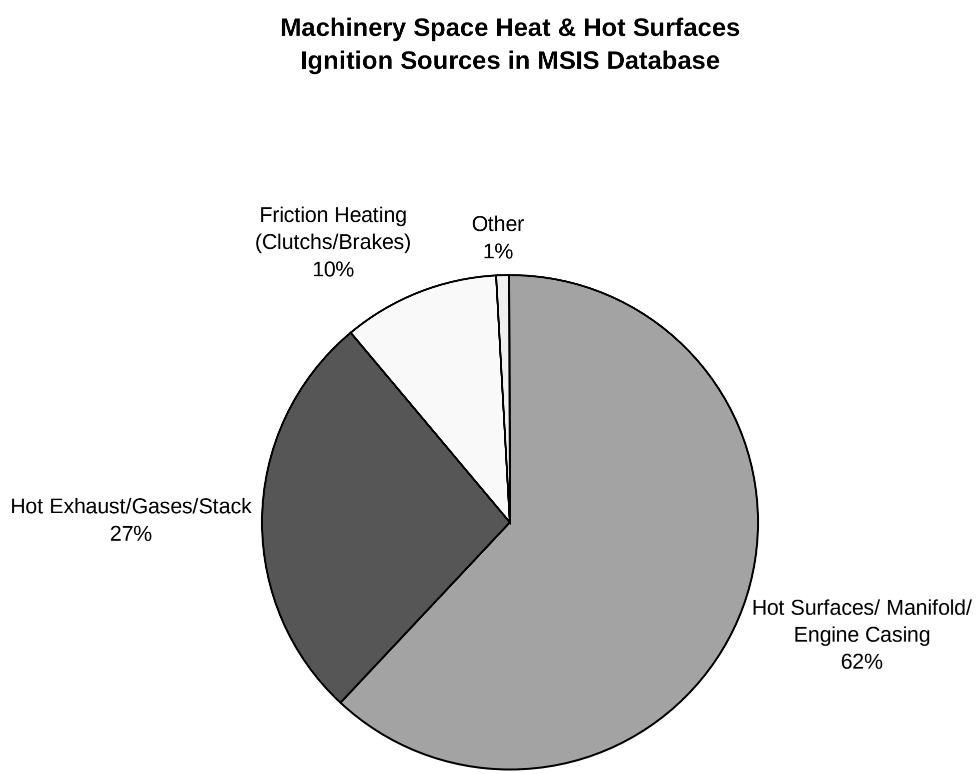


Figure 12 - Machinery Space Heat/Hot Surfaces Ignition Sources

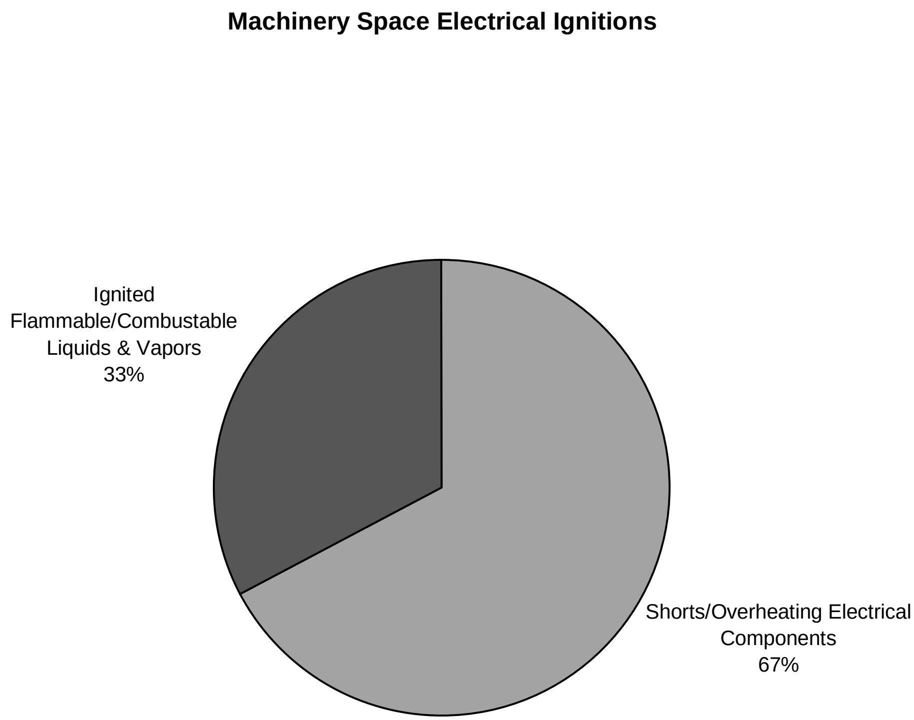


Figure 13 - Machinery Space Electrical Ignition Sources

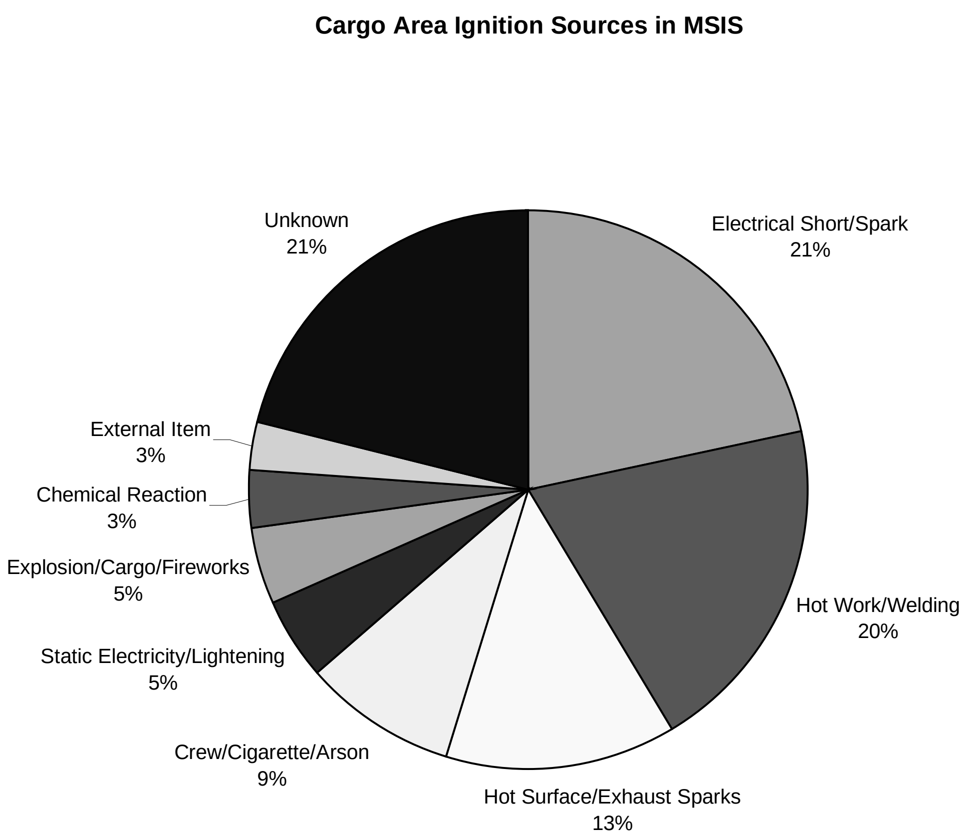


Figure 14 - Cargo Area Ignition Sources

ignition source (another vessel, shore facility, burning surface spill, etc.) were the groupings of the other common sources identified.

An analysis to determine which vessel types were accounting for these cargo area fires resulted in finding that fishing and freight vessels both accounted for 22% of the these incidents. This can be seen in Figure 15. Tank, recreational, tug/OSV, and passenger/ferry accounted for nearly an equal percentage of the remainder of vessel types. Cargo areas listed in the database for recreational vessels are assumed to be ship's stores.

Accommodation Space Sources

Fire and explosion incidents in accommodation and superstructure spaces were the third highest location in the MSIS database. They accounted for 16.0% of the incidents. Analysis for the sources found seven common sources and a grouping of unknown sources. Figure 16 shows those results. As with the cargo area incidents, electrical shorts and sparks were the leading source. They accounted for 31% of the incidents. Galley and cooking incidents were the second highest source at 25%. Unknown sources accounted for 19% of the incidents. Arson or crew attributed (cigarettes, etc.), hot work/welding, portable heaters, exhaust stacks, and external ignition sources (another vessel, shore facility, burning surface spill, etc.) were the groupings of the other sources identified.

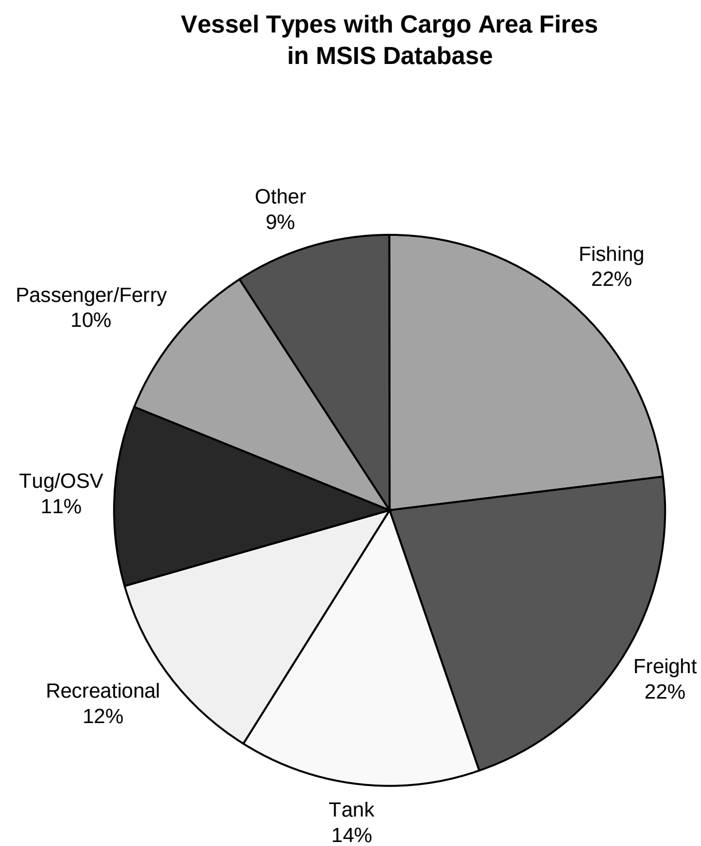


Figure 15 - Vessel Types with Cargo Area Incidents

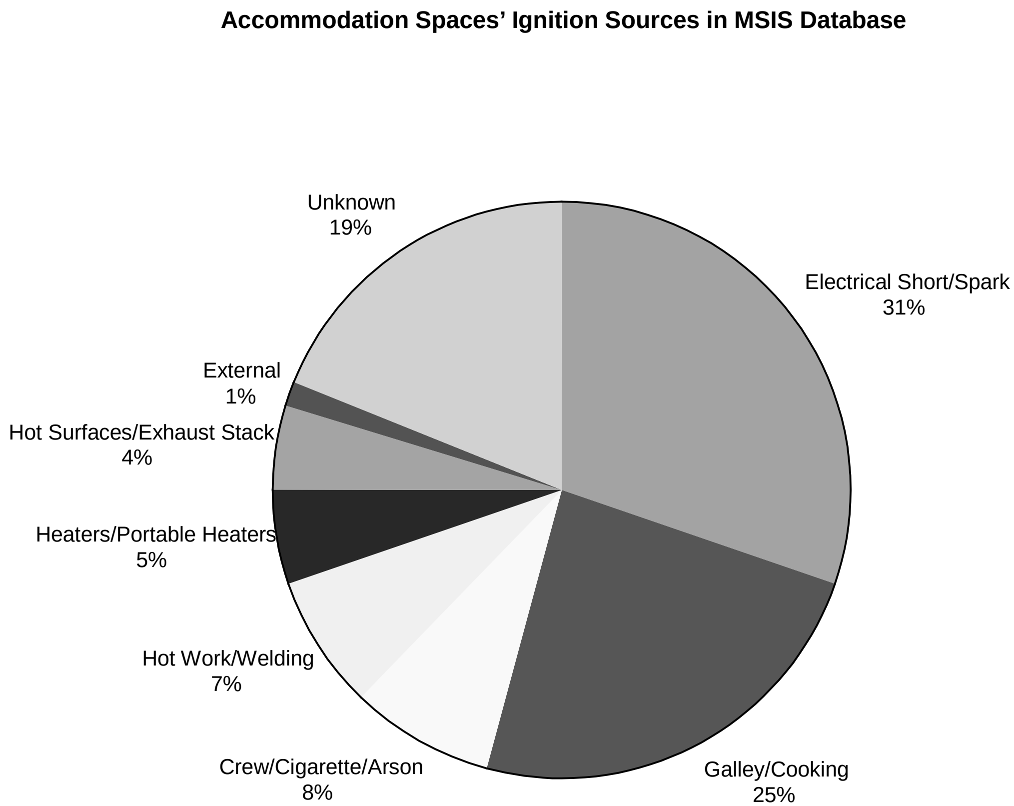


Figure 16 - Ignition Sources within Accommodation Spaces

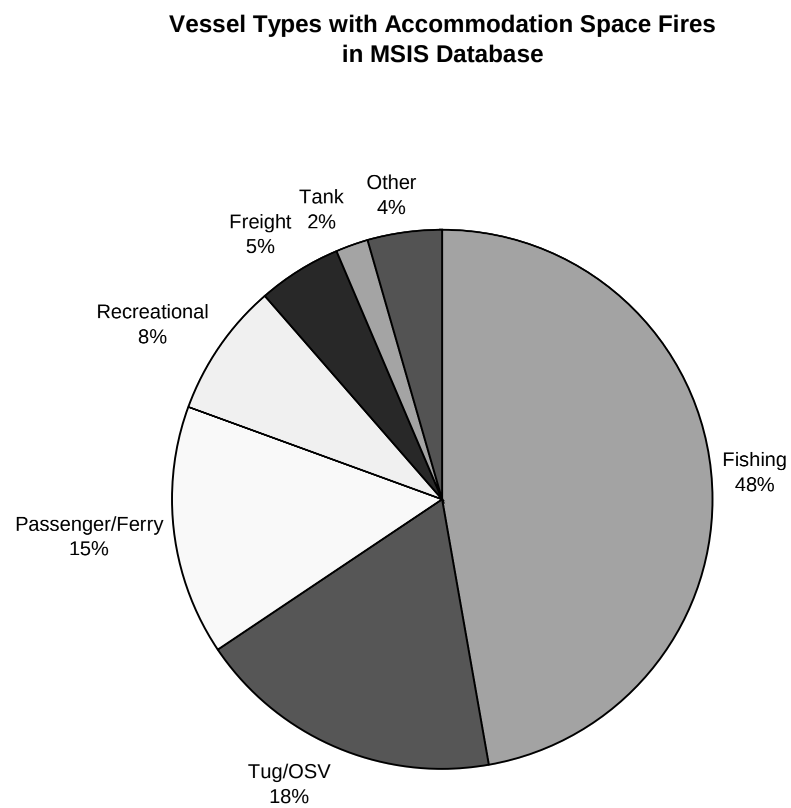


Figure 17 - Vessel Types with Accommodation Spaces Fires

A vessel type analysis to determine which sources were accounting for these accommodation and superstructure fires was performed. Figure 17 show the results of that analysis. Fishing vessels account for nearly half (48%) of the incidents. Tug/OSV and passenger/ferry vessels account for nearly equal percentages (18% and 15% respectively). Recreational, freight, tank and other vessels make up the remainder.

The ignition source analysis for machinery spaces indicates that heat/hot surfaces and electrical are the most common ignition source types. Further analysis of heated/hot surfaces indicates that the surfaces on engines, their manifolds, and their exhaust stacks account for a majority of those ignition sources. Analyses of the electrical ignition sources indicate that a majority of these are shorts and overheating of electrical components. For cargo area and accommodation/superstructure location incidents, analyses indicate that the electrical shorts or sparking, galley/cooking sources, and hot work/welding sources account for the majority of the incidents.

RISK ANALYSIS

Basing a decision on just the number of incidents or the differences in percent make-up of the incidents does not give a complete representation of the situation. There may be a large number of incidents on a certain type of vessel, but these incidents have a very low consequence (damage cost). These incidents would not be of greatest interest from the regulatory standpoint. Therefore, the decision model should include a calculation of the risk associated with the alternatives being considered. Risk is defined as the product of the probability of occurrence times the consequence of the occurrence.

From the standpoint of the Coast Guard decision-makers, risk would be the probability of a casualty occurring times the consequence (cost of the loss) of the casualty.

Any decision-making model should include the use of the best “expert opinion” available to make the risk calculation. In this model, the best expert opinion on the probability and consequences each lie within the separate databases. Trying to calculate the risk by vessel types therefore would consist of combining incongruent data. Due to the different populations in the two databases, combining the probability of one and the consequence of the other would be meaningless.

The Lloyd’s database in conjunction with Lloyd’s World Fleet data contains the best “expert opinion” on the probability of fire or explosion incidents occurring onboard different types of ships. It does not, however, have the costs of damages incurred.

The MSIS database contains the best available “expert opinion” on the consequence of casualties. The damage values associated with the incidents in the database provide the best assessment of the losses incurred. However, due too the lack of information of the total population of vessels covered, MSIS generated information lacks the probability of incidents occurring information.

Given this lack of total population data, the probability used in the risk calculations will be a conditional probability. The condition chosen is that a fire occurs on a vessel covered in the population of vessels covered by the MSIS database. What are the probabilities of it: it occurring on a given vessel type, it occurring in a given location, and it occurring due to a given ignition source.

CONSEQUENCE ANALYSIS

The MSIS database has the most useful information regarding the consequences of the fire and explosion incidents. It provides information on the number killed or missing as well as the number injured. It also lists the estimated value of the losses. There are numerous incidents where estimated value is not available, so there is a fair amount of uncertainty associated with these loss values. Due to the uncertainty with the information, it is estimated that values could be off by up to 50%. No additional information source could be found to substantiate or contradict these values.

The Lloyd's database lists if the vessel was scrapped or lost, but does not provide any information on the value of the scrapped or lost vessel. It does provide information on the number of persons killed in the incident. It does not list any missing persons (they are probably presumed dead and listed as such) nor injury information for the incidents.

There were 46 deaths reported for the 6-year period in the MSIS database. There were 4 persons listed as missing and 322 persons injured. The death and missing rates for each of the six years is shown in Figure 18. By the wide variation in the numbers from year to year, there is no general trend to these numbers.

The total reported estimated damage for the incidents in the MSIS database for the 6-year period is almost $228 million. This equates to over $182,000 per report incident. The estimated value of the damages per year is shown in Figure 19. There is an overall trend towards declining losses. Figure 20 shows a trend analysis of the loss rates for that period. There appears to be a general decline of approximately $9 million dollars per year. This is not a consistent decline, as seen by the variation in the year 1996.

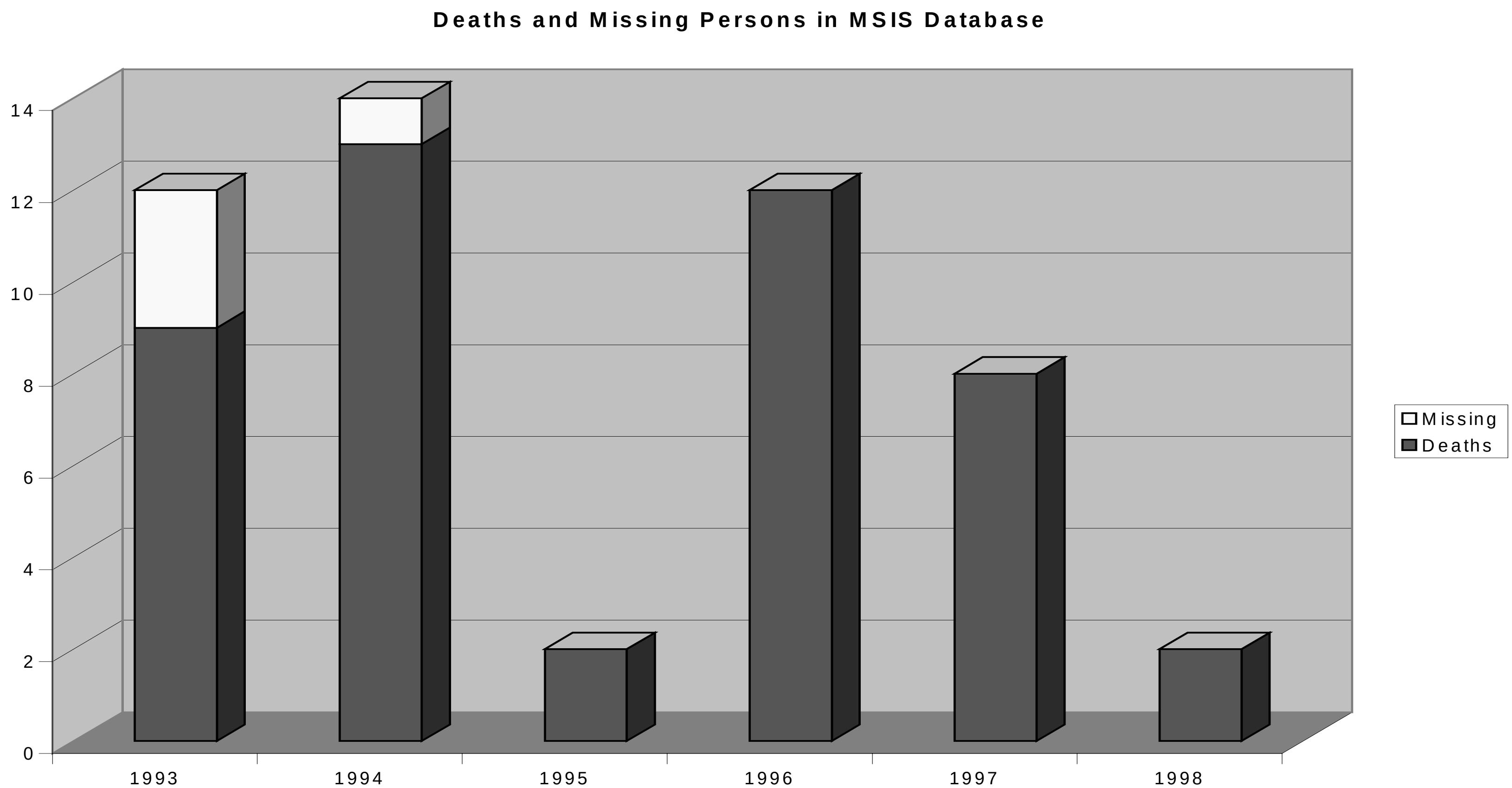


Figure 18 - Deaths and Missing Persons in MSIS

Estimated Value of Damage in MSIS Database

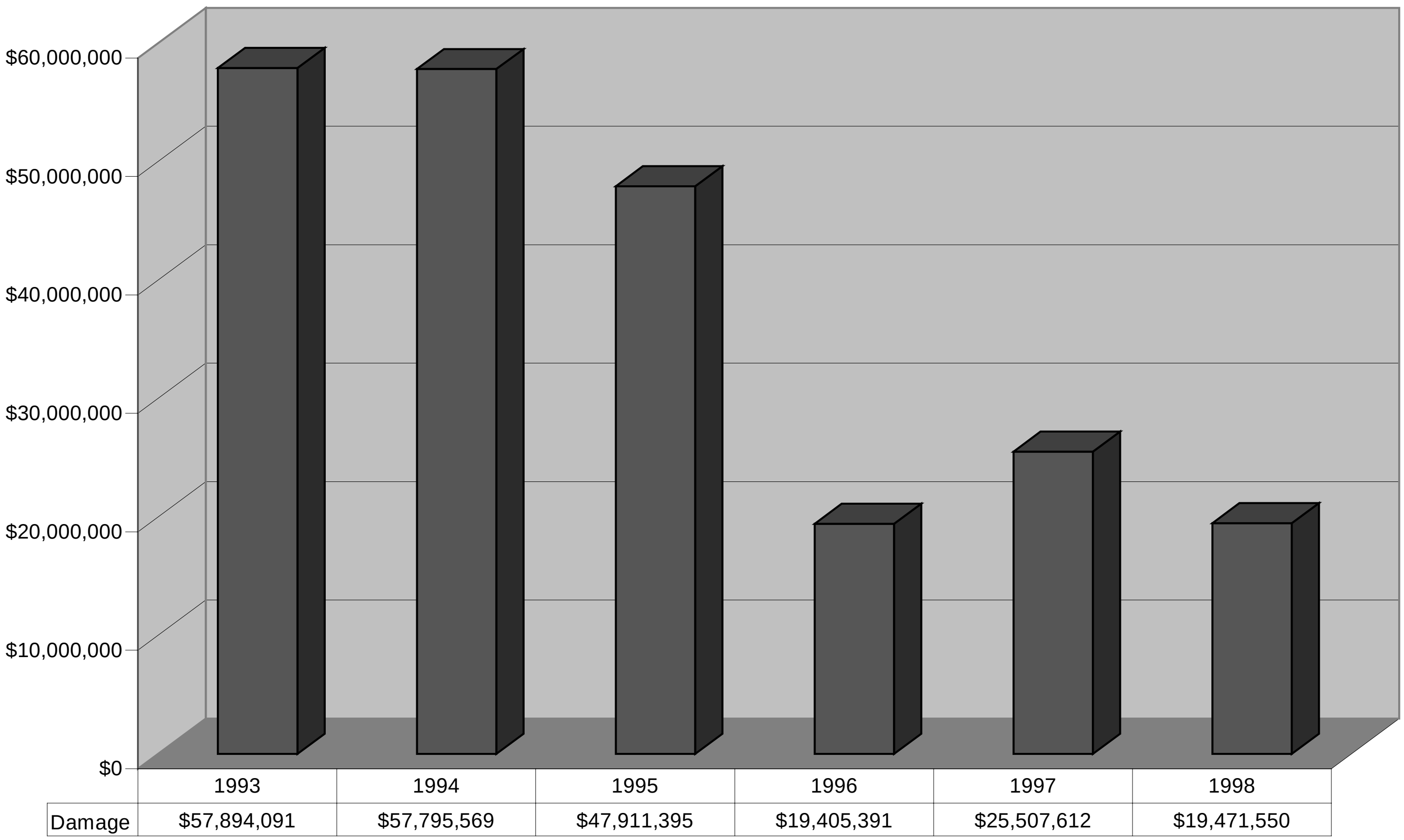


Figure 19 - Estimated Damage Value from MSIS

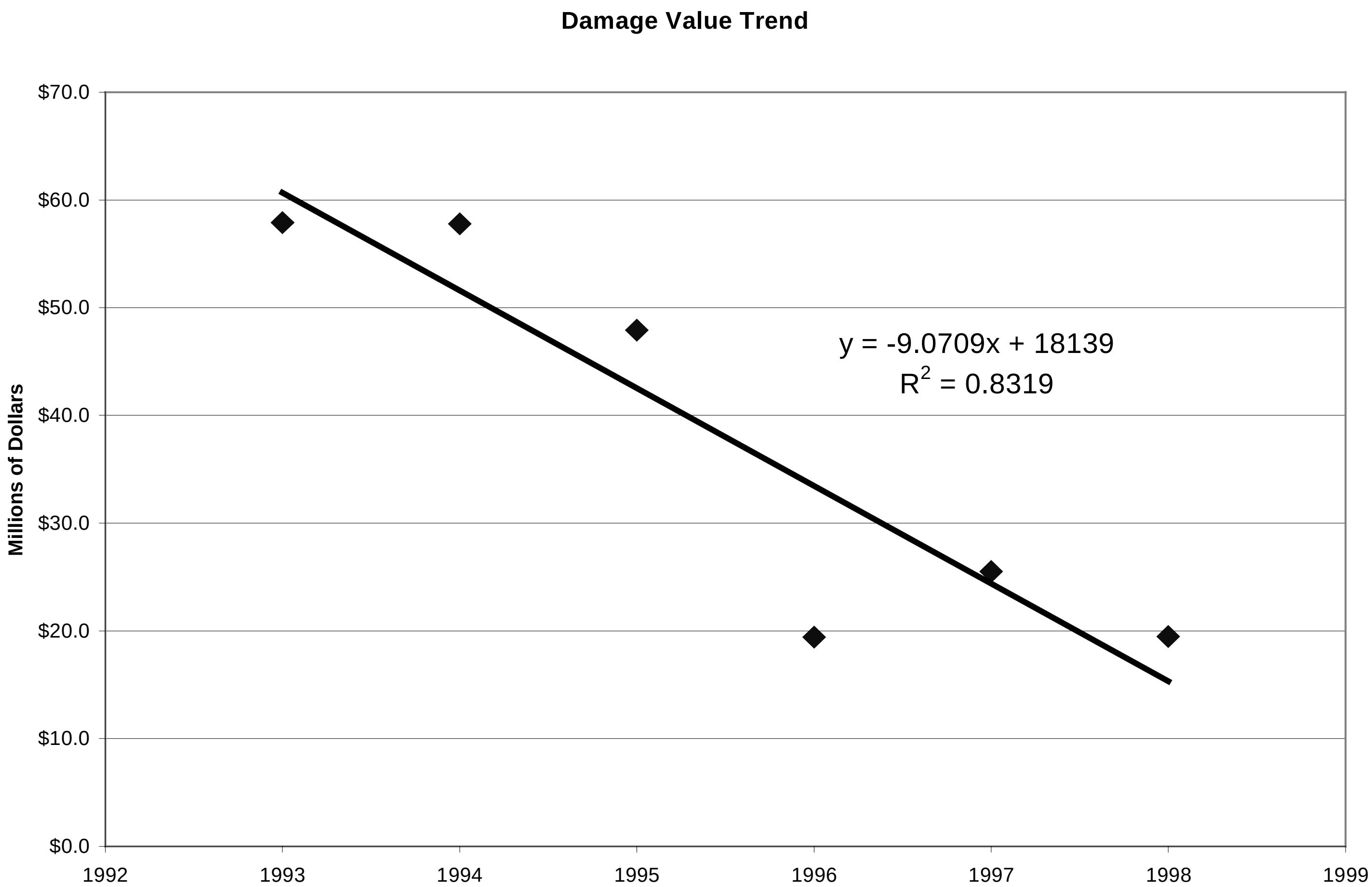


Figure 20 - Damage Value Trend Analysis

However, as stated above, there is significant uncertainty to these data due to missing data.

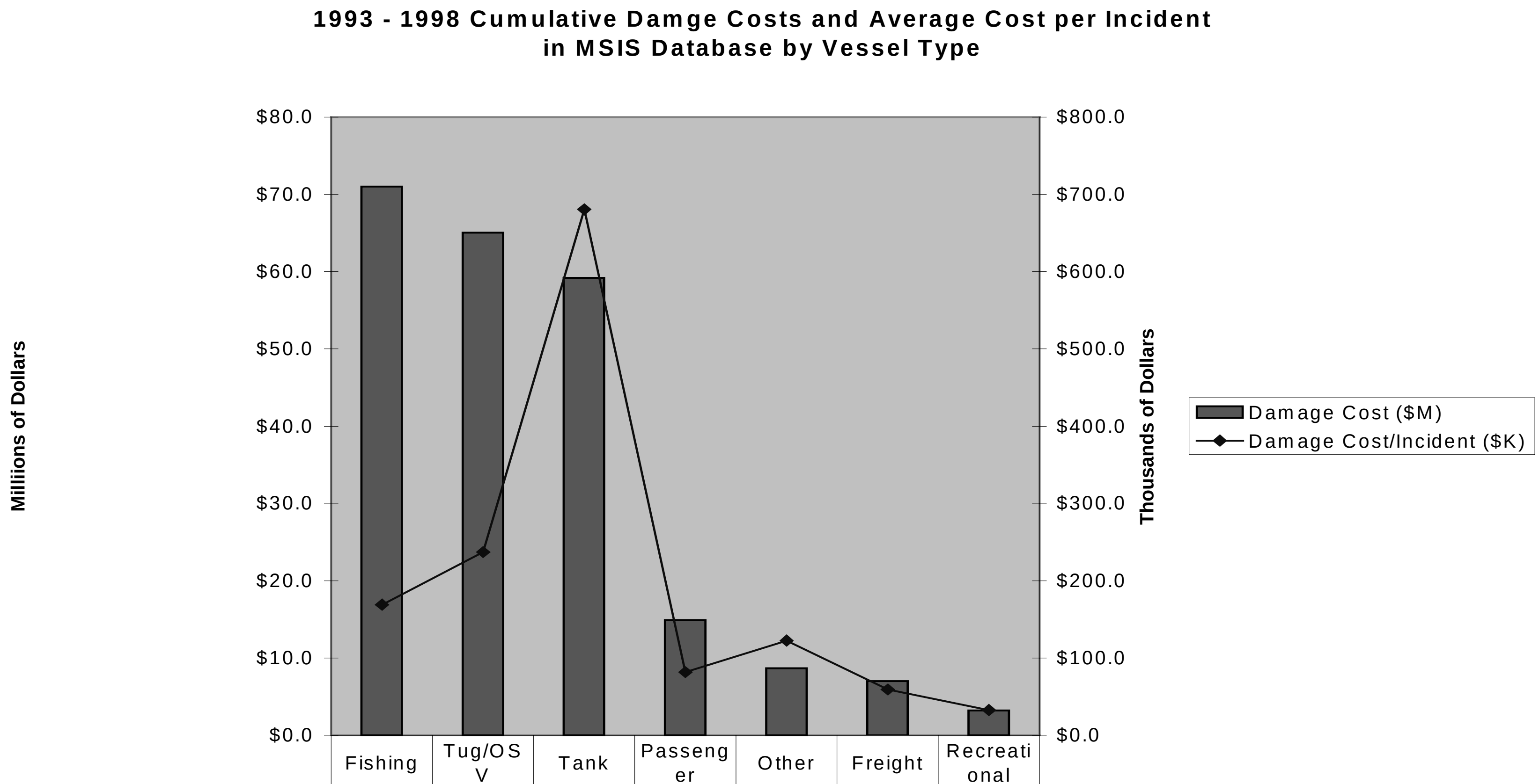
A breakdown of the damage amounts by the seven vessel types is shown in Figure 21. It shows the cumulative damage cost for the 6-year period and the average cost per incident. Fishing vessels have the largest cumulative loss ($71M) of the vessel types. Tug and Offshore Supply Vessels (OSV) have the second highest loss ($65M). Tank vessels have the third highest loss ($59.2M). However, tank vessels have the highest average cost per incident ($680K/incident). This can be attributed to the cost difference in the typical vessels and the severity of a typical incident occurring on tank vessels as compared to that of other types of vessels.

PROBALITITY ANALYSIS

The following probabilities are based on the condition that a fire has occurred on a vessel in the population of vessels covered in the MSIS database. The conditional probabilities, given a fire, that it will occur on a given vessel type are calculated. The conditional probabilities, given a fire that it will originate in a given location onboard the vessels, are calculated. And the conditional probabilities, given a fire that it will ignite by a given ignition source, are calculated.

VESSEL TYPE

The conditional probabilities of incidents by vessel type are calculated in Table 2 on a one-year average number of incidents. By taking the total number of incidents per vessel



	Fishing	Tug/OSV	Tank	Passenger	Other	Freight	Recreational
Damage Cost ($M)	$71.0	$65.0	$59.2	$14.9	$8.7	$7.0	$3.2
Damage Cost/Incident ($K)	$169.0	$237.2	$680.5	$81.9	$122.5	$59.3	$32.7

Figure 21 - Cumulative Damage Costs and Average Cost per Incident

type, for the 6-year period and dividing by the number of years provides an average yearly probability. The conditional probability of an incident per year on average is then calculated by dividing the one-year average number of incidents by the total average yearly number of incidents.

Table 2 – Conditional Probabilities by Vessel Type

Vessel Type	Total Incidents	Avg. Incidents/Year	Conditional Probability Incident/Fire/Year
Fishing	420	70.0	0.336
Tug/OSV	274	45.7	0.219
Tank	87	14.5	0.070
Passenger	182	30.3	0.146
Other	71	11.8	0.057
Freight	118	19.7	0.094
Recreational	98	16.3	0.078
Totals	1250	208.3	1.000

LOCATION OF ORIGIN

The conditional probabilities of a fire that has occurred originating in a given location onboard the vessel are calculated in Table 3. The locations chosen for this analysis are machinery spaces, cargo areas, accommodations/superstructure, external to the vessel, cargo pump rooms, and a general grouping of other locations. The conditional probabilities are calculated by taking the number of incidents for the given location and dividing it by the total number of incidents.

Table 3 – Conditional Probabilities for Locations of Origin

Fire Location	No. of Incidents	Conditional Probability Incident/Fire
Machinery Spaces	715	0.5720
Cargo Areas	217	0.1736
Accommodations	201	0.1608
External Fire Sources	12	0.0096
Cargo Pump Rooms	8	0.0064
Unknown	97	0.0776
Totals	1250	1.0000

IGNITION SOURCES

To calculate the conditional probabilities of the different ignition sources, it was determined that the most useful information for the decision-makers would be decomposing them by the three known locations with the highest probabilities. These locations are the machinery spaces, cargo spaces, and accommodation spaces.

Machinery Spaces

The conditional probabilities of fire originating in a machinery space being ignited by a given source are calculated in Table 4. The numbers of ignitions per given source are divided by the total number of incidents that occur in machinery spaces. The ignition sources chosen for analysis are heated/hot surfaces, electrical, internal to machinery, hotwork/welding, and anywhere the source can be identified.

Table 4 – Conditional Probabilities of Ignition Sources in Machinery Spaces

Ignition Source	No. of Incidents	Conditional Probability Mach Sp Source/Fire
Heat/Hot Surfaces	324	0.4538
Electrical	198	0.2773
Internal to Machinery	28	0.0392
Welding/Hotwork	17	0.0238
Unknown	147	0.2059
Totals	714	1.0000

Cargo Spaces

The conditional probabilities of a fire in a cargo area being ignited by a given source are calculated in Table 5. The number of ignitions per given source are divided by the total number of incidents that occur in cargo areas. The ignition sources chosen for this analysis are electrical, hotwork/welding, hot surfaces/exhaust sparks, crew/cigarettes/arson, static electricity/lightening, explosion/cargo/fireworks, chemical reaction, external to vessel, and sources that could not be determined.

Accommodation Spaces

The conditional probabilities of a fire in an accommodation space being ignited by a given source are calculated in Table 6. The number of ignitions per given source are

Table 5 – Conditional Probabilities of Ignition Sources in Cargo Areas

Ignition Source	No. of Incidents	Conditional Probability Cargo Area Source/Fire
Electrical Short/Spark	47	0.2166
Hot Work/Welding	43	0.1982
Hot Surface/Exhaust Sparks	29	0.1336
Crew/Cigarette/Arson	19	0.0876
Chemical Reaction	7	0.0323
External Item	6	0.0276
Static Electricity/Lightening	10	0.0461
Explosion/Cargo/Fireworks	10	0.0461
Unknown	46	0.2120

Table 6 – Conditional Probabilities of Ignition Sources in Accommodation Spaces

Ignition Source	No. of Incidents	Conditional Probability Accom Sp. Source/Fire
Electrical Short/Spark	61	0.3035
Galley/Cooking	48	0.2388
Crew/Cigarette/Arson	16	0.0796
Hot Work/Welding	15	0.0746
Heaters/Portable Heaters	11	0.0547
Hot Surfaces/Exhaust Stack	9	0.0448
External	3	0.0149
Unknown	38	0.1891

divided by the total number of incidents that occur in accommodation spaces. The ignition sources chosen for this analysis are electrical, galley/cooking, crew/cigarette/arson, hotwork/welding, heaters/portable heaters, hot surfaces/exhaust stacks, external to vessel, and any sources that could not be identified.

These conditional probabilities are then used with consequence data from the MSIS database to perform a risk analysis.

RISK CALCULATION

Risk is defined as the product of the probability of occurrence times the consequence of the occurrence. For the Coast Guard decision-makers, risk would be the probability of a casualty occurring times the consequence (cost of the loss) of the casualty. Due to the lack of population data on all the vessels that MSIS database casualties represent, the probability of an incident occurring cannot be calculated. Therefore, the risk calculations presented here are expected loss calculations. They are based on the conditional probability that a fire has occurred on a vessel in the population of vessels covered in the MSIS database.

EXPECTED LOSS BY VESSEL TYPE

The average yearly-expected loss associated with a fire or explosion incident on given vessel type, where a fire or explosion incident has occurred, is calculated in Table 7. It shows that the average yearly expected loss is equivalent to $56,800 dollars on a fishing vessel with a fire or explosion. The average yearly expected loss is equivalent to $52,000 dollars on a tug or offshore supply vessel (OSV) with a fire or explosion. The average yearly expected loss is equivalent to $47,360 dollars on a tank vessel with a fire or explosion.

Table 7 – Expected Loss per Vessel Type Given a Fire Occurrence

Vessel Type	Conditional Probability Incident/Fire/Year	Consequence Damage Cost/Incident	Expected Loss /Fire (Cost/Incident)
Fishing	0.336	$169,048	$56,800
Tug/OSV	0.219	$237,226	$52,000
Tank	0.070	$680,460	$47,360
Passenger	0.146	$81,868	$11,920
Other	0.057	$122,535	$6,960
Freight	0.094	$59,322	$5,600
Recreational	0.078	$32,653	$2,560

The Coast Guard has the least regulatory control of the two vessel types with the highest expected loss. They are fishing vessels and tugs. In resent years, the Coast Guard has initiated out reach efforts to industry associations for both of these types of vessels. The third highest expected loss is on tank vessels. These are probably the highest regulated vessels. The high expected loss for tank vessels could be attributed to the higher populations of tank barges to self-propelled vessels. Barges are less regulated than self-propelled tank vessels. However, due to limitations in the data available for this investigation, separation of these populations was not possible.

EXPECTED LOSS BY LOCATION OF ORIGIN

The average yearly-expected loss associated with a fire or explosion, originating in a given location onboard a vessel, are calculated in Table 8. The locations are machinery spaces, cargo areas, accommodations/superstructure, external to the vessel, cargo pump rooms, and a general grouping of other locations. The probabilities are from Table 3 in the previous section.

Table 8 – Expected Loss by Location Given a Fire Occurrence

Fire Location	Conditional Probability Incident/Fire	Consequence Damage Cost/Incident/Year	Expected Loss /Fire (Cost/Year)
Machinery Spaces	0.5720	$15,110,683	$8,643,311
Cargo Areas	0.1736	$4,964,023	$861,754
Accommodations	0.1608	$2,842,929	$457,143
External Fire Sources	0.0096	$45,083	$433
Cargo Pump Rooms	0.0064	$7,859	$50
Unknown	0.0776	$15,027,025	$1,166,097

The location with highest average yearly expected loss, onboard a vessel with a fire or explosion, is a machinery space. Its expected loss is over seven times the next highest location. The calculations show that the expected loss of a fire or explosion occurring in a machinery space, on a vessel with a fire is equivalent to $8.6 million dollars. This indicates that machinery spaces are an area for attention, and possible research and development resource allocation.

EXPECTED LOSS OF IGNITION SOURCES

Table 8 shows three known locations onboard a vessel with the highest expected loss of fires or explosions are machinery spaces, cargo areas, and accommodation spaces. Calculation of the expected loss associated with these three areas will potentially help identify component or system level research areas. Therefore, the following calculations are presented.

Ignition Sources in Machinery Spaces

The average yearly expected loss of given ignition source for fires or explosions originating within a machinery space, onboard a vessel where a fire has occurred, are calculated in Table 9.

Table 9 - Ignition Source Expected Losses in Machinery Spaces

Ignition Source	Conditional Probability Mach Sp Source/Fire	Consequence Damage Cost/Incident/Year	Expected Loss /Fire (Cost/Year)
Heat/Hot Surfaces	0.4538	$8,062,758	$3,658,731
Electrical	0.2773	$3,906,414	$1,083,291
Internal to Machinery	0.0392	$242,269	$9,501
Welding/Hotwork	0.0238	$2,418,465	$57,582
Unknown	0.2059	$480,778	$98,984

Heated or hot surfaces have the highest expected loss of the sources of ignition analyzed. The calculations show that the average yearly expected loss is equivalent to

$3.7 million dollars from a heated or hot surface, in a machinery space with a fire or explosion. The average yearly expected loss is equivalent to $1.1 million dollars for an electrical ignition source, in a machinery space with a fire or explosion. Both these ignition sources might warrant investigation and possible research and development resource allocation.

Ignition Sources in Cargo Areas

The average yearly expected loss associated with a given ignition source for fires or explosions originating in cargo areas are calculated in Table 10.

Table 10 - Ignition Source Expected Losses in Cargo Areas

Ignition Source	Conditional Probability Cargo Area Source/Fire	Consequence Damage Cost/Incident/Year	Expected Loss /Fire (Cost/Year)
Electrical Short/Spark	0.2166	$2,056,702	$445,461
Hot Work/Welding	0.1982	$930,895	$184,463
Hot Surface/Exhaust Sparks	0.1336	$510,931	$68,281
Crew/Cigarette/Arson	0.0876	$565,142	$49,482
Chemical Reaction	0.0323	$100,000	$3,226
External Item	0.0276	$110,000	$3,041
Static Electricity/Lightening	0.0461	$47,594	$2,193
Explosion/Cargo/Fireworks	0.0461	$13,500	$622
Unknown	0.2120	$629,259	$133,391

Electrical shorts and sparking have the highest expected loss of the ignition sources in cargo areas with a fire or explosion. The calculations show that the average yearly expected loss is equivalent to nearly $450 thousand dollars for electrical ignition sources of fires or explosions in cargo areas. If it is determined that cargo areas are a concern, then electrical ignition should be considered for allocation of research and development resources.

Ignition Sources in Accommodations

The average yearly expected loss associated with a given ignition sources in an accommodation space with a fire or explosion, are calculated in Table 11.

Table 11 - Ignition Source Expected Losses in Accommodation Spaces

Ignition Source	Conditional Probability Accom Sp. Source/Fire	Consequence Damage Cost/Incident/Year	Expected Loss /Fire (Cost/Year)
Electrical Short/Spark	0.3035	$882,013	$267,676
Galley/Cooking	0.2388	$771,920	$184,339
Crew/Cigarette/Arson	0.0796	$100,616	$8,009
Hot Work/Welding	0.0746	$327,258	$24,422
Heaters/Portable Heaters	0.0547	$60,333	$3,302
Hot Surfaces/Exhaust Stack	0.0448	$199,350	$8,926
External	0.0149	$63,088	$942
Unknown	0.1891	$438,350	$82,872

Electrical shorts and sparking are the ignition sources with the highest expected loss in accommodation spaces. The calculations show the average yearly expected loss is equivalent to nearly $270 thousand dollars from electrical ignition sources in accommodation spaces with a fire or explosion. If it is determined that accommodation spaces are of concern, then electrical ignition should be considered for allocation of research and development resources.

EXPERT PANEL

The panel of experts, for this decision-making methodology, are the decision-makers themselves. The majority of individuals on the panel are part of the fire safety staff of the Lifesaving and Fire Safety Division of the Coast Guard and they deal with the issues involved in these decisions on a daily basis. They not only help to identify problems, but they are instrumental in the process to correcting problems. Also included on the panel was a member of the Marine Safety and Environmental Protection Office's planning staff who provided the perspective on that program's goals. The final member is a member of the R &D Program's management team and provided their program's perspective.

The eight members of the panel all have engineering degrees. The degrees range from Bachelor to Masters. Their degrees include fire protection engineering, mechanical engineering, marine transportation, and business administration. The members are a mix of Coast Guard officers and civilian employees. Their ship related experience level ranges from 3 months to over 30 years, with an average of 13 years. Their experience level related to fire protection range from 1 year to over 30 years, with an average of 15 years.

The composition of the panel varied by the member's ability to participate in each of the three panel stages. The presentation of the database analysis and the brainstorming session was attended by six members of the panel. The information was presented to the other members of the panel either in written form or orally. The ranking of attributes questionnaire was completed by seven members of the panel. The rating of the alternatives was completed by four members of the panel. The reduced number of responses to the alternatives rating has not degraded the value of the input, as there was a very high degree of consistency in the responses.

PANEL'S MEETING

The panel met at US Coast Guard Headquarters on March 23rd 1999. The results of the databases' analyses were presented and discussed. The panel felt that the data reasonably represented the casualty incidents of their collective experience. There was no disagreement on the relative breakdown on the problem areas. Minor corrections in the presentation of the analysis were suggested and subsequently incorporated into this work.

After the results of database analyses were presented, the panel was asked to brainstorm to establish attributes and alternatives. The attributes will be used to rate the alternatives. The panel's selection of attributes and alternatives can be seen in the decision model.

DECISION MODEL

Given the eighteen alternatives and nineteen attributes by which to rate them, an AHP decision model was created. The structure of the model can be seen in the decision model displayed in Figure 22. At the highest level of the model is the goal of the decision to be made. The goal *(GOAL)* is to determine the most appropriate fire research areas or projects that the Lifesaving and Fire Safety Division should request for allocation of Coast Guard research and development resources.

The goal is decomposed into five general attribute groupings. They are Mandates, Program, Vessels Addressed, Pollution, and Collision. The Mandates group *(MANDATES)* is made up of issues that must be addressed by the Coast Guard in its regulatory efforts. This includes National Transportation Safety Board *(NTSB)* recommendations or the potential for recommendations on marine safety issues made to Coast Guard, for which a response is required. Issues *(IMOISSUE)* before or scheduled to come before the IMO's Maritime Safety Committee or its subcommittees. Issues *(BUSIPLAN)* that are in alignment with G-M's business plan. Congressional mandated items *(CONGRESS)* that the Coast Guard must present a response before Congress. Issues *(PUBOPN)* for which there is expected to be significant public opinion either for or against. And issues *(MARIND)* that are likely to have a positive or negative impact on the marine industry or portions thereof.

The second grouping of attributes (PROGRAM) consists of items related to the Coast Guard's R &D Program. The first is a cost to benefit issue *(COSTBENF)*. The second is a timeliness issue *(TIME)*. Third issue *(R&D)* is whether the research or

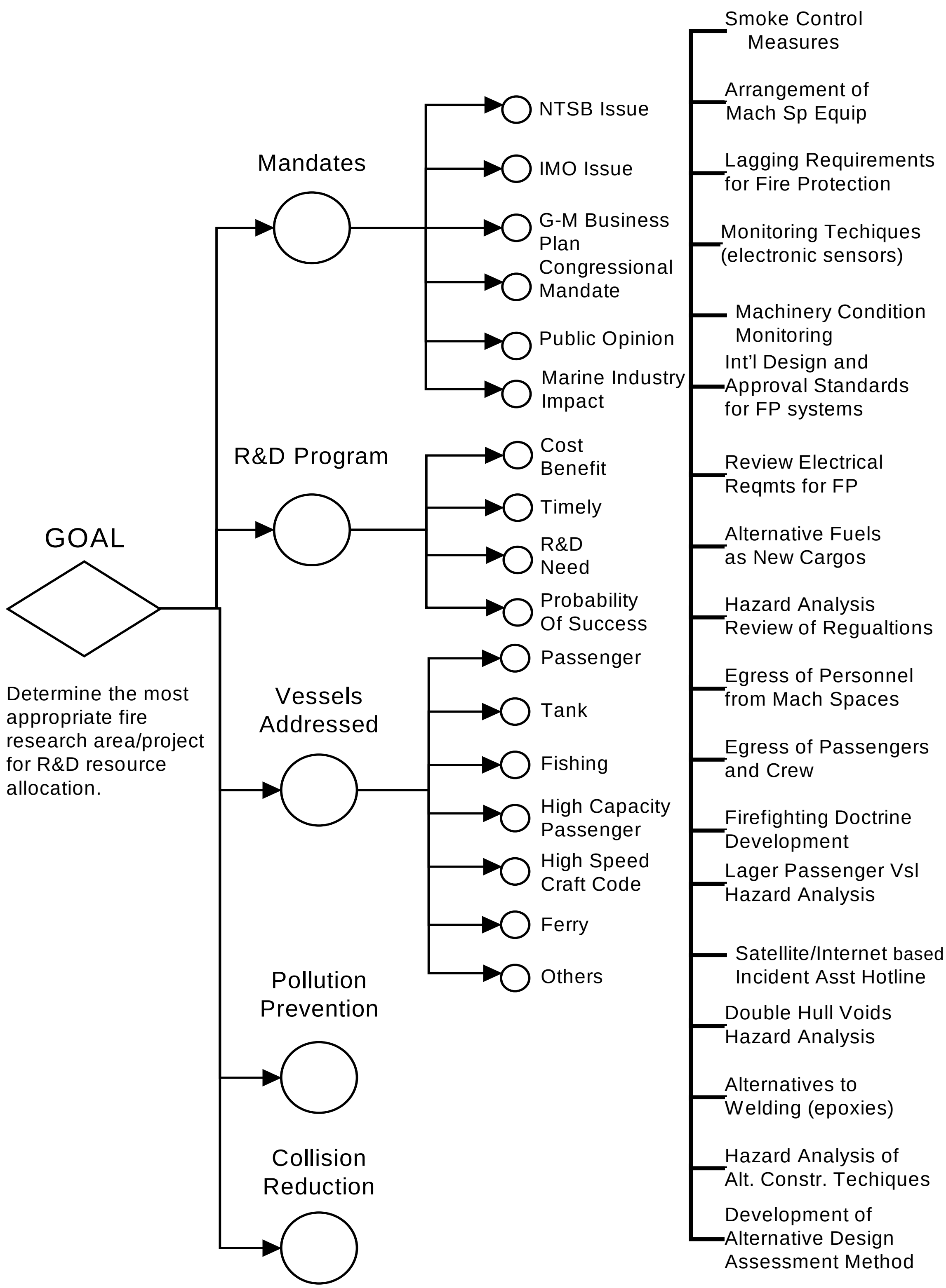


Figure 22 - Decision Model

development needed fits within the funding requirements. The fourth and final issue *(SUCPROB)* is the probability of whether successful resolution to the effort is anticipated.

The third grouping of attributes *(VSLADDR)* is made up of the six specific vessel types the panel chose to address and one general one for all other vessels *(OTHERVSL)*. The six types are passenger *(PASSVSL)*, tank *(TANKVSL)*, fishing *(FISHVSL)*, high capacity passenger *(HCPV)*, high speed craft code *(HSCVSL)*, and ferry vessels *(FERRY)*.

The final fourth and fifth groups are single item attributes. The first is pollution prevention potential *(POLLUTIO)*. The second is collision and allision reduction potential (COLLISIO).

Each of the attributes and alternatives are described as follows.

ATTRIBUTES

A brainstorming session was conducted to formulate the attributes by which to rate the alternatives. This was a free discussion and participants were encouraged to make any recommendations. The recommendations were discussed and the following nineteen attributes were selected. None of the attributes were considered essential, such that non-favorable ranking would preclude any further consideration in the decision.

1. **National Transportation Safety Board *(NTSB)*:** This attribute is to rank whether or not the alternative would affect a current or future finding from the National Transportation Safety Board (NTSB) or the Coast Guard's Marine

Incident Board. The NTSB is an independent investigation organization within the Department of Transportation. They are tasked with investigating significant safety related accidents on any of the country's transportation modes (air, highway, marine, or rail). They report their findings to the Secretary of Transportation, in which they assign recommendations to the organizations involved (federal or state government organizations as well as industry). The Coast Guard's Marine Incident Board is the Coast Guard's own internal investigation board. They make recommendations to the Commandant on their findings.

The Coast Guard is required to respond to the recommendations. The response is typically one of three responses. The first is some action (usually regulatory) to prevent reoccurrence. The second is to undertake a further investigation of the problem (typically a research effort). The third is dispute the recommendation based on technical grounds (may or may not involve a research effort).

For the purposes of ranking potential research areas, it would be desirable to have any alternative that would impact on a NTSB recommendation to score higher than one that does not. Therefore, an alternative that affects a NTSB issue would be preferred. An alternative that possibly might impact an issue would be next highest ranked. Finally, an alternative that does not would be the lowest ranked.

2. **International Maritime Organization *(IMOISSUE)*:** This attribute ranks whether or not the alternative is a current or future item before the International Maritime Organization's Maritime Safety Council (MSC) or its Subcommittees. Issues before the MSC or its Subcommittees can affect international safety regulations, Safety of Live At Sea (SOLAS).

   The Coast Guard is designated as the United States' representative to this international regulation forming body under the charter of the United Nations. As such, the Coast Guard must present the United States' position on the formulation of the SOLAS regulations. These regulations not only affect US flagged vessels travelling internationally, but also affect foreign flagged vessels that make port calls in US waters.

   Any alternative research and development area that would impact an item being considered at IMO would be more desirable than one that is not. Likewise, an alternative that possibly might affect an IMO issue would be the next desirable. Finally, one that does not affect an IMO issue would be least desirable from this perspective.

3. **G-M Business Plan (BUSIPLAN):** This attribute ranks whether or not the alternative is within the scope of the Marine Safety and Environmental Protection Office's (G-M) business plan. The business plan defines G-M's approach to help the Coast Guard reach its five strategic goals. The four

Coast Guard strategic goals encompassed by G-M's business plan are safety, protection of natural resources, mobility, and maritime security.

While G-M is carrying out its mission, in support of the four strategic goals, it has selected specific areas for its business focus. These include passenger vessel safety, pollution from tank vessel casualties, preparedness for catastrophic threats, fishing vessel capsizing/flooding/ sinking, and port state control.

All alternatives considered would theoretically support G-M's goals. This attribute is to rank whether or not an alternative addresses at least one of the five business focus areas within their business plan. An alternative that meets a focus area would rank higher than one that does not.

4. **Congressionally Mandated *(CONGRESS)*:** This attribute ranks whether or not the alternative affects a Congressionally mandated issue. The US Congress mandates items to the various departments within the government that it feels warrants action. The departments must respond to the mandate and present their findings to Congress.

   When the Coast Guard is mandated by Congress to address an issue, it has several avenues to address the issue. Several of these might be supported, either directly or indirectly, by research and development efforts. For example, if mandated to reduce oil spills as in the Oil Pollution Act of 1990, which resulted from, the Exxon Valdez oil spill. Numerous Coast Guard initiatives were undertaken to comply with this mandate, including double hull requirements for tank vessels, spill response planning, etc. One area of research that the Coast Guard chose to pursue was in-situ oil burning. This is where burning the oil off the surface of the water reduces an oil spill's impact.

A Congressionally mandated research effort, where Congress states what they want researched, would not involve this decision making process. The research would just be conducted as directed. Therefore, for the purposes of this attribute in the decision making process, it is only referring to Congressional mandates where the Coast Guard has the option to choose if research and development is appropriate for the mandated action. In this case, if an alternative supported a mandated issue, that would be a desirable result and would score higher than one that does not support a mandate.

5. **Public Opinion *(PUBOPN)*:** This attribute ranks whether or not the alternative is likely to be supported by or opposed by the public, and specifically the opinion of US taxpayers. The Coast Guard is federally funded by the US taxpayers. While the Congress determines the Coast Guard's budget and might mandate issues, it is ultimately the US taxpayers who determine what the Coast Guard does. Therefore, an alternative that is likely to receive public opinion support would be more desirable than one that would receive public criticism. That alternative would therefore score higher against this attribute.

6. **Marine Industry Adverse Impact *(MARIND)*:** This attribute ranks whether or not the alternative will adversely affect the US marine industry. Under its strategic goals, the Coast Guard must insure that its regulations do not place an unfair burden on US commercial vessels. The Coast Guard has several initiatives to reduce the burden on the US marine industry by the elimination of unnecessary regulation.

   Any alternative research and development area that has the potential to adversely affect maritime commerce without a justifiable benefit would be less desirable than one that has possible positive impact. Therefore, a positive impact alternative would score higher than a negative impact.

7. **Cost Benefit *(COSTBENF)*:** This attribute ranks whether or not the estimated cost of the alternative is warranted with respect to the expected benefit. An alternative that provides higher benefit for less cost, is the more desirable one. Therefore, an alternative with a lower cost to benefit ratio would score higher.

8. **Timely *(TIME)*:** This attribute ranks whether the estimated time to complete the necessary research or development meets the needs of the problem. A research effort that can't be completed until after the issue needs to be resolved, say to support a final IMO vote, is less desirable than an alternative that can be completed in a timely manner. The more timely alternative would score higher.

9. **Research & Development Funds Needed *(R&D)*:** This attribute ranks whether or not the alternative requires research or development that falls within the allowances of the RDT&E funding. Congress imparts strict requirements on monies provided for research and development. An issue that might require investigation, but not research or development work that falls within the restrictions, is considered to be within the conduct of normal business and funded with operational funds of that program, not with RDT&E funds. The programs are allowed to spend their operational funds to conduct needed research or development if it is not funded through the R&D program. This is limited by the availability of operational funds with which to conduct the research.

   A program may decide for example, to fund a low cost research effort that is of particular importance to an operational effort, but it is not an effort that would likely be funded through the R&D program. Therefore, this attribute not only ranks whether the alternative meets the R&D funding requirements, but also if the effort will require going to the R&D program for support versus operationally funding it. An alternative that meets the funding requirements and needs R&D program support would score higher than one that doesn't.

10. **Probability of Success *(SUCPROB)*:** This attribute ranks the likelihood of success of either a research or development effort on the alternative. An alternative with a higher probability of success would score higher than one with a low probability of success.

Which types of vessels does the alternative affect? Does it affect all vessels, such as a machinery space item in which all vessels have some type of machinery space? Does the alternative only affect a specific type of vessel, which may only represent a small portion of the fleet the Coast Guard regulates? Alternatively, does it affect a type of vessel that the Coast Guard currently has limited regulatory control on, i.e. fishing vessels?

The six vessel types selected as attributes are passenger vessels, tank vessel, fishing vessels, high capacity passenger vessels, high-speed craft code vessels, ferry vessels. One additional category was added to incorporate all vessel types not specifically addressed. These seven attributes were grouped into one group, Vessels Addressed *(VSLADDR)*. The selection of these vessel types as attributes was impacted by the database analyses presented to the panel. A detail description of each attributes' impact follows.

11. **Passenger Vessels *(PASSVSL)*:** Passenger vessels included in this attribute are vessels that carry more than 12 passengers. These vessels can range from small dinner excursion vessels up through the largest cruise liner with thousands of passengers. The potential loss of life on this type of vessel is much higher. These vessels carry more of the general public than any other vessel type. Casualties on these vessels draw more attention than almost any other type.

The database analysis does not show a significant historical expected loss associated with this vessel type, see Table 7. The panel felt that the potential for the loss of life, and high profile associated with this vessel type warranted a separate attribute. Reduction of passenger vessel casualties is an area that G-M has selected as one of its business focus areas. Therefore, an alternative that impacts passenger vessels would score higher than one that does not.

12. **Tank Vessels *(TANKVSL)*:** Vessels included under this attribute are any bulk liquid cargo-carrying vessel. This includes crude oil carriers, product carriers, and chemical carriers. The vessels range in size from barges up through super tankers (VLCC's). These vessels carry a relatively small number of crew, so the potential for large loss of life is small. The impact of a fire or explosion casualty on one of these vessels can range from spill of its cargo into the water or a large lethal cloud of toxic gases from the burning cargo.

    The database analyses showed that this type of vessel had the highest cost per incident rate, see Figure 21. They also have the third highest expected loss, see Table 7. Its calculated expected loss given a fire occurrence is 83% of the highest calculated expected loss. The panel felt that despite it being a highly regulated vessel type, it warranted a separate attribute. An alternative that affects tank vessels would score higher than one that does not.

13. **Fishing Vessels *(FISHVSL)*:** Fishing vessels attribute includes commercial fishing vessels and vessels related to fishing, i.e., processing and freezing

vessels. The size of the crew onboard a vessel varies with the size and type of vessel. The loss per incident for fires or explosions onboard fishing vessels is the third highest, Figure 21. The high conditional probability, given a fire or explosion on a vessel, that it is a fishing vessel gives it the highest calculated expected loss, Table 7.

Despite the Coast Guard having the least regulatory control on this vessel type, its high-calculated expected loss warranted its inclusion as a separate attribute. An alternative that affects fishing vessels would score higher than an alternative that did not affect fishing vessels for this attribute.

14. **High Capacity Passenger Vessels *(HCPV)*:** High capacity passenger vessels include very large cruise ships and smaller vessels with a high capacity per size. These latter vessels are typically gaming boats that travel routes on rivers or close to shore. The routes' close proximity to external emergency support allows them to have higher capacities than other vessels.

    These vessels are included in the passenger vessel category in the database analyses. As with other passenger vessels, the historical calculated expected loss, given that a fire occurs, does not warrant a separate attribute. However, the panel felt that the potential expected loss of high fatalities or injuries if a fire or explosion did occur, that the separate attribute was justified.

15. **High Speed Craft Code Vessels *(HSCVSL)*:** High speed craft code vessels are a special group of vessel under a separate set of regulations under SOLAS.

The vessels are typically passenger vessels that travel at high speeds. There are special provisions for vessels that travel routes in close proximity to external emergency support. The code allows the vessel to be constructed to different material requirements. While these vessels, like the HCPV, are included in the passenger vessel category of the database analyses, the panel felt that the unique aspects of this type of vessel warranted a separate attribute. This higher perceived risk is related to the panel's relatively short experience with this type of vessel. An alternative that affects a HSC vessel would score higher than an alternative that did not.

16. **Ferry Vessels *(FERRY)*:** Ferry vessels are a subset of passenger vessels. They are categorized as ferries due to the transport of not only passengers, but also vehicles and some cargo. Due to unique design considerations to accommodate vehicles and generally higher passenger carrying capacity, the panel felt ferry vessels warranted a separate attribute. This perceived higher risk probably stems from accidents like the sinking of the MS Estoina, a RoRo ferry sailing out of Stockholm, Sweden in 1994 with 1054 passengers and crew onboard.

17. **Other Vessels *(OTHERVSL)*:** This attribute covers all remaining vessel types not specifically identified above and was used to insure that the relative rankings included all possible vessels.

18. **Pollution Prevention *(POLLUTIO)*:** This attribute ranks whether or not the alternative has potential to reduce pollution incidents. For example, a machinery space fire prevention improvement might reduce the likelihood of a vessel loosing steerage while navigating in restrictive waters, thereby reducing the chance of grounding and subsequent spill. Therefore, an alternative that potentially reduces the likelihood of a pollution incident would score higher than one that does not.

19. **Collision/Allision Reduction *(COLLISIO)*:** This final attribute ranks whether or not the alternative has the potential to reduce collisions and allisions. Allision is the admiralty law term for the inadvertent contact between a vessel and another fixed object above the water other than another vessel. A vessel striking a pier or wharf, as occurred in New Orleans, is an example of an allision. Collisions and allisions have the potential for loss of live, sinking of the vessel, and the release of cargo or ships fuel. It is desirable to reduce the potential occurrence of these types of incidents. An alternative that potentially could reduce the likelihood of occurrence would score higher than one that would not under this attribute.

ALTERNATIVES

After the attributes were established, the brainstorming session turned its focus to identification of alternatives. These are areas in which research or development work might improve the fire safety of a vessel. It might be an item that would affect only a certain type of vessel, or it might affect all vessels. The panel was encouraged to put forth any ideas. A general discussion of the alternatives was conducted and the following eighteen alternatives were selected:

1. **Smoke Control Measures:** Smoke control measures would consist of investigations of means of safely managing the removal of smoke in the event of a fire onboard. The goal of any effort would be to keep the smoke away from the passengers and/or crew. As an example, a research project might be investigations on ventilation systems that would slightly pressurize either vertical escape zones or adjacent occupied zones.

   Since all vessels have a crew, and some carry passengers, this alternative would potentially affect all vessel types in the Vessels Addressed *(VSLADDR)* branch of the decision tree. Attributes under the Mandates *(MANDATES)* and Program *(PROGRAM)* branches would have unique responses as to whether or not they are potentially affected by such an alternative. The likelihood that any smoke control measures would reduce the likelihood of either pollution incidents or collision/allisions is very remote. Due to the low expected loss calculated in the database analyses, the inclusion of this alternative is probably based on the panel's experience.

2. **Arrangement of Equipment in Machinery Spaces:** Arrangement of equipment in machinery spaces might be an investigation of separating machinery space equipment into compartmentalized areas to prevent a fire from spreading beyond its point of origin. Any such effort would need to consider many other functional

aspects such as manning requirements of such an arrangement, the vessel's energy performance impacts, maintainability, and others.

Since all commercial vessels have some type of machinery space (for main propulsion or auxiliary purposes). This alternative would potentially affect all vessel types in the Vessels Addressed *(VSLADDR)* branch of the decision tree. Attributes under the Mandates *(MANDATES)* and Program *(PROGRAM)* branches would have unique responses as to whether or not they are potentially affected by such an alternative. Since a machinery space fire could adversely affect the vessel's propulsion or steering, it is possible that such an alternative could reduce the chance of Pollution *(POLLUTIO)* and Collisions/Allisions *(COLLISIO)*. The alternative's selection by the panel is attributable to the high calculated expected loss, (Table 8), that fires will occur in machinery spaces as found in the database analyses.

3. **Lagging Requirements with Fire Protection as the Goal:** Lagging is an industrial term to denote insulation type materials applied to objects, such as pipes, manifolds, etc. In this context, it is referring to the use of lagging materials on hot surfaces. Hot surfaces are defined as surfaces with temperatures at or above the auto-ignition temperature of hydrocarbon fuels. The current marine design practice for specifying the need for lagging on hot surfaces falls into one of two general categories. One is the need to prevent a burn from accidental contact by a person's skin. The second is to reduce the heat load transferred into the

space to maintain habitability, thereby reducing the ventilation system size and power requirements.

A development effort might look at identifying and testing specification requirements to be applied to lagging to prevent gaps in the lagging large enough to allow the penetration of an accidental fuel spray from coming in contact with the hot surfaces and igniting. This alternative could be effective on all vessel types, as well as potentially reduce the chance of pollution and collisions/allisions. Its selection by the panel is attributable to the high calculated expected loss, (Table 8), that fires will occur in machinery spaces as found in the database analyses.

4. **Monitoring Techniques for Machinery Spaces:** This alternative might include an investigation of the reduced hazards associated with the use of electronic sensors versus the current practice of running small diameter gage tubing from an operational component to a central control board. These electronic sensors can eliminate the long runs of pressurized flammable liquids, which are susceptible to damage, that can lead to fires.

   This alternative could be effective on all vessel types, as well as potentially reduce the chance of pollution and collisions/allisions. Its selection by the panel is attributable to the high expected loss, given a fire (Table 8), that fires will occur in machinery spaces as found in the database analyses.

5. **Machinery Condition Monitoring to Prevent Casualties:** This alternative might consist of investigation of the hazard reduction that might be gained from the use of sensors or monitoring techniques that could potentially reduce catastrophic component failures that can result in fires. The component monitoring would be based on defining an acceptable range for a parameter. When the component's value exceeded that range, it would initiate corrective action/maintenance before the component could reach the point of catastrophic failure.

   This alternative could be effective on all vessel types, as well as potentially reduce the chance of pollution and collisions/allisions. Its selection by the panel is attributable to the high expected loss, given a fire (Table 8), that fires will occur in machinery spaces as found in the database analyses.

6. **Development of International Design and Approval Standards for Fire Protection Systems:** This alternative might consist of the development of a method to equate the current prescriptive fire safety requirements for components to a set of standardized requirements for the design of fire protection systems. The current prescriptive requirements for components are uniquely applied by the designer and the approving administration (flag state). This results in vessels that "meet" all the same standards yet have a wide spread on their level of actual fire safety.

This alternative would potentially affect all vessel types equally. It has the potential to also reduce the chance for pollution and collisions/allisions. An alternative like this one is not likely to be seen in the data analyses. Its inclusion by the panel is probably attributable to their experience.

7. **Review of Electrical Standards with respect to Fire Protection:** Due to the expected loss calculated for incidents caused by electrical sources, Tables 9, 10 and 11, it was probably felt by the panel that a fire hazard analysis review of the current electrical standards would be appropriate. Such a review with a high emphasis on fire protection might identify improvements that could reduce the number of these types of fires. This alternative would potentially affect all vessel types, reduce pollution, prevent collisions and allisions.

8. **Alternative Fuels as New Types of Cargo, Impact on Existing Systems:** Most requirements for tank vessel cargo deck fire fighting foam systems were established in the late seventies and early eighties. Since that time, some types of cargoes, like gasoline, have been reformulated with chemical additives and blends of additives. These additives are used for fuel system cleansing, performance enhancement, as well as air pollution control. Methyl Tertiary Butyl Ether (MTBE) is an example of an air pollution control additive in gasoline formulations. These additives in either neat form or in the final gasoline formulations can potentially change the effectiveness of the cargo deck firefighting foam systems. This alternative might consist of evaluating the

existing foam systems against new formulations to determine if changes in the system requirements are necessary.

This alternative would only affect tank vessels. Under the Tank (TANKVSL) attribute, this alternative would score high, but score low under the other vessel types. It could potentially reduce pollution incident rates so it would score high there, but is not likely to reduce the chances of collisions or allisions, so it would not score high under that attribute. The panel may have included this alternative because of the calculated expected loss for tank vessels, Table 7. They also may have included it based on there experience.

9. **Hazard Analysis Review of all Regulations, using a Systems Approach:** This alternative would consist of a hazard analysis of all regulations related to fire safety as a whole system. It would encompass the prescriptive material, suppression system, and detection system requirements, as well as any performance requirements for a combined “ship system” analysis. This alternative could be effective on all vessel types, as well as potentially reduce the chance of pollution and collisions/allisions. It would likely score high on all of these attributes. The database analysis results would not show any linkage to this alternative, so the panel probably selected it based on their experience.

10. **Egress of Personnel from Machinery Spaces:** This alternative would likely consist of adaptation of existing building-based evacuation models to the inherent complexities found in shipboard machinery spaces. Given the high expected loss

calculated for machinery space fires, Table 8, the panel probably chose to select this alternative. With machinery spaces of some type on every commercial vessel, this alternative would affect all of the vessel type attributes.

11. **Egress of Passengers and Crew, including Human Factors Issues:** As with the previous alternative, this one would likely be the adaptation of existing building-based evacuation models to the unique aspects of shipboard evacuations. Some of the unique aspects include that evacuees travel up rather than down, the ship can be listing to one side or the other, making travelling up stairways more difficult, the ship can be rolling in a high sea-state, and evacuees must evacuate to muster stations then board lifeboats.

    This alternative would affect all vessels, and especially all passenger vessels. It would not affect the chance of pollution, collisions or allisions. The database analyses did not get to this level of detail, therefore; the selection by the panel is probably based on their experience.

12. **Firefighting Doctrine Development, including Human Factors Issues:** The methods and techniques used to fight a shipboard fire are often called the firefighting doctrine. The unique aspects of shipboard firefighting, flooding and capsizing potential, make the importance of knowledgeable attack of the fire very important. In addition, shipboard construction uses steel bulkheads as fire boundaries, primarily the ship's main vertical zone bulkheads. Even if the firefighters are on the non-fire side of those bulkheads, they can be subjected to

high-radiated heat flux. This can affect their performance due to heat stress as well as fatigue. This alternative might consist of research and testing of methods to reduce the adverse impacts of these aspects.

Since all vessel types experience some fires, this alternative would be applicable to all those attributes. Pollution, collisions, and allisions would not directly be affected by this alternative. The database analyses did not analyze to the level of detail to determine the type or effectiveness of any firefighting efforts with the incidents. Therefore, this alternative was probably selected by from the panels' experience.

13. **Larger Passenger Ships (high capacity) Hazard Analysis:** This alternative would consist of performing a hazard analysis on large passenger ships. It would address the unique problems associated with large passenger ships. These include evacuation issues (safe-haven locations onboard verses lifeboats), smoke movement, maintaining integrity of the main vertical zones, flooding issues, and others. This alternative would only affect passenger vessels; so it would score highly for that attribute and low for the remaining vessel types. It would not affect pollution reduction or reduce the likelihood of collision or allision. The database analyses did not identify passenger vessels as one of the highest expected loss vessel types. Therefore, the panel's selection of this alternative was based on their perception that the potential for the loss of life, and high profile associated with this vessel type warranted its inclusion. Reduction of passenger

vessel casualties is an area that G-M has selected as one of its business focus areas.

14. **Satellite or Internet Based Hazardous Incident Assistance Hotline:** Shipboard fire casualties have numerous unique aspects, some of which where identified in the Alternative 12 above. The expertise to deal effectively with these situations may not exist onboard or the knowledgeable person(s) may be missing or incapacitated. This alternative might consist of investigating the requirements of information that might be kept in a user supported international assistance hotline. The hotline would be available via some commonly available communications vehicle. It might provide the onboard response person with important information, stability calculations, or assistance in determining the most appropriate method of attack. This might be an extension of the Atlantic Merchant Vessel Emergency Reporting System, AMVER, a now worldwide vessel of opportunity assistance program maintained by the Coast Guard.

    This alternative would be applicable to all vessel types. Pollution, collisions, and allisions could be affected by this alternative. The database analyses did not analyze to the level of detail to determine the type or effectiveness of any assistance response might have with the incidents. Therefore, this alternative was probably selected by from the panels' experience.

15. **Double Hull Void Spaces Hazard Analysis:** This alternative would consist of a fire hazard analysis of tank vessel double hull void spaces. Double hull

requirements for tank vessels were required by the Oil Pollution Act of 1990, which resulted from the Exxon Valdez oil spill. Due to cracking of the tank's boundaries from the ship's movement and bending while at sea, small leaks can develop into these void spaces. Depending on the cargo's flammability, explosive atmospheres can develop in these spaces. This alternative might consist of a hazard analysis of these spaces to determine that appropriate safety measures are taken to prevent the ignition of these atmospheres. This alternative would only be applicable to tank vessels and could reduce the chances of a pollution incident related to an explosion and fire within these spaces. The database analyses did not identify this location as a high expected loss. Therefore, the panels selection is probably based upon their experience.

16. **Alternatives to Welding:** This alternative would probably consist of an investigation of alternative methods of repair to the vessel's structure without welding. It would probably investigate epoxy type adhesives that would fasten the steel without the need to weld it. Hotwork (cutting using a torch) and welding was identified as the ignition source with the second highest expected loss in cargo space fires, Table 10. It is the fourth highest ignition source expected loss in accommodation space fires, Table 11. It was a lower expected loss in machinery spaces, Table 9. This alternative affects all vessel types but would not affect the chance of pollution, collisions, and allisions.

17. **Hazard Analysis of Alternative Construction Techniques**: Shipbuilders are investigating new method of constructing ships. One method that reduces time

and therefore cost, is the fastening of bulkhead joints with adhesives as opposed to traditional mechanical fastening or welding. This alternative would consist of a hazard analysis, and possibly testing the ability of this technique to resist the passage of flame or loss of its fastening ability. This could potentially affect all vessel types and could have some impact on the chances of pollution, collisions, and allisions. The database analyses did not identify this area as a problem area.

18. **Development of an Alternative Design Assessment Methodology:** This alternative would develop a methodology that shipbuilders or owners could use to prove alternative designs provide equivalent level of safety to the regulations. Currently, if an alternative design is contemplated, the party must request approval of the design based upon its equivalency. A standard method does not exist by which the Coast Guard assesses the equivalency of the alternative. This alternative would develop a methodology for that determination. This could potentially affect all vessel types and would not impact the chances of pollution, collisions, and allisions. The database analyses did not analyze to a level of detail to identify this as a problem area. This is clearly a case where the panel experience resulted in the selection of this alternative.

EXPERT CHOICE™ SOFTWARE

A software package was chosen to perform the AHP. The software is Expert Choice™ Professional version 9.5. It is one of a group of decision making software packages from Expert Choice, Inc. located in Pittsburgh, PA. It is a Microsoft Windows™ based software program that is run on a personal computer (PC). It is based on the Analytic Hierarchy Process (AHP), the multicriteria or multiobjective decision making process developed by Thomas L. Saaty.

ANALYSIS OF ENCODED OPINIONS

The analysis of the decision model used three of the programs modules. The first was the Evaluation and Choice module. The model's structure was entered into the module. The large number of alternatives would have made the resulting pairwise comparison of all attributes and alternatives an arduous task. One hundred seventy one (171) pairwise comparisons would have been required for each panel member. Therefore, the Ratings module portion of the software was incorporated into the analysis.

Rating was done by structuring the decision model into the Evaluation and Choice module down to the alternatives level. Rather than entering the eighteen alternatives, two or three-point intensity scales were entered. An example of an intensity scale is the one used for the NTSB attribute. It is a three-point scale, *Affects*, *Possible*, and *No Affect*. The program's three-point standard scores of 0.711, 0.243, and 0.046 were assigned to them respectively. For attributes with a two-point scale, e.g., *Meets* and *Doesn't Meet*, scores of 0.900 and 0.100 were assigned to those respectively. The goal of assigning an intensity scale was to use a simple standard rating criterion that could be quickly used across the numerous alternatives.

The attributes were pairwise compared by the panel in the form of questionnaires. Figure 23 is an example of the *MANDATES* questionnaire. See Appendix A for a complete sample set of the questionnaires answered by panel members. Each attribute

Determine the most appropriate fire research areas/projects.

Node: 10000

Compare the relative IMPORTANCE with respect to: MANDATES < GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	NTSB	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	IMOISSUE
2	NTSB	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	BUSIPLAN
3	NTSB	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	CONGRESS
4	NTSB	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	PUBOPN
5	NTSB	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	MARIND
6	IMOISSUE	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	BUSIPLAN
7	IMOISSUE	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	CONGRESS
8	IMOISSUE	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	PUBOPN
9	IMOISSUE	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	MARIND
10	BUSIPLAN	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	CONGRESS
11	BUSIPLAN	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	PUBOPN
12	BUSIPLAN	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	MARIND
13	CONGRESS	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	PUBOPN
14	CONGRESS	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	MARIND
15	PUBOPN	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	MARIND

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
MANDATES	Addresses mandates or regulatory issues.
NTSB	NTSB Recommendation issue
IMOISSUE	IMO issue
BUSIPLAN	Fits into G-M business plan
CONGRESS	Congressional Mandate
PUBOPN	Public Opinion
MARIND	Adverse Impact on Marine Industry

RDC

Figure 23 – Mandates Attribute Questionnaire

was compared against all other attributes on that level of the model. The panel's inputs were synthesized into priorities for the attributes, Figure 24. A zero to one numerical scale was assigned to the priority scales. The *MANDATES* branch had the highest priority in the panel's opinion. The Congressional Mandate (*CONGRESS*) attribute had the highest priority under the *MANDATES* branch. This result would be expected considering Congress' ultimate control over the Coast Guard. The POLLUTION and COLLISION branches had high priorities, probable due to their tie to G-M's Business Plan.

The model, with the derived priorities, was then converted into the Ratings module of the software. Here the eighteen alternatives are entered and the intensity scale for each alternative assigned to make up the ratings' criteria. . A zero to one numerical scale was assigned to the intensity scales. Figure 25 shows a portion of the *MANDATES'* rating questionnaire. See Appendix B for the complete sample set of ratings' questionnaires.

The panel's input from the rating of the alternatives' questionnaires were then inputted into the Ratings module. The ratings were combined using the priorities established for each of the attributes and a resulting ranking of the alternatives was established. Table 12 shows the relative rankings of the eighteen alternatives, from highest to lowest. The table also shows the percentage of the maximum for each of the alternatives. The complete decomposition of the model with derived priorities for the top five alternatives can be seen in Appendix C.

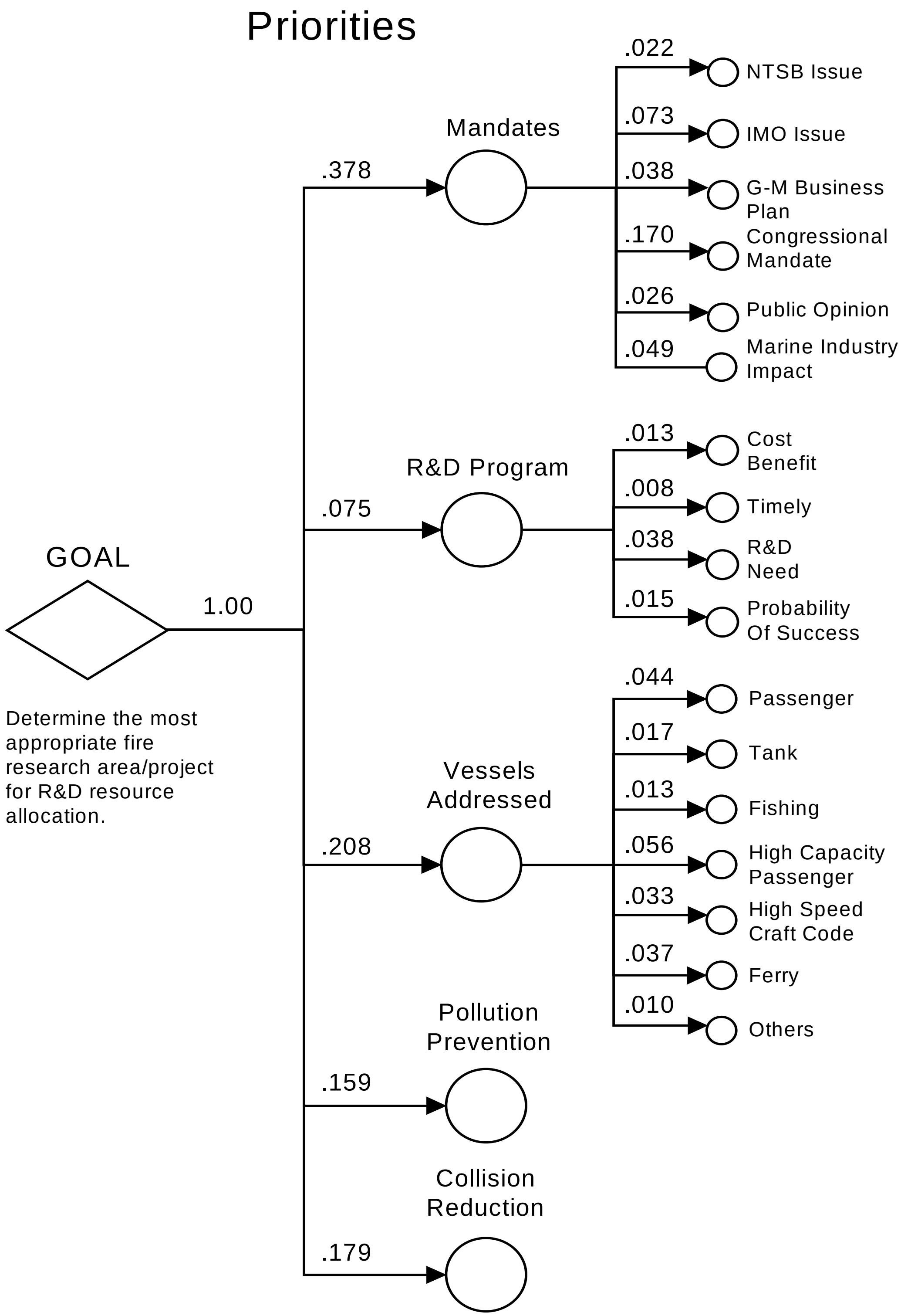


Figure 24 – Model with Panel's Priorities

Areas of for Possible Research	NTSB issues			IMO issue			G-M Bussiness Plan	
	Affects	Possible	No Affects	Issue	Possible	Not	Meets	Does Not
Smoke Control Measures								
Mach Space - Arrangement of equipment								
Mach Space - Lagging wrt Fire Protection								
Mach Space - Monitoring techniques to red cas								
Mach Space - Monitoring of equipment condition								
Int'l design & approval stds for Fire Prot Systems								
Electrical standards review wrt Fire Protection								
Alternative Fuels as cargo wrt Fire Prot								
Hazard Analysis Review of Regulations								
Egress of Mach Spaces								
Egress of Passengers & Crew								
Fire fighting doctrine development incl HF								
Larger Passenger Ship hazard analysis								
Satellite/Internet call up hazard assistance								
Double hull void space hazard analysis								
Alternatives to welding								
Alt construction techniques haz anal - adhesives, etc.								
Develop alt design assessment methodology								

Figure 25 – Mandates Alternatives Rating Questionnaire

Table 12 - Alternatives' Ratings

No.	Alternative	Rating Score	% of Maximum
1	Egress of Passengers & Crew	0.5272	100.0%
2	Int'l design & approval stds. for Fire Prot Systems	0.5152	97.7%
3	Hazard Analysis Review of Regulations	0.5099	96.7%
4	Develop alt design assessment methodology	0.5066	96.1%
5	Mach Space - Lagging wrt Fire Protection	0.4857	92.1%
6	Satellite/Internet call up hazard assistance	0.4668	88.5%
7	Mach Space - Monitoring techniques to red casu	0.4648	88.2%
8	Fire fighting doctrine development incl. HF	0.4583	86.9%
9	Alternatives to welding	0.4548	86.3%
10	Mach Space - Monitoring of equipment condition	0.4496	85.3%
11	Double hull void space hazard analysis	0.4463	84.6%
12	Smoke Control Measures	0.4459	84.6%
13	Larger Passenger Ship hazard analysis	0.4418	83.8%
14	Alt construction techniques haz. anal. - adhesives etc.	0.4038	76.6%
15	Egress of Mach Spaces	0.4013	76.1%
16	Electrical standards review wrt Fire Protection	0.3984	75.6%
17	Mach Space - Arrangement of equipment	0.3329	63.1%
18	Alternative Fuels as cargo wrt Fire Protection	0.3176	60.3%

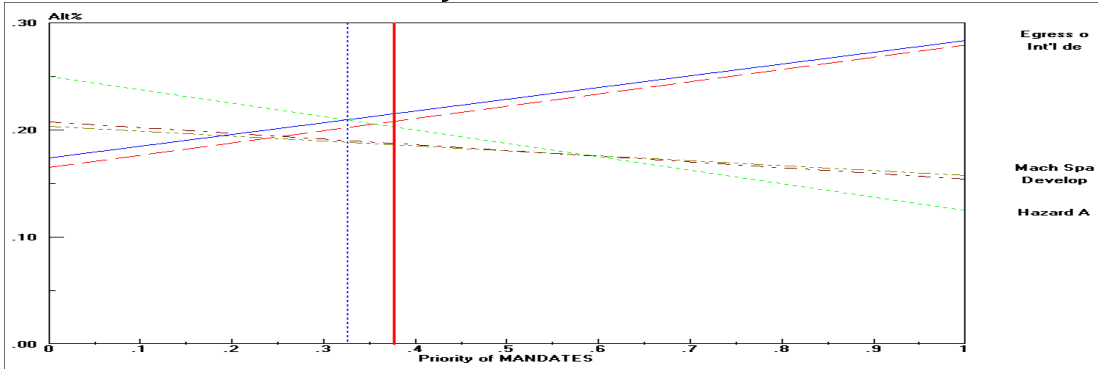
The results of the decision analysis indicate that the most appropriate alternative is Egress of Passengers & Crew *(EGRESS O)*. Considering the issues within the *MANDATES*, *PROGRAM*, vessels addressed (VSLADDR), *POLLUTION*, and *COLLISION* attributes, it meets more of those objectives than the other seventeen alternatives. As can be seen in the percentage of maximum column, there is a tight grouping in the top four or five alternatives.

SENSITIVITY ANALYSIS

For sensitivity analyses on the results, the top five alternatives were converted to a relative model between those five and analyzed in the Sensitivity module of the software. Here the relative influence of the attributes can be assessed by plotting the gradient sensitivity. These plots are graphical linear representations of the alternative's ratings against each of the attributes' priorities.

Figures 26 through 30 show the sensitivity graphs for each of the five top-level attributes. In each, the bold solid vertical line represents the encoded priority of the panel plotted on the x-axis. The priorities of the alternatives are plotted on the slanted vertical lines against the y-axis. The highest plotted alternative for any given value of priority of the attribute is displayed. The location where one alternatives line crosses another's is called the trade-off point. The value on the attribute's axis (x-axis) is where one alternative would be traded-off for the other. The dashed vertical lines are located at the trade-off points for the alternatives for the various plotted attributes.

Gradient Sensitivity w.r.t. GOAL for nodes below GOAL



Abbreviation	Definition
MANDATES	Addresses mandates or regulatory issues.
PROGRAM	R&D Program issues.
VSLADDR	Vessels Addressed
POLLUTIO	Pollution Prevention potential.
COLLISIO	Collision and Allision reduction potential.

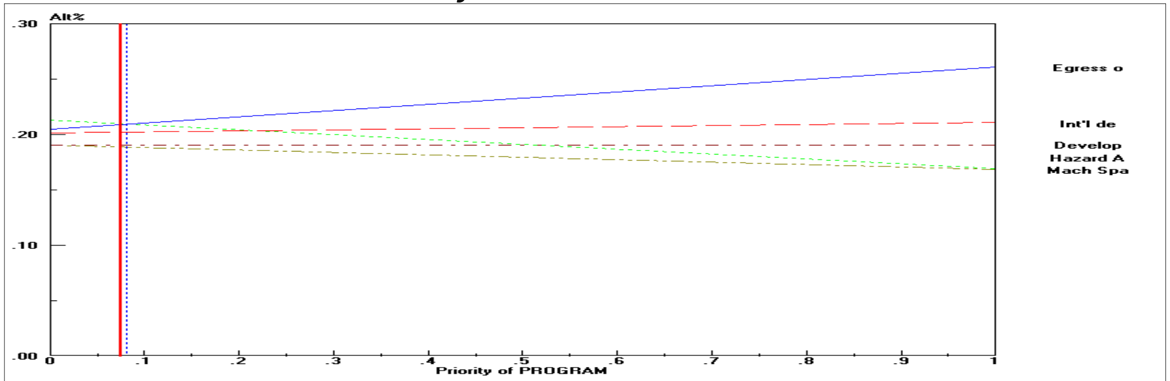
Egress o	Egress of Passengers & Crew
Int'l de	International Design & Approvals Standards for Fire Protection Sy
Hazard A	Hazard Analysis Review of Regulations
Develop	Develop Alternative Design Assessment Methodology
Mach Spa	Investigate Machinery Space Lagging wrt Fire Protection

Distributive Mode

(What-If Scenario)

Figure 26 – MANDATES Sensitivity Graph

Gradient Sensitivity w.r.t. GOAL for nodes below GOAL



Abbreviation	Definition
MANDATES	Addresses mandates or regulatory issues.
PROGRAM	R&D Program issues.
VSLADDR	Vessels Addressed
POLLUTIO	Pollution Prevention potential.
COLLISIO	Collision and Allision reduction potential.

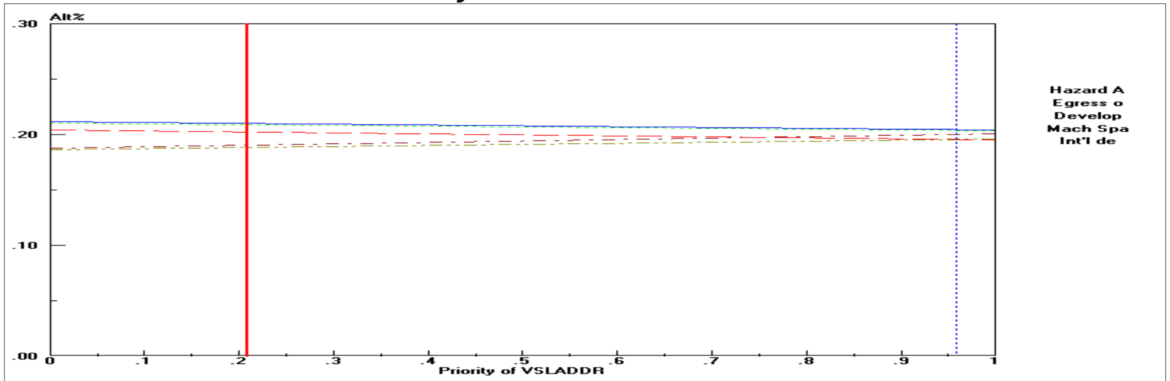
Egress o	Egress of Passengers & Crew
Int'l de	International Design & Approvals Standards for Fire Protection Sy
Hazard A	Hazard Analysis Review of Regulations
Develop	Develop Alternative Design Assessment Methodology
Mach Spa	Investigate Machinery Space Lagging wrt Fire Protection

Distributive Mode

(What-If Scenario)

Figure 27 – PROGRAMS Sensitivity Graph

Gradient Sensitivity w.r.t. GOAL for nodes below GOAL



Abbreviation	Definition
MANDATES	Addresses mandates or regulatory issues.
PROGRAM	R&D Program issues.
VSLADDR	Vessels Addressed
POLLUTIO	Pollution Prevention potential.
COLLISIO	Collision and Allision reduction potential.

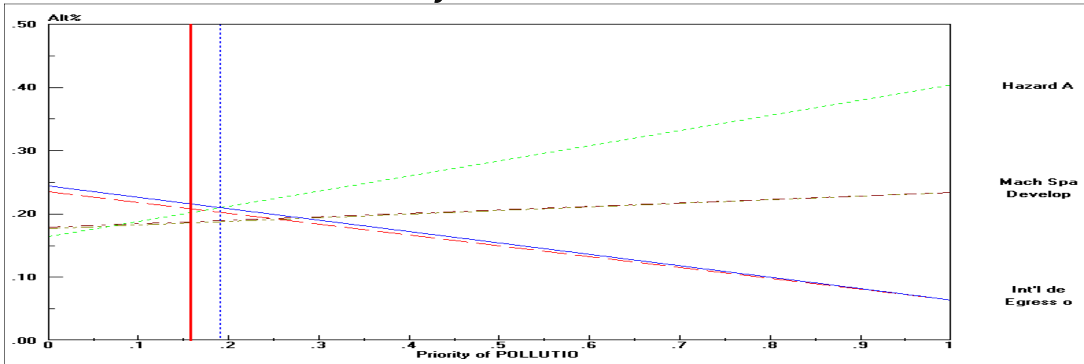
Egress o	Egress of Passengers & Crew
Int'l de	International Design & Approvals Standards for Fire Protection Sy
Hazard A	Hazard Analysis Review of Regulations
Develop	Develop Alternative Design Assessment Methodology
Mach Spa	Investigate Machinery Space Lagging wrt Fire Protection

Distributive Mode

(What-If Scenario)

Figure 28 – Vessels Addressed (VSLADDR) Sensitivity Graph

Gradient Sensitivity w.r.t. GOAL for nodes below GOAL



Abbreviation	Definition
MANDATES	Addresses mandates or regulatory issues.
PROGRAM	R&D Program issues.
VSLADDR	Vessels Addressed
POLLUTIO	Pollution Prevention potential.
COLLISIO	Collision and Allision reduction potential.

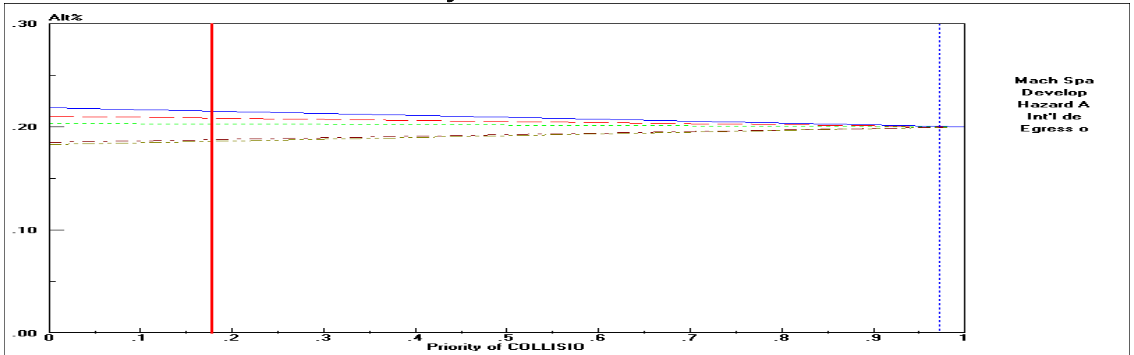
Egress o	Egress of Passengers & Crew
Int'l de	International Design & Approvals Standards for Fire Protection Sy
Hazard A	Hazard Analysis Review of Regulations
Develop	Develop Alternative Design Assessment Methodology
Mach Spa	Investigate Machinery Space Lagging wrt Fire Protection

Distributive Mode

(What-If Scenario)

Figure 29 – POLLUTIONS Sensitivity Graph

Gradient Sensitivity w.r.t. GOAL for nodes below GOAL



Abbreviation	Definition
MANDATES	Addresses mandates or regulatory issues.
PROGRAM	R&D Program issues.
VSLADDR	Vessels Addressed
POLLUTIO	Pollution Prevention potential.
COLLISIO	Collision and Allision reduction potential.

Egress o	Egress of Passengers & Crew
Int'l de	International Design & Approvals Standards for Fire Protection Sy
Hazard A	Hazard Analysis Review of Regulations
Develop	Develop Alternative Design Assessment Methodology
Mach Spa	Investigate Machinery Space Lagging wrt Fire Protection

Distributive Mode

(What-If Scenario)

Figure 30 – COLLISIONS Sensitivity Graph

Figure 26 shows the sensitivity gradient graph for the *MANDATES* attribute. It shows that if *MANDATES* had lower priority in the panel opinion, at a value of 0.34 versus the current value of 0.37, then Hazard Analysis Review of Regulations *(HAZARD A)* would be the preferred alternative over the current Egress of Passengers & Crew *(EGRESS O)* alternative. This represents the fact that more of the MANDATES issues are affected by Egress of Passengers & Crew *(EGRESS O)* alternative than the Hazard Analysis Review of Regulations *(HAZARD A)* alternative.

Figure 27 shows the sensitivity gradient graph for the *PROGRAM* attribute. It shows the tradeoff point with then Hazard Analysis Review of Regulations *(HAZARD A)* occurs just slightly below the current priority. This is essentially saying that from the point of view of the *PROGRAM's* issues, the two alternatives are identical.

Figure 28 shows the sensitivity gradient graph for the vessels addressed *(VSLADDR)* attribute. It shows that the two alternatives, Egress of Passengers & Crew *(EGRESS O)* and the Hazard Analysis Review of Regulations *(HAZARD A)* priorities are equal across the seven vessel type groupings. Neither alternative has a higher priority.

Figure 29 shows the sensitivity gradient graph for the *POLLUTION* attribute. It shows that a trade-off to the Hazard Analysis Review of Regulations *(HAZARD A)* alternative occurs if *POLLUTION* had a higher priority with the panel.

Figure 30 shows the sensitivity gradient graph for the *COLLISION* attribute. It shows that a trade-off point between the Egress of Passengers & Crew *(EGRESS O)* and the Hazard Analysis Review of Regulations *(HAZARD A)* alternatives occur if *COLLISION* had a higher priority with the panel.

The sensitivity analysis indicates the two alternatives, Egress of Passengers & Crew *(EGRESS O)* and the Hazard Analysis Review of Regulations *(HAZARD A)* have very similar priorities and that only slight changes in the encoded priorities could result in the inverse of their final rating. Therefore selection of one alternative over the other would not be a significant deviation from the panel's encoded priorities.

CONCLUSIONS

The risk-based decision methodology presented in this work was used to generate a ranked list of potential areas for fire research and development resource allocation. The work was performed for the United States Coast Guard, to support its regulatory programs on fire safety for commercial vessels. The ranking of the list of possible areas was derived from a six-step process.

The first step was the determination of historical fire problems with the highest risk for commercial vessels under the Coast Guards' regulatory authority. This was performed by analyzing information from two marine casualty databases. An expert panel of fire safety regulatory decision-makers was then assembled. Expected loss analysis of the historical casualty information from the two databases was used to inform to the panel. A multi-attribute decision model was constructed based on the panel's recommendations. The panel then performed pairwise comparisons of the attributes to establish the relative importance of each attribute. The comparisons were then synthesized using an Analytical Hierarchy Process in a commercial software package. The panel also formulated eighteen alternative areas for possible R & D resource allocation. The alternatives were rated against the attributes using a simple two or three-point scoring model. The rating results were totaled to generate the ranked list of alternative fire research areas. Sensitivity analysis was performed to assess the relative importance of the different attributes. The results were then presented to the Coast Guard decision-makers to assist them in their research and development resource allocation efforts.

The methodology presented here has three main attributes that should be very beneficial to the Coast Guard. The first is that it calculates the expected loss for various vessel types, fire origin locations on the vessels, and the ignition sources based on documented historical incidents. The past decision process was more subject to the availability heuristic bias. The decision-makers could easily be swayed by one or two large fire incidents or their perception of a trend in incidents occurring. The process however does not prevent this type of potentially valuable "expert opinion" from being encoded into the calculations. Instead, it attempts to foster the best of both expert encodings, the panel's knowledge and the historical casualty information.

The second beneficial attribute of the method is that it is aligned with the Research and Development Program's (G-SIR) rating system. By having this low level method use similar attributes as used in the higher level rating system, areas for research and development that are submitted for R&D resource allocation will be better aligned for ranking well in the higher level rating system.

The final benefit of the method is that it provides documentation of the decision. This can be useful at a later point when questions may arise as to why a particular research effort was undertaken. More importantly, it provides important measurement data points for the Marine Safety and Environmental Protection program's efforts to comply with the Government Performance and Results Act (GPRA). This law requires that all government programs measure their performance and demonstrate the results of their efforts. Regulatory actions must demonstrate that the benefits of the regulation out weigh the cost of implementing it. This method will support these types of efforts in the R&D decision making process.

The analysis of the information from the two databases resulted in the identification of fishing vessels as the vessel type with the highest expected loss given that a fire occurs on a vessel. The second highest expected loss occurs with tug and offshore supply vessel types. Analysis of the location of origin of a fire on a vessel indicated that machinery spaces had the highest expected loss. Cargo areas and accommodation spaces were the second and third highest expected loss locations. Analysis of ignition sources identified hot surfaces and electrical ignitions as the highest expected loss in machinery spaces and electrical ignitions as the highest expected loss in cargo areas as well as accommodation spaces. The risk analysis was limited by the lack of vessel population data for the fleet that encompasses all of the incidents in the Coast Guard's MSIS database. If reliable estimates for the population of this fleet can be found, the risk analysis presented here could be strengthened to a true risk calculation.

Lloyd's database lacked severity information (cost of damages), so risk calculations could not be performed on its information.

The decision-making process resulted in a list of ranked research and development areas for possible consideration for research and development resources allocation. The top five alternatives were subjected to a sensitivity analysis to determine the relative importance each rating attribute had on the respective rankings. This analysis indicated that the top two alternatives had similar priorities and that with only slight changes in the encoded attributes' priorities could have resulted in a reversal of their final ranking. The top two alternatives were Egress of Passengers & Crew *(EGRESS O)* and the Hazard Analysis Review of Regulations *(HAZARD A)*. Therefore, selection of one alternative over the other would not be a significant deviation from the panel's encoded priorities.

From this decision-making effort, the Coast Guard should consider for possible allocation of research and development resources the Egress of Passengers and Crew *(EGRESS O)* alternative and the Hazard Analysis Review of Regulations *(HAZARD A)* alternative. Either of these two areas will address the greatest number of high-expected loss problem areas found in the historical casualty information.

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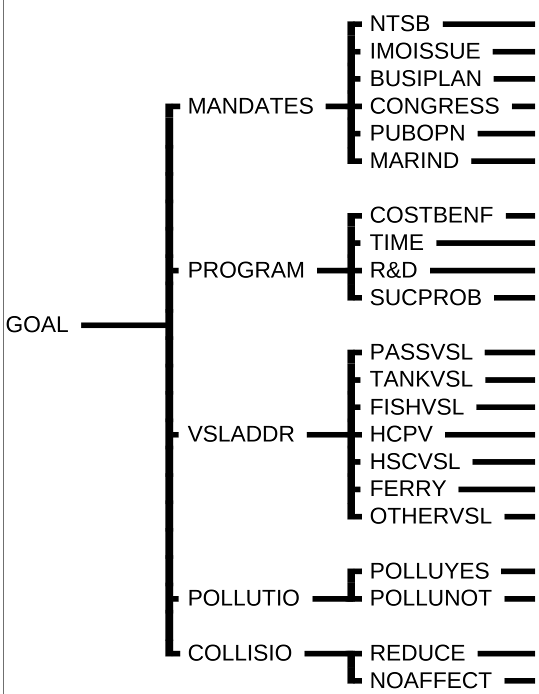
6. Lloyd's Register of Shipping World Fleet Statistics, 1997, Lloyd's Register of Shipping, London, 1998.

APPENDIX A

Attributes Questionnaire

Determine the most appropriate fire research areas/projects.



RDC

Determine the most appropriate fire research areas/projects.

Distributive Mode

Abbreviation	Definition
GOAL	
ADVERSE	Adverse public opinion possible.
AFFECTS	Affects this vessel type.
BUSIPLAN	Fits into G-M business plan
BUSNOT	Does not meet G-M's business plan goals.
COLLISIO	Collision and Allision reduction potential.
CONGRESS	Congressional Mandate
COSTBENF	Cost Benefit
DOESN'T	Doesn't address this vessel type.
FERRY	Ferry Vessles
FISHVSL	Fishing Vessel safety
HCPV	High Capacity Passenger vessel
HSCVSL	High Speed Craft Code vessels
IMOISSU	Will affect an IMO issue.
IMOISSUE	IMO issue
IMONOT	No affect on IMO issues expected.
IMOPOSS	Will possibly affect IMO issue or future IMO issue.
LIKELY	Success in the project likely.
MANDATE	Congressial Mandated item.
MANDATES	Addresses mandates or regulatory issues.
MANDNOT	Not Congressionally mandated issue.
MARADVRS	Adversely impacts on marine industry.
MARIND	Adverse Impact on Marine Industry
MARNEUTR	Neither supports or adversely impacts marine industry.
MEETS	Meets G-M Business Plan.
NEGATIVE	Has negative cost benefit.
NOAFFECT	Will likely have no affect on reducing collisions and allisions.
NOTR&D	Issue requires no R&D effort.
NOTTIME	Expected results will not meet anticipated time requirements.
NTSB	NTSB Recommendation issue
NTSBISSU	Will directly affect NTSB issue.
NTSBNOT	No affect on any NTSB issues.
NTSBPOSS	Possible will affect NTSB issue.
OTHERVSL	Other Vessel type.
PASSVSL	Affect passenger vessels
POLLUNOT	Not likely to reduce potential for pollution incidents.
POLLUTIO	Pollution Prevention potential.
POLLUYES	Likely will reduce potential for pollution incidents.
POSITIVE	Has positive cost benefit.
POSSIBLE	Success of project is possible.
PROGRAM	R&D Program issues.
PUBOPN	Public Opinion
R&D	Is R&D needed?
REDUCE	Potential to reduce collision and allision incidents.
SUCPROB	Probability of success of an effort.
SUPPORT	Has public opinion support.
SUPPORTS	Will support marine industry.
TANKVSL	Affect Tank vessels safety
TIME	Time to complete
TIMELY	Will timely meet needs.
UNLIKELY	Success of project is unlikely.
VSLADDR	Vessels Addressed
YESR&D	R&D efforts are needed.

RDC

Determine the most appropriate fire research areas/projects.

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	MANDATES	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	PROGRAM
2	MANDATES	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	VSLADDR
3	MANDATES	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	POLLUTIO
4	MANDATES	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	COLLISIO
5	PROGRAM	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	VSLADDR
6	PROGRAM	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	POLLUTIO
7	PROGRAM	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	COLLISIO
8	VSLADDR	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	POLLUTIO
9	VSLADDR	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	COLLISIO
10	POLLUTIO	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	COLLISIO

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
MANDATES	Addresses mandates or regulatory issues.
PROGRAM	R&D Program issues.
VSLADDR	Vessels Addressed
POLLUTIO	Pollution Prevention potential.
COLLISIO	Collision and Allision reduction potential.

Determine the most appropriate fire research areas/projects.

Node: 10000

Compare the relative IMPORTANCE with respect to: MANDATES < GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	NTSB	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	IMOISSUE
2	NTSB	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	BUSIPLAN
3	NTSB	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	CONGRESS
4	NTSB	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	PUBOPN
5	NTSB	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	MARIND
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7	IMOISSUE	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	CONGRESS
8	IMOISSUE	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	PUBOPN
9	IMOISSUE	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	MARIND
10	BUSIPLAN	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	CONGRESS
11	BUSIPLAN	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	PUBOPN
12	BUSIPLAN	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	MARIND
13	CONGRESS	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	PUBOPN
14	CONGRESS	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	MARIND
15	PUBOPN	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	MARIND

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
MANDATES	Addresses mandates or regulatory issues.
NTSB	NTSB Recommendation issue
IMOISSUE	IMO issue
BUSIPLAN	Fits into G-M business plan
CONGRESS	Congressional Mandate
PUBOPN	Public Opinion
MARIND	Adverse Impact on Marine Industry

Node: 20000

Compare the relative IMPORTANCE with respect to: PROGRAM < GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	COSTBENF	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	TIME
2	COSTBENF	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	R&D
3	COSTBENF	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	SUCPROB
4	TIME	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	R&D
5	TIME	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	SUCPROB
6	R&D	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	SUCPROB

Abbreviation	**Definition**
Goal	Determine the most appropriate fire research areas/projects.
PROGRAM	R&D Program issues.
COSTBENF	Cost Benefit
TIME	Time to complete
R&D	Is R&D needed?
SUCPROB	Probability of success of an effort.

Node: 30000

Compare the relative IMPORTANCE with respect to: VSLADDR < GOAL

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9=EXTREME

1	PASSVSL	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	TANKVSL
2	PASSVSL	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	FISHVSL
3	PASSVSL	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	HCPV
4	PASSVSL	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	HSCVSL
5	PASSVSL	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	FERRY
6	PASSVSL	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	OTHERVSL
7	TANKVSL	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	FISHVSL
8	TANKVSL	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	HCPV
9	TANKVSL	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	HSCVSL
10	TANKVSL	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	FERRY
11	TANKVSL	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	OTHERVSL
12	FISHVSL	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	HCPV
13	FISHVSL	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	HSCVSL
14	FISHVSL	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	FERRY
15	FISHVSL	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	OTHERVSL
16	HCPV	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	HSCVSL
17	HCPV	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	FERRY
18	HCPV	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	OTHERVSL
19	HSCVSL	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	FERRY
20	HSCVSL	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	OTHERVSL
21	FERRY	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	OTHERVSL

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
VSLADDR	Vessels Addressed
PASSVSL	Affect passenger vessels
TANKVSL	Affect Tank vessels safety
FISHVSL	Fishing Vessel safety
HCPV	High Capacity Passenger vessel
HSCVSL	High Speed Craft Code vessels
FERRY	Ferry Vessles
OTHERVSL	Other Vessel type.

APPENDIX B

Ratings Questionnaire

GOAL: Determine the Most appropriate fire research areas/projects

Rating of Alternatives for Mandate Issues.

Check the appropriate box for each alternative area listed

Areas of for Possible Research	NTSB issues			IMO issue			G-M Bussiness Plan	
	Affects	Possible	No Affects	Issue	Possible	Not	Meets	Does Not
Smoke Control Measures								
Mach Space - Arrangement of equipment								
Mach Space - Lagging wrt Fire Protection								
Mach Space - Monitoring techniques to red cas								
Mach Space - Monitoring of equipment condition								
Int’l design & approval stds for Fire Prot Systems								
Electrical standards review wrt Fire Protection								
Alternative Fuels as cargo wrt Fire Prot								
Hazard Analysis Review of Regulations								
Egress of Mach Spaces								
Egress of Passengers & Crew								
Fire fighting doctrine development incl HF								
Larger Passenger Ship hazard analysis								
Satellite/Internet call up hazard assistance								
Double hull void space hazard analysis								
Alternatives to welding								
Alt construction techniques haz anal - adhesives, etc.								
Develop alt design assessment methodology								

GOAL: Determine the Most appropriate fire research areas/projects
Rating of Alternatives for Mandate Issues.

Check the appropriate box for each alternative area listed

Areas of for Possible Research	Congressional		Public Opinion		Marine Industry Impact		
	Mandate	Not	Supportive	Adverse	Supports	Neutral	Adverse
Smoke Control Measures							
Mach Space - Arrangement of equipment							
Mach Space - Lagging wrt Fire Protection							
Mach Space - Monitoring techniques to red cas							
Mach Space - Monitoring of equipment condition							
Int'l design & approval stds for Fire Prot Systems							
Electrical standards review wrt Fire Protection							
Alternative Fuels as cargo wrt Fire Prot							
Hazard Analysis Review of Regulations							
Egress of Mach Spaces							
Egress of Passengers & Crew							
Fire fighting doctrine development incl HF							
Larger Passenger Ship hazard analysis							
Satellite/Internet call up hazard assistance							
Double hull void space hazard analysis							
Alternatives to welding							
Alt construction techniques haz anal - adhesives, etc.							
Develop alt design assessment methodology							

GOAL: Determine the Most appropriate fire research areas/projects
Rating Alternatives for Program Issues.

Check the appropriate box for each alternative area listed

Areas of for Possible Research	Cost Benefit		Time Requirements		R&D is needed		Probability of Success		
	Positive	Negative	Timely	Not	Yes	No	Likely	Possible	Unlikely
Smoke Control Measures									
Mach Space - Arrangement of equipment									
Mach Space - Lagging wrt Fire Protection									
Mach Space - Monitoring techniques to red cas									
Mach Space - Monitoring of equipment condition									
Int'l design & approval stds for Fire Prot Systems									
Electrical standards review wrt Fire Protection									
Alternative Fuels as cargo wrt Fire Prot									
Hazard Analysis Review of Regulations									
Egress of Mach Spaces									
Egress of Passengers & Crew									
Fire fighting doctrine development incl HF									
Larger Passenger Ship hazard analysis									
Satellite/Internet call up hazard assistance									
Double hull void space hazard analysis									
Alternatives to welding									
Alt construction techniques haz anal - adhesives, etc.									
Develop alt design assessment methodology									

GOAL: Determine the Most appropriate fire research areas/projects
Rating Alternatives for Vessels Addressed.

Check the appropriate box for each alternative area listed

Areas of for Possible Research	Passenger Vsls		Tank Vessels		Fishing Vsls		High Cap Pass Vsls	
	Affected	Not	Affected	Not	Affected	Not	Affected	Not
Smoke Control Measures								
Mach Space - Arrangement of equipment								
Mach Space - Lagging wrt Fire Protection								
Mach Space - Monitoring techniques to red cas								
Mach Space - Monitoring of equipment condition								
Int'l design & approval stds for Fire Prot Systems								
Electrical standards review wrt Fire Protection								
Alternative Fuels as cargo wrt Fire Prot								
Hazard Analysis Review of Regulations								
Egress of Mach Spaces								
Egress of Passengers & Crew								
Fire fighting doctrine development incl HF								
Larger Passenger Ship hazard analysis								
Satellite/Internet call up hazard assistance								
Double hull void space hazard analysis								
Alternatives to welding								
Alt construction techniques haz anal - adhesives, etc.								
Develop alt design assessment methodology								

GOAL: Determine the Most appropriate fire research areas/projects
Rating Alternatives for Vessels Addressed.

Check the appropriate box for each alternative area listed

Areas of for Possible Research	High Speed Craft		Ferry		Other Vessels	
	Affected	Not	Affected	Not	Affected	Not
Smoke Control Measures						
Mach Space - Arrangement of equipment						
Mach Space - Lagging wrt Fire Protection						
Mach Space - Monitoring techniques to red cas						
Mach Space - Monitoring of equipment condition						
Int'l design & approval stds for Fire Prot Systems						
Electrical standards review wrt Fire Protection						
Alternative Fuels as cargo wrt Fire Prot						
Hazard Analysis Review of Regulations						
Egress of Mach Spaces						
Egress of Passengers & Crew						
Fire fighting doctrine development incl HF						
Larger Passenger Ship hazard analysis						
Satellite/Internet call up hazard assistance						
Double hull void space hazard analysis						
Alternatives to welding						
Alt construction techniques haz anal - adhesives, etc.						
Develop alt design assessment methodology						

APPENDIX C

Decomposition of the Model with Derived Priorities for the Top Five Alternatives

Determine the most appropriate fire research areas/projects.

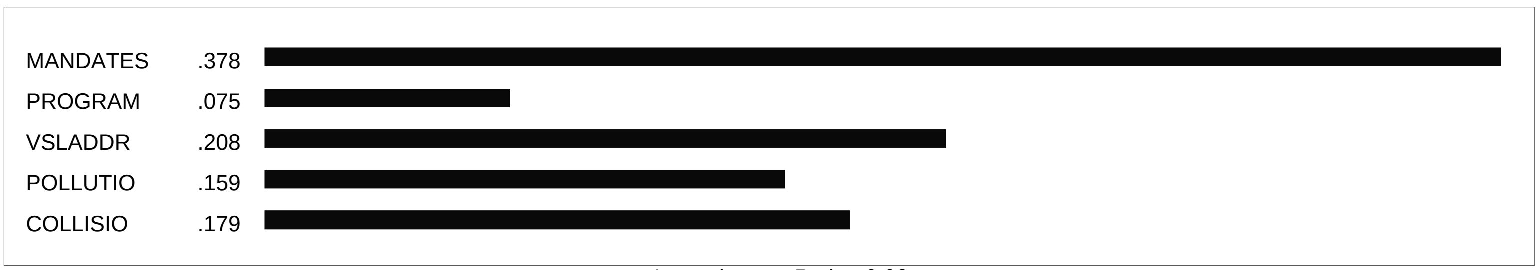
Node: 0

Compare the relative IMPORTANCE with respect to: GOAL

	PROGRAM	VSLADDR	POLLUTIO	COLLISIO
MANDATES	5.3	2.3	1.8	2.1
PROGRAM		(2.1)	(2.1)	(2.9)
VSLADDR			1.6	1.5
POLLUTIO				(1.2)

Row element is __ times more than column element unless enclosed in ()

Abbreviation	**Definition**
Goal	Determine the most appropriate fire research areas/projects.
MANDATES	Addresses mandates or regulatory issues.
PROGRAM	R&D Program issues.
VSLADDR	Vessels Addressed
POLLUTIO	Pollution Prevention potential.
COLLISIO	Collision and Allision reduction potential.



Inconsistency Ratio =0.02

RDC

Goal Plex w/Derived Priorities

Determine the most appropriate fire research areas/projects.

Node: 10000

Compare the relative IMPORTANCE with respect to: MANDATES < GOAL

	IMOISSUE	BUSIPLAN	CONGRESS	PUBOPN	MARIND
NTSB	(4.6)	(2.1)	(6.8)	1.1	(1.7)
IMOISSUE		1.9	(3.6)	2.7	1.9
BUSIPLAN			(5.5)	1.3	1.0
CONGRESS				3.9	3.3
PUBOPN					(3.2)

Row element is __ times more than column element unless enclosed in ()

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
MANDATES	Addresses mandates or regulatory issues.
NTSB	NTSB Recommendation issue
IMOISSUE	IMO issue
BUSIPLAN	Fits into G-M business plan
CONGRESS	Congressional Mandate
PUBOPN	Public Opinion
MARIND	Adverse Impact on Marine Industry

RDC

Mandates Plex w/Derived Priorities

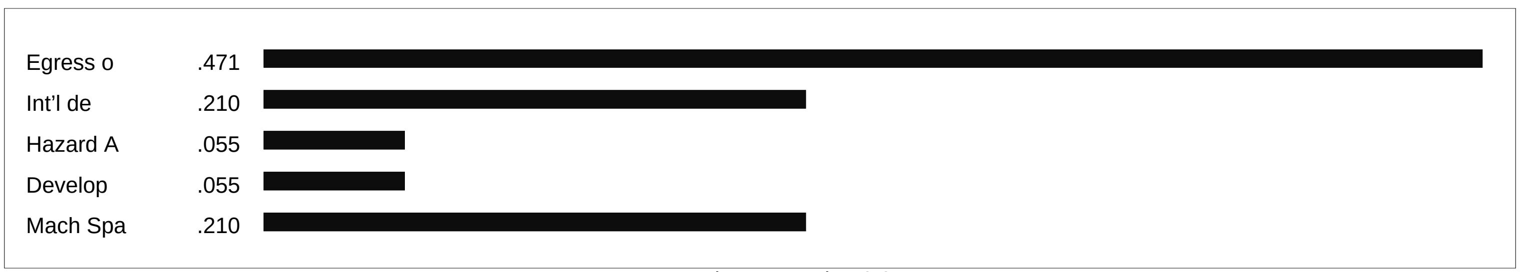
Determine the most appropriate fire research areas/projects.

Node: 11000

Data with respect to: NTSB < MANDATES < GOAL

Egress o	.56133
Int'l de	.24966
Hazard A	.06498
Develop	.06498
Mach Spa	.24966

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
MANDATES	Addresses mandates or regulatory issues.
NTSB	NTSB Recommendation issue
Egress o	Egress of Passengers & Crew
Int'l de	International Design & Approvals Standards for Fire Protection Sy
Hazard A	Hazard Analysis Review of Regulations
Develop	Develop Alternative Design Assessment Methodology
Mach Spa	Investigate Machinery Space Lagging wrt Fire Protection



Inconsistency Ratio =0.0

RDC

NTSB Issues Plex w/Derived Priorities

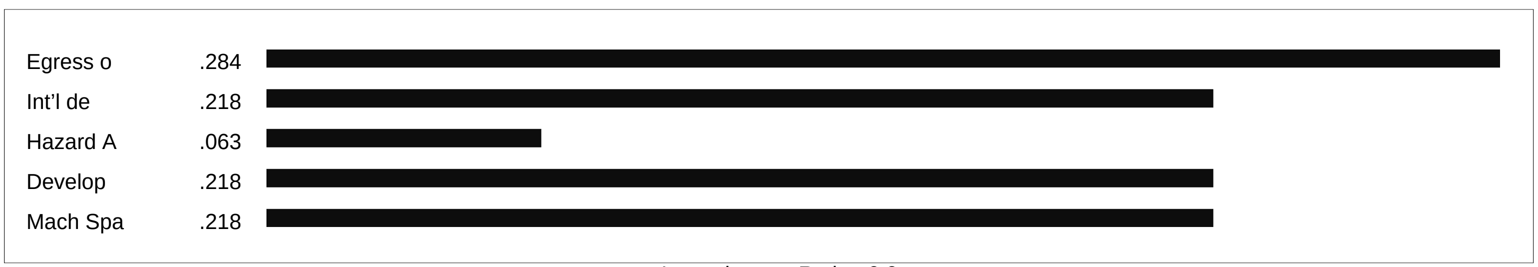
Determine the most appropriate fire research areas/projects.

Node: 12000

Data with respect to: IMOISSUE < MANDATES < GOAL

Egress o	1.
Int'l de	.76762
Hazard A	.22228
Develop	.76762
Mach Spa	.76762

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
MANDATES	Addresses mandates or regulatory issues.
IMOISSUE	IMO issue
Egress o	Egress of Passengers & Crew
Int'l de	International Design & Approvals Standards for Fire Protection Sy
Hazard A	Hazard Analysis Review of Regulations
Develop	Develop Alternative Design Assessment Methodology
Mach Spa	Investigate Machinery Space Lagging wrt Fire Protection



Inconsistency Ratio =0.0

RDC

IMO Issues Plex w/Derived Priorities

Determine the most appropriate fire research areas/projects.

Node: 13000

Data with respect to: BUSIPLAN < MANDATES < GOAL

Egress o	.40741
Int'l de	1.
Hazard A	1.
Develop	1.
Mach Spa	.7037

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
MANDATES	Addresses mandates or regulatory issues.
BUSIPLAN	Fits into G-M business plan
Egress o	Egress of Passengers & Crew
Int'l de	International Design & Approvals Standards for Fire Protection Sy
Hazard A	Hazard Analysis Review of Regulations
Develop	Develop Alternative Design Assessment Methodology
Mach Spa	Investigate Machinery Space Lagging wrt Fire Protection

Inconsistency Ratio =0.0

RDC

G-M Business Plan Plex w/Derived Priorities

Determine the most appropriate fire research areas/projects.

Node: 14000

Data with respect to: CONGRESS < MANDATES < GOAL

Egress o	.40741
Int'l de	.40741
Hazard A	.11111
Develop	.11111
Mach Spa	.11111

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
MANDATES	Addresses mandates or regulatory issues.
CONGRESS	Congressional Mandate
Egress o	Egress of Passengers & Crew
Int'l de	International Design & Approvals Standards for Fire Protection Sy
Hazard A	Hazard Analysis Review of Regulations
Develop	Develop Alternative Design Assessment Methodology
Mach Spa	Investigate Machinery Space Lagging wrt Fire Protection

Inconsistency Ratio =0.0

RDC

Congressional Mandate Plex w/Derived Priorities

Node: 15000

Data with respect to: PUBOPN < MANDATES < GOAL

Egress o	1.
Int'l de	1.
Hazard A	.7037
Develop	.7037
Mach Spa	.55556

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
MANDATES	Addresses mandates or regulatory issues.
PUBOPN	Public Opinion
Egress o	Egress of Passengers & Crew
Int'l de	International Design & Approvals Standards for Fire Protection Sy
Hazard A	Hazard Analysis Review of Regulations
Develop	Develop Alternative Design Assessment Methodology
Mach Spa	Investigate Machinery Space Lagging wrt Fire Protection

Inconsistency Ratio =0.0

Public Opinion Plex w/Derived Priorities

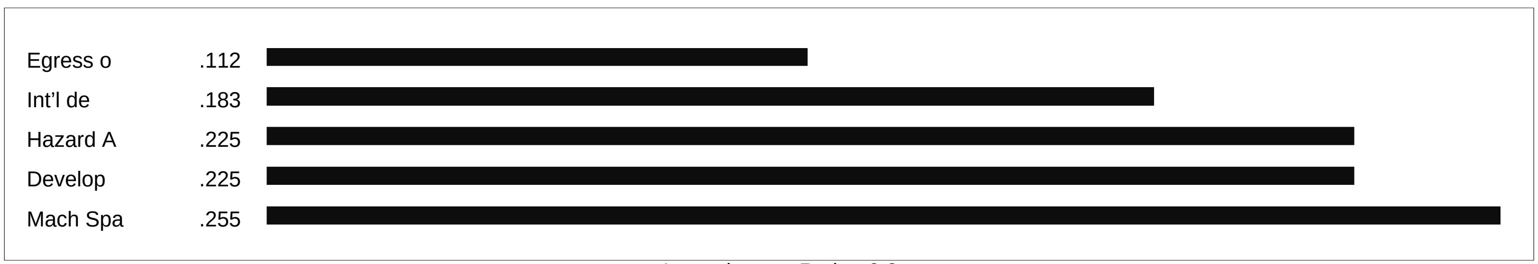
Determine the most appropriate fire research areas/projects.

Node: 16000

Data with respect to: MARIND < MANDATES < GOAL

Egress o	.342
Int’l de	.56133
Hazard A	.68833
Develop	.68833
Mach Spa	.78067

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
MANDATES	Addresses mandates or regulatory issues.
MARIND	Adverse Impact on Marine Industry
Egress o	Egress of Passengers & Crew
Int’l de	International Design & Approvals Standards for Fire Protection Sy
Hazard A	Hazard Analysis Review of Regulations
Develop	Develop Alternative Design Assessment Methodology
Mach Spa	Investigate Machinery Space Lagging wrt Fire Protection



Inconsistency Ratio =0.0

RDC

Adverse Marine Impact Plex w/Derived Priorities

Determine the most appropriate fire research areas/projects.

Node: 20000

Compare the relative IMPORTANCE with respect to: PROGRAM < GOAL

	TIME	R&D	SUCPROB
COSTBENF	2.0	(3.3)	(1.2)
TIME		(3.3)	(2.1)
R&D			2.9

Row element is __ times more than column element unless enclosed in ()

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
PROGRAM	R&D Program issues.
COSTBENF	Cost Benefit
TIME	Time to complete
R&D	Is R&D needed?
SUCPROB	Probability of success of an effort.

Inconsistency Ratio =0.02

RDC

R & D Program Issues Plex w/Derived Priorities

Determine the most appropriate fire research areas/projects.

Node: 21000

Data with respect to: COSTBENF < PROGRAM < GOAL

Egress o	1.
Int'l de	.7037
Hazard A	.7037
Develop	.7037
Mach Spa	.7037

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
PROGRAM	R&D Program issues.
COSTBENF	Cost Benefit
Egress o	Egress of Passengers & Crew
Int'l de	International Design & Approvals Standards for Fire Protection Sy
Hazard A	Hazard Analysis Review of Regulations
Develop	Develop Alternative Design Assessment Methodology
Mach Spa	Investigate Machinery Space Lagging wrt Fire Protection

Inconsistency Ratio =0.0

RDC

Cost Benefit Plex w/Derived Priorites

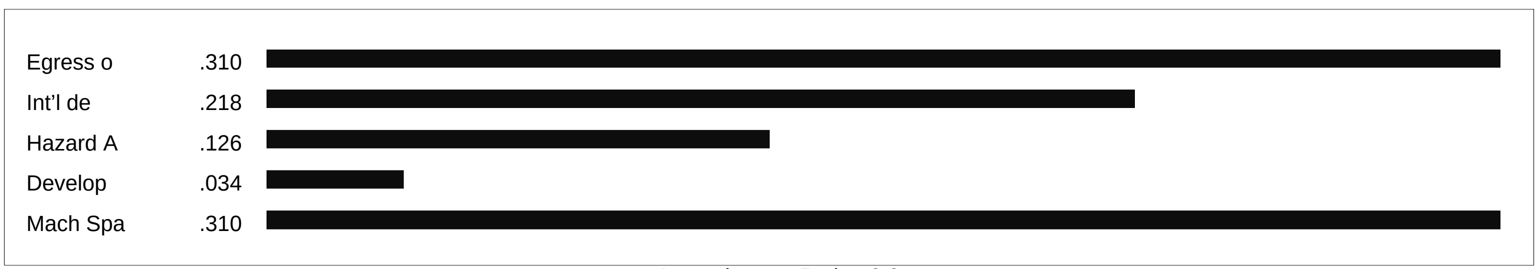
Determine the most appropriate fire research areas/projects.

Node: 22000

Data with respect to: TIME < PROGRAM < GOAL

Egress o	1.
Int'l de	.7037
Hazard A	.40741
Develop	.11111
Mach Spa	1.

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
PROGRAM	R&D Program issues.
TIME	Time to complete
Egress o	Egress of Passengers & Crew
Int'l de	International Design & Approvals Standards for Fire Protection Sy
Hazard A	Hazard Analysis Review of Regulations
Develop	Develop Alternative Design Assessment Methodology
Mach Spa	Investigate Machinery Space Lagging wrt Fire Protection



Inconsistency Ratio =0.0

RDC

Time to Complete Plex w/Derived Priorities

Determine the most appropriate fire research areas/projects.

Node: 23000

Data with respect to: R&D < PROGRAM < GOAL

Egress o	1.
Int'l de	.7037
Hazard A	.7037
Develop	1.
Mach Spa	.40741

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
PROGRAM	R&D Program issues.
R&D	Is R&D needed?
Egress o	Egress of Passengers & Crew
Int'l de	International Design & Approvals Standards for Fire Protection Sy
Hazard A	Hazard Analysis Review of Regulations
Develop	Develop Alternative Design Assessment Methodology
Mach Spa	Investigate Machinery Space Lagging wrt Fire Protection

Inconsistency Ratio =0.0

RDC

Is R & D Needed Plex w/Derived Priorities

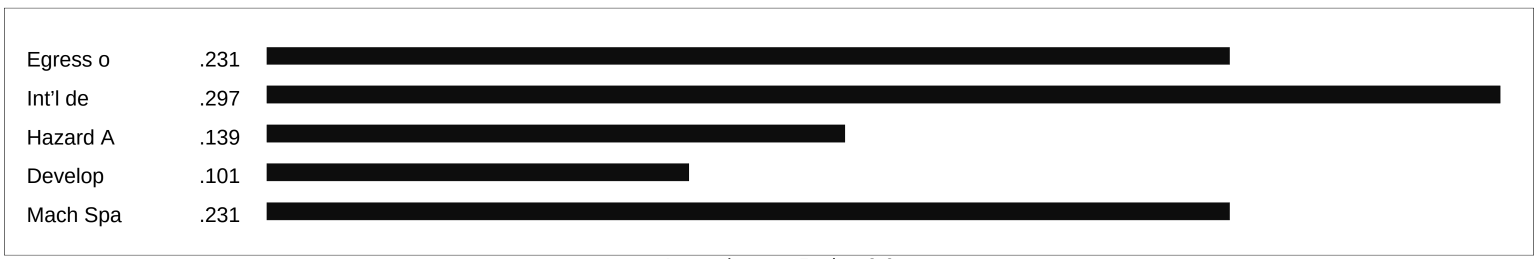
Determine the most appropriate fire research areas/projects.

Node: 24000

Data with respect to: SUCPROB < PROGRAM < GOAL

Egress o	.78067
Int'l de	1.
Hazard A	.46899
Develop	.342
Mach Spa	.78067

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
PROGRAM	R&D Program issues.
SUCPROB	Probability of success of an effort.
Egress o	Egress of Passengers & Crew
Int'l de	International Design & Approvals Standards for Fire Protection Sy
Hazard A	Hazard Analysis Review of Regulations
Develop	Develop Alternative Design Assessment Methodology
Mach Spa	Investigate Machinery Space Lagging wrt Fire Protection



Inconsistency Ratio =0.0

RDC

Probability of Success Plex w/Derived Priorities

Node: 30000

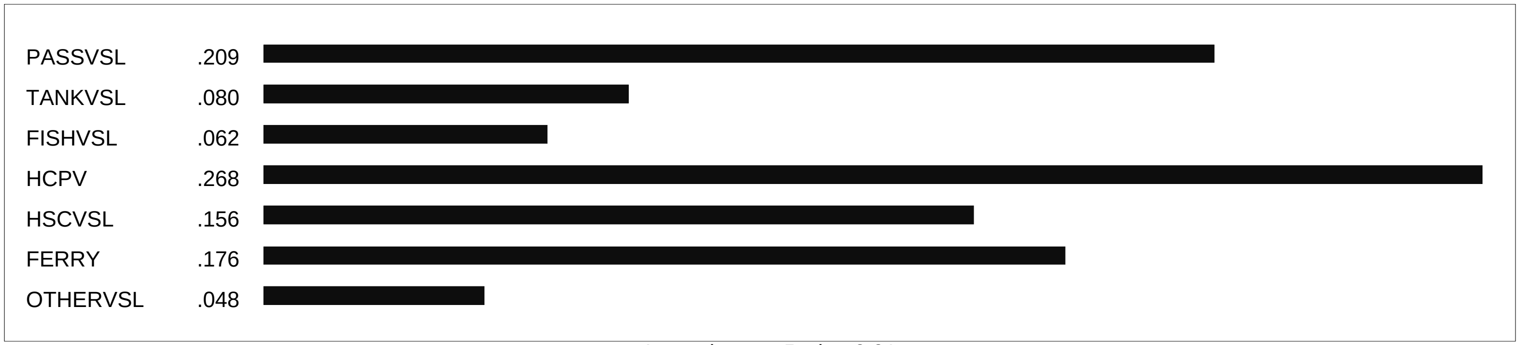
Compare the relative IMPORTANCE with respect to: VSLADDR < GOAL

	TANKVSL	FISHVSL	HCPV	HSCVSL	FERRY	OTHERVSL
PASSVSL	3.6	4.0	(1.6)	1.0	1.4	3.5
TANKVSL		1.3	(3.2)	(1.8)	(2.5)	2.2
FISHVSL			(3.1)	(2.7)	(3.0)	1.3
HCPV				2.4	1.5	4.6
HSCVSL					(1.1)	3.4
FERRY						3.7

Row element is __ times more than column element unless enclosed in ()

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
VSLADDR	Vessels Addressed
PASSVSL	Affect passenger vessels
TANKVSL	Affect Tank vessels safety
FISHVSL	Fishing Vessel safety
HCPV	High Capacity Passenger vessel
HSCVSL	High Speed Craft Code vessels
FERRY	Ferry Vessles
OTHERVSL	Other Vessel type.

Determine the most appropriate fire research areas/projects.



Inconsistency Ratio =0.01

RDC

Vessels Addressed Plex w/Derived Priorities Part 2

Determine the most appropriate fire research areas/projects.

Node: 31000

Data with respect to: PASSVSL < VSLADDR < GOAL

Egress o	1.
Int'l de	1.
Hazard A	1.
Develop	1.
Mach Spa	1.

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
VSLADDR	Vessels Addressed
PASSVSL	Affect passenger vessels
Egress o	Egress of Passengers & Crew
Int'l de	International Design & Approvals Standards for Fire Protection Sy
Hazard A	Hazard Analysis Review of Regulations
Develop	Develop Alternative Design Assessment Methodology
Mach Spa	Investigate Machinery Space Lagging wrt Fire Protection

Inconsistency Ratio =0.0

RDC

Passenger Vessels Plex w/Derived Priorities

Determine the most appropriate fire research areas/projects.

Node: 32000

Data with respect to: TANKVSL < VSLADDR < GOAL

Egress o	1.
Int'l de	1.
Hazard A	1.
Develop	1.
Mach Spa	1.

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
VSLADDR	Vessels Addressed
TANKVSL	Affect Tank vessels safety
Egress o	Egress of Passengers & Crew
Int'l de	International Design & Approvals Standards for Fire Protection Sy
Hazard A	Hazard Analysis Review of Regulations
Develop	Develop Alternative Design Assessment Methodology
Mach Spa	Investigate Machinery Space Lagging wrt Fire Protection

Inconsistency Ratio =0.0

RDC

Tank Vessels Plex w/Derived Priorities

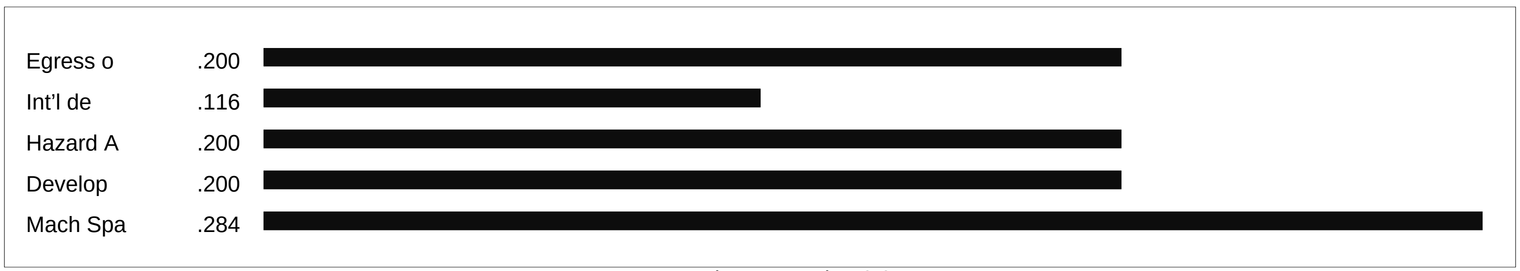
Determine the most appropriate fire research areas/projects.

Node: 33000

Data with respect to: FISHVSL < VSLADDR < GOAL

Egress o	.704
Int'l de	.40741
Hazard A	.704
Develop	.704
Mach Spa	1.

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
VSLADDR	Vessels Addressed
FISHVSL	Fishing Vessel safety
Egress o	Egress of Passengers & Crew
Int'l de	International Design & Approvals Standards for Fire Protection Sy
Hazard A	Hazard Analysis Review of Regulations
Develop	Develop Alternative Design Assessment Methodology
Mach Spa	Investigate Machinery Space Lagging wrt Fire Protection



Inconsistency Ratio =0.0

RDC

Fishing Vessels Plex w/Derived Priorities

Determine the most appropriate fire research areas/projects.

Node: 34000

Data with respect to: HCPV < VSLADDR < GOAL

Egress o	1.
Int'l de	1.
Hazard A	1.
Develop	1.
Mach Spa	1.

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
VSLADDR	Vessels Addressed
HCPV	High Capacity Passenger vessel
Egress o	Egress of Passengers & Crew
Int'l de	International Design & Approvals Standards for Fire Protection Sy
Hazard A	Hazard Analysis Review of Regulations
Develop	Develop Alternative Design Assessment Methodology
Mach Spa	Investigate Machinery Space Lagging wrt Fire Protection

Inconsistency Ratio =0.0

RDC

High Capacity Passenger Vessels Plex w/Derived Priorities

Node: 35000

Data with respect to: HSCVSL < VSLADDR < GOAL

Egress o	1.
Int’l de	1.
Hazard A	1.
Develop	1.
Mach Spa	.704

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
VSLADDR	Vessels Addressed
HSCVSL	High Speed Craft Code vessels
Egress o	Egress of Passengers & Crew
Int’l de	International Design & Approvals Standards for Fire Protection Sy
Hazard A	Hazard Analysis Review of Regulations
Develop	Develop Alternative Design Assessment Methodology
Mach Spa	Investigate Machinery Space Lagging wrt Fire Protection

Inconsistency Ratio =0.0

High Speed Craft Code Vessels Plex w/Derived Priorities

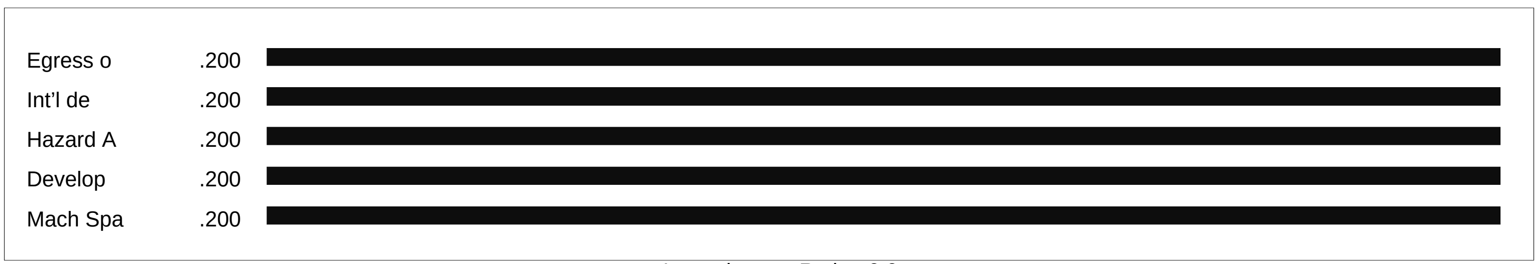
Determine the most appropriate fire research areas/projects.

Node: 36000

Data with respect to: FERRY < VSLADDR < GOAL

Egress o	1.
Int'l de	1.
Hazard A	1.
Develop	1.
Mach Spa	1.

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
VSLADDR	Vessels Addressed
FERRY	Ferry Vessles
Egress o	Egress of Passengers & Crew
Int'l de	International Design & Approvals Standards for Fire Protection Sy
Hazard A	Hazard Analysis Review of Regulations
Develop	Develop Alternative Design Assessment Methodology
Mach Spa	Investigate Machinery Space Lagging wrt Fire Protection



Inconsistency Ratio =0.0

RDC

Ferry Vessels Plex w/Derived Priorities

Determine the most appropriate fire research areas/projects.

Node: 37000

Data with respect to: OTHERVSL < VSLADDR < GOAL

Egress o	1.
Int'l de	.704
Hazard A	1.
Develop	.704
Mach Spa	.704

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
VSLADDR	Vessels Addressed
OTHERVSL	Other Vessel type.
Egress o	Egress of Passengers & Crew
Int'l de	International Design & Approvals Standards for Fire Protection Sy
Hazard A	Hazard Analysis Review of Regulations
Develop	Develop Alternative Design Assessment Methodology
Mach Spa	Investigate Machinery Space Lagging wrt Fire Protection

Inconsistency Ratio =0.0

RDC

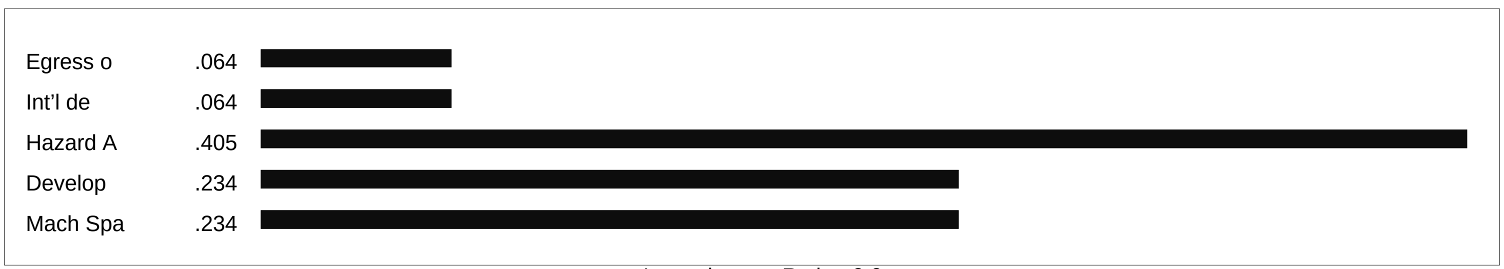
Other Vessel Types Plex w/Derived Priorities

Node: 40000

Data with respect to: POLLUTIO < GOAL

Egress o	.11111
Int'l de	.11111
Hazard A	.704
Develop	.407
Mach Spa	.407

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
POLLUTIO	Pollution Prevention potential.
Egress o	Egress of Passengers & Crew
Int'l de	International Design & Approvals Standards for Fire Protection Sy
Hazard A	Hazard Analysis Review of Regulations
Develop	Develop Alternative Design Assessment Methodology
Mach Spa	Investigate Machinery Space Lagging wrt Fire Protection



Inconsistency Ratio =0.0

Pollution Prevention Potential Plex w/Derived Priorities

Node: 50000

Data with respect to: COLLISIO < GOAL

Egress o	.11111
Int'l de	.11111
Hazard A	.11111
Develop	.11111
Mach Spa	.11111

Abbreviation	Definition
Goal	Determine the most appropriate fire research areas/projects.
COLLISIO	Collision and Allision reduction potential.
Egress o	Egress of Passengers & Crew
Int'l de	International Design & Approvals Standards for Fire Protection Sy
Hazard A	Hazard Analysis Review of Regulations
Develop	Develop Alternative Design Assessment Methodology
Mach Spa	Investigate Machinery Space Lagging wrt Fire Protection

Inconsistency Ratio =0.0

Collision and Allision Reduction Potential Plex w/Derived Priorities