SAFEDOR

design, operation and regulation for safety

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Editorial

The SAFEDOR Consortium is pleased to welcoming you as a reader of the 3rd SAFEDOR Newsletter, which appears bi-annually and informs about research activities and progress of the SAFEDOR Project. More detailed public domain information about the SAFEDOR project is provided in the Annual Public Reports, available on-line (http://www.safedor.org).

The SAFEDOR newsletters address readers from organisations from the whole spectrum of the maritime industry: flag state and government administrations, classification societies, designers, operators, researchers, educators, and practitioners of risk-based design. This third issue of the SAFEDOR newsletters introduces innovative ship design methods and related design software tools.

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Advanced Design Methods & Tools Activities in Brief

One of the principal and strategic objectives of SAFEDOR vision is to develop innovative ship design methods and tools to assess operational, extreme, accidental and catastrophic scenarios, accounting for the human element, and integrate these into a design environment.

Risk-based design entails the systematic integration of risk analysis in the design process targeting risk prevention / reduction as a design objective. To pursue this activity effectively, an integrated design environment to facilitate and support a holistic approach to ship design is needed enabling appropriate trade-offs and advanced decision-making, leading to optimal ship design solutions.

Risk-based ship design requires the availability of tools to predict the safety performance of the ship and its components. Therefore, a significant effort in SAFEDOR has been given to the development and refinements of such methods and tools. The safety issues mostly dealt with are associated with accidental loads like collision, grounding and fire. Effective procedures have been proposed, discussed, programmed, verified and partly validated with experimental data.

The SAFEDOR achievements so far in the development of innovative design methods and tools are summarised in the following:

- Fast and accurate flooding prediction tool for passenger vessels was developed.
- Structural reliability formulations for damaged ship hulls were developed.
- Two new methods to predict probability of loss of intact stability were developed.
- Prediction of collision and grounding probability was enhanced with new operator model, loss-of-steering model and new drift model.
- New methods for prediction of fire safety of container cargo and for fire safety of passenger ships were developed.
- New tool to generate fault trees for system failures was developed.

The following flowchart illustrates the envisaged integration of tools into the SAFEDOR Risk based design.

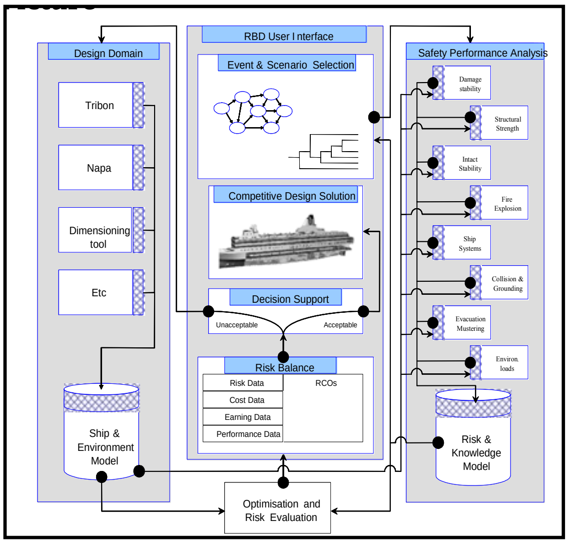


Figure 1: Tools Development Process

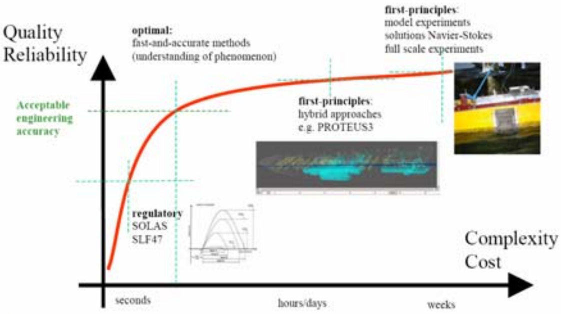
At the present stage, developed methods and tools have been only partly validated, but this process is still ongoing. Further details on the so-far achievements regarding the development of innovative methods and tools within the SAFEDOR research project are provided in the following pages. Additional information may be found in other publications of relevant SAFEDOR consortium partners, to appear in year 2007 and subsequent years. The reader might regularly check the SAFEDOR website (http://www.safedor.org) for updated information.

Flooding & Damage Stability

The main focus herein is on the development of fast flooding prediction methods and tools maintaining the accuracy of first principles time-domain simulations.

The loss of stability of a ship when subject to a damage and environmental impact could be categorized with respect to the time it takes from an instant of hull breach to an instant of capsize. The event of capsizing can be very rapid, of the order of a few seconds to a few minutes, during initial transient stages of flooding, or of the order of a few minutes to a few hours when progressive flooding take place, or it can be of the order of minutes to hours or days in case residual stability at an attained equilibrium is overcome by an additional amount of floodwater sustained by the action of waves.

In principle, the methodology addressing vessel's survivability should be capable of addressing any of these modes, especially when the stability is to be assessed in the context of risk to life. Advanced means to undertake such a comprehensive assessment exist. However, real application is not so straightforward due to the computational effort involved. Hence, as it is common in any engineering practice, a compromise is necessary to be found that can strike a balance between accuracy and practicality, as shown in Figure 2:



It is for this reason that deterministic regulations have been the principal instrument, provided by authorities as an alternative to highly complex tools, and developed with the purpose of quantifying relevant physical phenomena (such as stability) *fast*, and thus to be used routinely for verifying that a design is commensurate with the set standards.

Within the constraints of the present project's resources and time schedule, the approach adopted is based on the current rules addressing subdivision, which are accepted by the pertinent maritime community and authorities at large. Thus, the formulation in principle addresses all three modes of capsizing. Moreover, appropriate interpretation of the conceptualising underlying these rules, has allowed for formulation of a relationship between ship parameters, flooding extend and loading, and the severity of the critical environment, in an explicit manner.
At the same time, the revision of the prior experience with modelling of the *survival time* in the context of SAFEDOR objectives, have allowed putting forward the formulation of the "*time to capsize*", subject to the specific flooding extent, loading and environmental conditions, and which promises fast and accurate solution, hopefully acceptable in the near future by the authoritative bodies for use in the design process.

The main breakthroughs in the method development have been:

- Association of the index "s" (*ref. IMO SLF 47/17, September 2004*) with the severity of the critical sea state causing ship capsizing.
- Approximation of the capsize band, i.e. a range of sea conditions within which the probability of

vessel capsizing increases from nearly zero to nearly one as the sea state increases, with a standardised normal distribution.

- Conception that the random process of the time it takes the vessel to capsize after hull breach and flooding, as benchmarked today mostly in the context of the Stockholm Agreement procedure, can be shown to be well approximated by an established process of Bernoulli trials.

These three elements are the fundamental components of the new method. An indicative figure of results of the work performed to date is presented next:

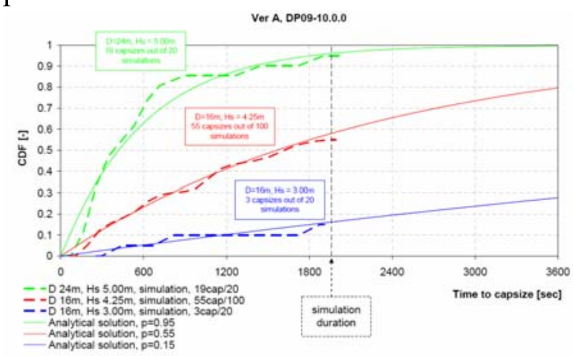


Figure 3: Cumulative probability function, CDF, of time to capsize for various simulation cases. Comparison with analytical model. Note the limitation of numerical simulation to ~ 30min simulated time.

The model has been found to be fast and straightforwardly implementable in any computerized design system, but the full validation process is still ongoing.

***Relevant public reference**: A. Jasionowski & D. Vassalos, "Fast and Accurate Flooding Prediction", SAFEDOR Summer Meeting, Hamburg, 19/6/2007.*

Structural Reliability

The primary goal in developing probabilistic models for loads and structural capacity is to apply structural reliability analysis to calibrate a design equation for the limit states corresponding to: hull girder collapse due to global bending moments. With increased computational capacity, it is now possible to link state-of-the-art first principle analysis tools for load effects and capacity into probabilistic analysis models. Structural Reliability Analysis can then efficiently be used for the calibration of design codes to a consistent reliability level. In addition, cost-effectiveness analysis is used to evaluate the target reliability level and risk control options.

The main focus is herein Structural Reliability Analyses (SRA) of the hull girder failure in intact condition due to heavy weather, and hull girder failure after collision damage. Two test ships have been analysed; a Very Large Crude-oil Carrier (VLCC) and a Large Liquefied Natural Gas (LLNG) carrier.

Probabilistic models for load effects (including identification of the most critical damage scenarios) and probabilistic models for collapse limit state have been completed.

In the case of the VLCC subjected to analysis in both intact and damaged conditions, the reference scantlings are chosen such that the annual probability of failure is approximately 10^{-3} for the intact case, which is line with the results in IACS submission, "*Goal-Based New Ship Construction Standards, Linkage between FSA and GBS*", IMO MSC 81/NF.6, February 2006. The annual probabilities of failure for the intact and damaged conditions are reported in Table 1.

Table 1 Annual probabilities of failure			
Case	Probability, ref. period	VLCC Net	VLCC Gross
Intact failure, severe weather	Annual	$7.2\cdot10^{-4}$	$4.0\cdot10^{-5}$
Failure of damaged ship, "Worldwide" environment (ww)	1 week, conditional on collision	$1.8\cdot10^{-3}$	$1.0\cdot10^{-4}$
Failure of damaged ship, "Collison" environment (coll)	1 week, conditional on collision	$8.3\cdot10^{-5}$	
Probability of collision event (*)	Annual	10^{-2}	

(*) Conservatively chosen value.

It is seen that the probability of failure is a factor of 18 higher for the net (deduct 50% of corrosion addition for all members) scantlings compared to gross. Furthermore, it is seen that the annual probability of failure in the case of the damaged conditions are sensitive to the assumption regarding environmental conditions at the time of collision. If the propose collision environment is applied, the probability of failure in the damaged condition is almost reduced to 0.1 times that of the intact case, even before the probability of the collision event itself is considered.

The cost benefit results are illustrated in Figure 4:

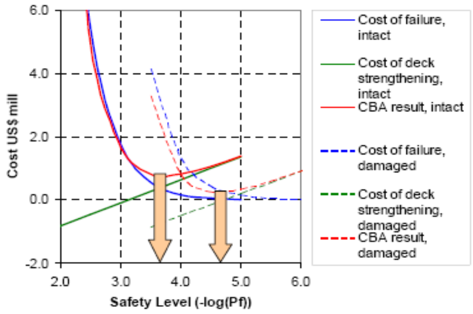


Figure 4: Cost Benefit Analysis results, intact and damaged conditions. Cost optimum target reliability levels for the two cases are indicated by arrows.

Negative values at low safety levels means a reduction in deck scantlings compared to the reference scantlings. Note that the probability of failure for the intact case in open sea is higher than the probability of hull girder failure following damage times the probability of the damage itself. A second curve is given for the costs associated with failure. The sum of the two curves gives the result of the Cost Benefit Analysis, and the cost optimum can be taken from the minimum of this curve. The most important costs are those related to the environmental consequences.

The cost benefit analyses show that the scantlings at the cost optimum target safety level for the damaged case are lower than those for the intact case. There is therefore not a need for a structural criterion for the damaged condition, the intact criterion is dimensioning. Deck strengthening is not a cost effective risk control option concerning the damaged condition, since the ship is not likely to break after a collision even with a rather extensive damaged.

If the damage penetrates the double side, pollution will occur, and suitable risk control options in this respect are to be related to compartmentation and operational aspects rather than hull girder strength. The loss of stability of the ship after damage with flooding is more of a concern than the strength issue.

Relevant public reference*: Hørte, T., Skjong R., Friis-Hansen P., Teixeira A. P., Viejo De Francisco, F., "Probabilistic Methods Applied to Structural Design And Rule Development", Proc. RINA conference on Developments in Classification and International Regulations, Jan. 2007, London, UK.*

Intact Stability

Here the effort is to develop and evaluate the elements of a probabilistic framework for quantifying the probability of "capsizing" (or rather of exceeding specified extreme motion levels) for any given ship. As there is no unique solution to this problem, several probabilistic approaches were compared. Stochastic wave data served as input to advanced ship motion codes, suitable for modelling intact ship capsize in extreme seas. In addition, possible risk control options were identified and assessed from a ship design and operation perspective.

Two new approaches to predict the probability of capsize were developed. Based on state-of-art environmental data the new prediction methods aim to dramatically shorten the computational effort by targeting effectively critical wave conditions. The alternative frameworks were reviewed for their implementation potential. Moreover, nonlinear seakeeping prediction methods applied by the various members were compared.

Of special interest was the development of a probabilistic stability assessment method that is embeddable upon a "risk-based" framework. The feasibility of the method was shown through application to: a) a ROPAX ferry, assessed for operation on a specific route across the Mediterranean Sea (see Fig. 5); b) a post-panamax containership operated on a North-Atlantic route. A key finding resulting from the analysis of the ROPAX on this Mediterranean route was that she shows extremely low probability of instability when mean seasonal values are considered, even for winter. On the other hand, the operation of the containership in the more hazardous North-Atlantic is well reflected in the calculated probabilities in extreme (but not improbable) conditions.

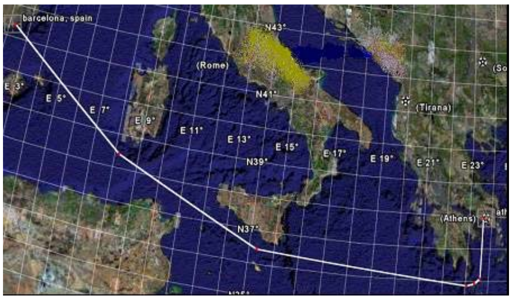


Fig. 5: ROPAX route: Barcelona to Piraeus.

A novel type of stability diagram is proposed, illustrating the scaled critical time along a route for targeted types of instability (Fig.6). This is valuable input for the ship design process as it helps to assess objectively the risk of specific capsize modes. Besides, such "localised" probabilistic figures of instability could be a useful aid for weather routeing and other decision support. Summed probabilities of instability for beam-sea resonance, parametric rolling and pure-loss of stability for the studied ROPAX and containership, are shown in Table 2:

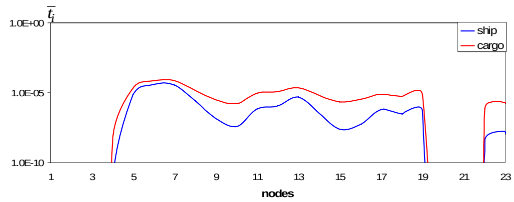


Figure 6: Variation of critical time ratios of beam-sea resonance from Hamburg to New York for the post-panamax containership.

	ROPAX	containership
Ship: ($\varphi > 35^o$)	6.58 * 10^{-17}	7.77 * 10^{-5}
Cargo: (α_v>6.04m/s^2)	7.84 * 10^{-13}	2.30 * 10^{-4}

Table 2: Summed probabilities of instability

***Relevant public reference**: Spyrou K., N. Themelis & S. Niotis, "Towards a Full Risk-Based Assessment of Ship Stability", SAFEDOR Midterm Conference, Brussels, May 2007.*

Collision and Grounding

Collision and grounding probability predictions were enhanced with operator effects, drifting and loss of power. Prevention of collision and grounding damages is likely to be more cost-effective than mitigation of consequences. Therefore, probabilistic models of the ship operator on a bridge were refined, models predicting failure of propulsion and steering were developed, and drift models were validated. All developments aim at a better prediction of collisions and grounding frequencies in a risk-based framework.
The primary goal is to provide a methodological approach that is capable of predicting the probability of collision and grounding events taking into account ship systems, environment and people by estimating:
- the causation factor, with due account to the integrated bridge system
- the probability of disabled ship as function of ship type
- the probability of a disabled ship drifting towards objects etc.

Suitable Risk Control Options that affect the probability of collision or grounding were identified and evaluated.

Human and organizational issues are known to be the main causes for collision and grounding events. Thus, it is vital to model the human actions well. Thus, Risk Control Options were considered for different bridge systems using Bayesian Networks and identification of new and more effective bridge layouts.

A stationary model for the calculation of the drift of disabled ships was developed and validated. The model operates on few data items that characterise hull areas and environmental information. With this model, drift calculations can be performed more efficiently in collision and grounding scenarios.

Another model has been established to predict the reliability of the propulsion and steering gear of a ship. This is done by combining a qualitative system description with a quantitative description in a Bayesian network. The result is three networks, the propulsion, the steering and the electrical power network, which are combined into one describing the entire system. An attempt was made to include maintenance, as this is very likely where efforts can be made to reduce the failure rate.

In Table 3 a number of risk control options for preventing collision is shown in the first column. In the second column, the estimated impact is given and the third column contains the probability of having a collision together with the relative decrease in the collision probability using the RCO. The scenario used is not a single scenario but instead the Bayesian network procedure has simulated a number of scenarios. So the results in the table are averaged values.

In Table 4 possible risk controls and their impact is listed. The last column shows the effect on the grounding probability as calculated by the Bayesian network. It is seen that all the risk control options give a reduction in the grounding probability. The most effective measure seems to be ECDIS with track control.

Risk Control Option /impact C(collision) or G(grounding)	*Amount of the impact*	*Reduction of collision probability, as calculated by the Bayesian Network Distance: 2-3 Nm $P_{initial}$ = 18.5 %*
Increase training through simulation (C)(G)	3% improvement of detection time and time to perform manoeuvre	P=17.8 % Δrel=3.8 %
Bow camera systems with monitors on the bridge (C)	12% improvement of detection time	16.6 % Δrel=10.3 %
Night Vision Equipment (C)	5% improvement of detection time given night time	17.6% Δrel=4.9 %
Integration of AIS with ARPA radar (C)	12% improvement of detection time	16.6 % Δrel=10.3 %
Enhanced weather routing (integrated system) (C)	5% improvement of time of manoeuvring	17.6 % Δrel=4.9 %
Track predictor system (for tracking in shallow and traffic areas) (C)	10% improvement of detection time	16.7 % Δrel=9.3 %
Drift prediction handbook (integrated with radar or ECDIS system) (C)	2% improvement of detection time	18.2 % Δrel=1.6 %

Table 3: Risk control options for preventing collision

Risk Control Option /impact C(collision) or G(grounding)	*Amount of the impact*	*Reduction of collision probability, as calculated by the Bayesian Network Distance:1.25-2 Nm $P_{initial}$ = 43.6 %*
Squat charts integrated in traffic management system (G)	3% improvement of detection time	42.9 % Δrel=1.6 %
Increase training through simulation (C)(G)	3% improvement of detection time and time to perform manoeuvre	42.5 % Δrel=2.5 %
ECDIS with track control (G)	36% improvement of detection time	35.6 % Δrel=18.4 %
Track Control System (G)	23% improvement of time to perform manoeuvre	39.8 % Δrel=8.7 %
Grounding Avoidance System – GAS (G)	15% improvement of detection time	40.0 % Δrel=8.3 %

Table 4: Risk control options for preventing grounding

Relevant public references:

Leva M.C., Friis-Hansen P., Sonne Ravn E. and Lepsøe A. (2006), "SAFEDOR: A practical approach to model the action of an Officer of the Watch in collision scenarios," Proceedings of ESREL 2006, Lisbon, Portugal.

Fire and Explosion

Quantitative Risk Analysis (QRA) with a view to evaluate the risk to cargo stored in containers and to human life in passenger vessels has been studied for specific fire scenarios.

Developments related to the prevention of fire and explosions were focused on cargo ships, on one hand, and on passenger ships, on the other hand. A risk model for container fires was established and simulations performed to quantify effects of possible risk control options. A new approach to model fire for passenger ships was developed proposing to adapt concepts from the probabilistic damage stability to a new probabilistic fire framework.

In terms of cargo fire safety, a quantitative risk model for cargo fires has been developed (see Figure 6 for an overview). The model used fire engineering calculation results and Bayesian probabilistic modelling. Following from a Qualitative Design review, a fire scenario inside a closed cargo hold of a container vessel has been evaluated.

A representative vessel design (2500 TEU) was used as case study where prescriptive (according to currently available rules) fire protection measures were adopted. A second case, in which alternative fire safety arrangements not required or in excess of current requirements, was also considered. The risk control options include measures such as improved container designs with better sealing and better thermal resistance and properties, fire detection systems for containers, advanced fire detection for cargo holds, as well as different automatic and manual fire extinguishing measures.

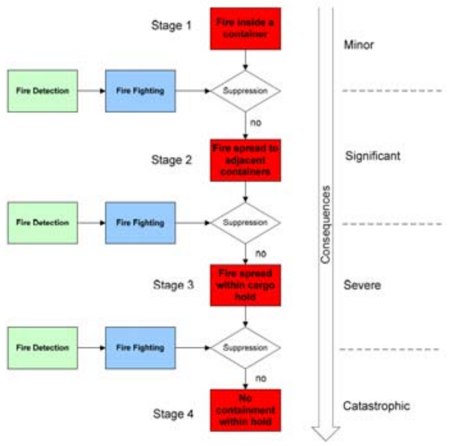


Figure 6: Fire stages covered by the risk model

Fire simulations were conducted to support the probabilistic modelling of the fire scenario and assess the effectiveness of the evaluated RCOs.

Finally, cost-effectiveness analyses were conducted and based on the risk analyses results; the risk reducing influence of each RCO has been quantified, delivering the result that only very inexpensive measures are reasonable at all when the historic incident frequency of 0.001 per year is considered (see Figure 7). The work carried out led to the following main conclusions:

- Although CFD modelling proved very useful in gaining insight, the overall level of understanding about the fire progression inside containers and into the hold as well as effectiveness of fire suppression options is still insufficient for proper quantification of the consequences, and hence of the risk.
- Very little information is available on fire ignition inside containers. This makes it difficult to address the probability modelling of ignition.
- Given the various uncertainties and the lack of understanding associated with fire progression and suppression in cargo areas, a general quantification covering a top-level scenario at the current stage is impossible. More research addressing the a.m. gaps would be needed to arrive at a standard tool for daily engineering work.

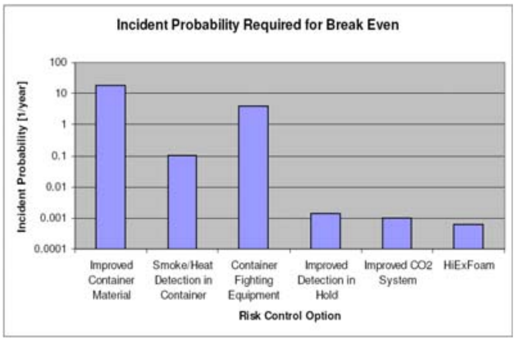


Figure 7: Fire stages covered by the risk model

Concerning passenger ship fire safety, a systematic methodology was developed to undertake fire risk analysis (mainly smoke) within the risk-based design. The methodology can be used during early design stages for performing *fire risk screening*, a well known concept in the offshore sector, which becomes useful for identifying the ship areas where vulnerability to fire has to be addressed. The implementation can be done in a standard product modelling tool (such as NAPA or CATIA), where the current ship layout with geometry, topological and space attribute information will be available.

Relevant public reference*: Povel, D., Langbecker, U., Dausendschön, K., Sinai, Y., Owens, M., Gehl, S., Forsman, B., Ellis, J. and Riedel, K. (2007), "Risk assessment for container ships focusing on cargo fire," Proc. of*

RINA conference on Design and Operation of Container vessels, London, United Kingdom.

Ship System Safety Analysis

The main objective is the development of a tool supporting the safety analysis of ship systems. A new technique to create fault trees and FMEA tables from system descriptions inside a standard system simulation package was developed. Enhancements include entering annotations to systems and components related to failure modes. The new technique is now available as R&D plug-in for a commercial simulation package and is currently being extended to employ a genetic algorithm for optimization.

The developed methodology is currently leading to a valuable and effective tool to support the application of automated safety analysis that can be used to facilitate the inclusion of reliability and safety as part of the iterative design processes for new and innovative marine engineering designs, eventually resulting in safer, more reliable products.

Relevant public reference: Walker M. and Papadopoulos Y.(2006), "PANDORA: The time of PAND gates," INCOM 2006, 12th IFAC Int'l Symposium on Information Control Problems in Manufacturing, St Etienne, France.

Conclusions

For the next generation of innovative ship types, there seems to be no alternative to risk-based design, operation and regulation, which in turn demands a dedicated tool-box.

Development insofar resulted in six novel tools addressing flooding, structural integrity, collision & grounding, fire for cargo and passenger ships, and system safety analysis complementing the tool-box of the ship designer.

Planned development will focus on risk-cost models for decision-making and the implementation of a prototype design environment.

For updated information, please refer to the SAFEDOR website at http://www.safedor.org.

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