Transportation risk modeling of tanker ship operation

Autor(en): **Rabien, U.**

Objekttyp: **Article**

Zeitschrift: **IABSE reports = Rapports AIPC = IVBH Berichte**

Band (Jahr): **42 (1983)**

PDF erstellt am: **10.07.2024**

Persistenter Link: https://doi.org/10.5169/seals-32411

Nutzungsbedingungen

Die ETH-Bibliothek ist Anbieterin der digitalisierten Zeitschriften. Sie besitzt keine Urheberrechte an den Inhalten der Zeitschriften. Die Rechte liegen in der Regel bei den Herausgebern.
Die auf der Plattform e-periodica veröffentlichten Dokumente stehen für nicht-kommerzielle Zwecke in Lehre und Forschung sowie für die private Nutzung frei zur Verfügung. Einzelne Dateien oder Ausdrucke aus diesem Angebot können zusammen mit diesen Nutzungsbedingungen und den korrekten Herkunftsbezeichnungen weitergegeben werden.
Das Veröffentlichen von Bildern in Print- und Online-Publikationen ist nur mit vorheriger Genehmigung der Rechteinhaber erlaubt. Die systematische Speicherung von Teilen des elektronischen Angebots auf anderen Servern bedarf ebenfalls des schriftlichen Einverständnisses der Rechteinhaber.

Haftungsausschluss

Alle Angaben erfolgen ohne Gewähr für Vollständigkeit oder Richtigkeit. Es wird keine Haftung übernommen für Schäden durch die Verwendung von Informationen aus diesem Online-Angebot oder durch das Fehlen von Informationen. Dies gilt auch für Inhalte Dritter, die über dieses Angebot zugänglich sind.

Ein Dienst der *ETH-Bibliothek*
ETH Zürich, Rämistrasse 101, 8092 Zürich, Schweiz, www.library.ethz.ch

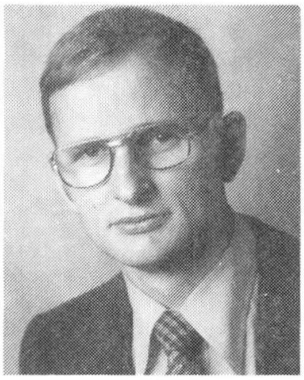
http://www.e-periodica.ch

Transportation Risk Modeling of Tanker Ship Operation

Modèle d'analyse de risque pour la navigation des pétroliers

Modelle für die Risikoanalyse in der Tankerschiffahrt

U. RABIEN
Dr.-Ing.
Germanischer Lloyd
Hamburg Fed. Rep. of Germany



U. Rabien, geb. 1938. Schiffstechnik Studium an der Technischen Universität Berlin, Promotion an der Techn. Universität Hannover, Arbeiten auf dem Gebiet des CAD und verwandten Bereichen an den beiden Universitäten und im Sonderforschungsbereich 98, jetzt in der Forschungsabteilung des Germanischen Lloyd.

SUMMARY

Fault tree methodology is applied to quantify transportation risk of marine traffic systems comprising potential catastrophic events. Operational conditions and risks as well as structural failures are modeled. Main concepts of modeling include local and temporal subdivision of the system.

RÉSUMÉ

L'analyse logique de la sécurité ou du risque des systèmes navals présentant une grande quantité de dangers et de facteurs opérationnels est réalisée à l'aide de la méthode d'arbre de défauts. Les méthodes de calcul sont expliquées avec l'exemple du trafic des pétroliers dont la structure est variable dans le temps et dans l'espace.

ZUSAMMENFASSUNG

Zur rationalen Erfassung von Zuverlässigheit oder Risiko bei Seeverkehrssystemen mit hohem Gefahrenpotential und überwiegend operativen Komponenten wird die Fehlerbaumtechnik eingesetzt. Die Methoden der Berechnung und der Modellierung werden am Beispiel des Tankerverkehrs erläutert, wobei die logische Struktur vor allem nach lokalen und zeitlichen Bereichen gegliedert wird.

1. INTRODUCTION

To calculate the reliability of a complex system rationally we need a method, which enables us to model the system's behaviour and to quantify its relevant characteristics. In this context, also for assessing alternatives under the economic aspect, it is important to incorporate into the model information on "mechanical" as well as on "operational" reliability. We define components or events related to technical hardware as "mechanical", and components or conditions resulting from operation and handling as "operational". In marine traffic operational system components are of major significance. To a high degree they depend on the traffic situation and in particular on human factors. A reduction of risk by increasing the reliability of mechanical components may be more costly or of less effect upon overall reliability. Of course, if marine traffic would become a highly automated system, the main emphasis would have to be placed on the hardware.

2. COMPUTATIONAL MODEL

Fault tree methodology is a suitable tool to analyse systems with high potential risks. A fault tree model is obtained by collecting all events of relevance for a current top event (e.g. collision) and linking them according to their causal relationships by logical operators (AND, OR). Given the probability of occurrence of basic events, i.e. of events not considered as being caused by other events, it is possible to compute the importance of individual components or sets of components quantitatively (e.g. as reliability importance).

Let y_i be the state indicators of the n components (basic events) of a system, with

$$y_i = \begin{cases} 1, & \text{in case of occurrence of the event} \\ 0, & \text{in case of non-occurrence of the event} \end{cases} \qquad (1)$$

then the state of the system is characterized by the value of the structure function:

$$s_F = s_F\ (y_1, \ldots\ldots\ldots\ldots\ldots, y_n) = s_F\ (\underline{y}) \qquad (2)$$

with

$$s_F = \begin{cases} 1, & \text{in case of occurrence of the top event} \\ & \text{(system failure)} \\ 0, & \text{in case of non-occurrence of the top event} \end{cases} \qquad (3)$$

Index F indicates that the structure function models a failure; y_i are indicators for occurrence of failures or of conditions favouring the occurrence of failures. For the purposes of quantitative analysis the design function of large systems is usually represented with the aid of min cut sets M_j and min path sets W_j. If n_M is the number of min cut sets and n_W the number of minimum path sets, the structure function of the system can be expressed by

$$s_F(y) = \prod_{j=1}^{n_W}\left(1 - \prod_{i\in W_j}(1-y_i)\right) = 1 - \prod_{j=1}^{n_M}\left(1 - \prod_{i\in M_j} y_i\right) \qquad (4)$$

If Y_i are the random quantitites of the basic event states, the following applies for the expected value of the structure function:

$$E\left[\prod_{j=1}^{n_W}\left(1-\prod_{i\in W_j}(1-Y_i)\right)\right] \leq E\left[S_F(Y)\right] \leq E\left[1-\prod_{j=1}^{n_M}\left(1-\prod_{i\in M_j}Y_i\right)\right] \tag{5}$$

With $q_i = P[Y_i = 1] = E[Y_i]$, and assuming statistically independent basic events, the following rough estimate holds [6]:

$$\prod_{j=1}^{n_W}\left(1-\prod_{i\in W_j}(1-q_i)\right) \leq E\left[S_F(Y)\right] \leq 1-\prod_{j=1}^{n_M}\left(1-\prod_{i\in M_j}q_i\right) \tag{6}$$

If Y_i equals 1 after occurrence of event i at time t (otherwise $Y_i = o$) and assuming constant failure rates λ_i the following applies

$$q_i(t) = E[Y_i(t)] = 1 - e^{-\lambda_i t} \tag{7}$$

Of course, the absolute value of a failure probability thus calculated is of minor significance, since bounds of acceptable risks are difficult to define. However, the effects of changes in the probability of occurrence of basic events or of changes in the tree structure allow practically relevant decisions with respect to system safety. A measure of importance, which takes into account structural importance and probability of occurrence of a component i, is the reliability importance, [6]:

$$I_i = \frac{\partial S_F^*(q_i)}{\partial q_i} = S_F^*(1_i, \underline{q}) - S_F^*(0_i, \underline{q}) \tag{8}$$

S_F^* is the random value of the structure function S_F reduced according to idempotency of Boolean variables ($y_i \cdot y_i = y_i$); $S_F^*(1_i, \underline{q}) = (S_F(\underline{q})$ with $q_i = 1)$ and $S_F(0_i, \underline{q}) = (S_F(\underline{q})$ with $q_i = 0)$; $\underline{q} = (q_1, q_2 \ldots q_n)$.

Narrower bounds than those given in (5), (6) are [7]:

$$E\left[S_F\right]\begin{cases} \leq E\left[\prod_{i\in M_1}Y_i\right] + \sum_{j=2}^{n_M}\left(E\left[\prod_{i\in M_j}Y_i\right] - \max_{k=1}^{j-1}\left(E\left[\prod_{i\in M_j}Y_i \prod_{i\in M_k}Y_i\right]\right)\right) \\ \geq E\left[\prod_{i\in S_1}Y_i\right] + \sum_{j=2}^{n_M}\max\left(0,\ E\left[\prod_{i\in M_j}Y_i\right] - \sum_{k=1}^{j-1}E\left[\prod_{i\in M_j}Y_i \prod_{i\in M_k}Y_i\right]\right) \end{cases} \tag{9}$$

The preparation of this kind of risk model includes two major tasks: development of the logical tree structure and collection or theoretical acquisition of basic event data. Structural and quantitative analysis of the model is left to computer programs, [1,2,3,4,5].

3. DEVELOPMENT OF TREE STRUCTURES

Fault tree modeling for marine transportation requires a specific methodology. Automatical tree generation by computer is not possible due to the lack of a detailed definition of the system. One modeling method (type 1) is to derive subtree structures for local areas (e.g. harbour, traffic separation scheme) from relevant events occurring there. However, such a subtree is of little use when developing subtrees for other areas. Generalisation will hardly be possible. This may also lead to structural weaknesses of the overall model. Another approach (type 2) appears more appropriate. An overall tree structure is developed. Considering one essential element of the system, e.g. the tanker, some critical events are chosen (e.g. collision, grounding, ramming). All other events with relevance to the critical events are collected and linked in subtrees. The same procedure may be repeated within the subtrees down to the basic events, for which probability data have to be specified. Subsequently, such basic models are adapted to the conditions prevailing in the local area considered e.g. by omitting irrelevant substructures and adjusting probability data. Structural adaptations can be made by setting events TRUE or FALSE or by using an editing program [4]. Thus, when developing new trees, existing subtrees can be used. This procedure considers that a theoretical model is never perfect and therefore has to be supplemented by experience gained during its practical application.

Another essential factor is the degree of resolution of the model: It is, for instance, not possible to model human error only by one basic event. On the other hand, it is not practicable to model any conceivable detail of what may happen. Another important concept is the introduction of time frames (according to [8]), relating events to:

- the short-time frame, if events occur in critical situations, when the time remaining to take preventive measures is very short, so that system failure becomes highly likely;
- the intermediate-time frame, if events combine giving rise to a critical situation, unless successfully prevented;
- long-time frame, if events relate to general misjudgements, miscalculated risks, etc., which may contribute to an accident at a later stage.

If the behaviour of system components is not in compliance with binary logic, it can be modeled by comparison with threshold values. The fault tree structure should be preapred with regard to data availability. Finally, the model should be verified with the aid of case studies.

4. SAMPLE MODELS OF TANKER OPERATION

A type 1 model (according to [9]) developed from local areas is shown in Fig.1. This model structure was subdivided with respect to critical events (collision, grounding, ramming) and below this level with respect to local areas. Thus, ramming of a bridge in area 3 has been modeled in a separate subtree, while other events in area 3 can be found in the subtree "collision". A collision scenario was also developed in detail in [10] by means of directed graphs [11]. The concept of a safety zone moving with the critical object (tanker) is introduced, within which the object is surrounded by a smaller critical zone; Fig.2.

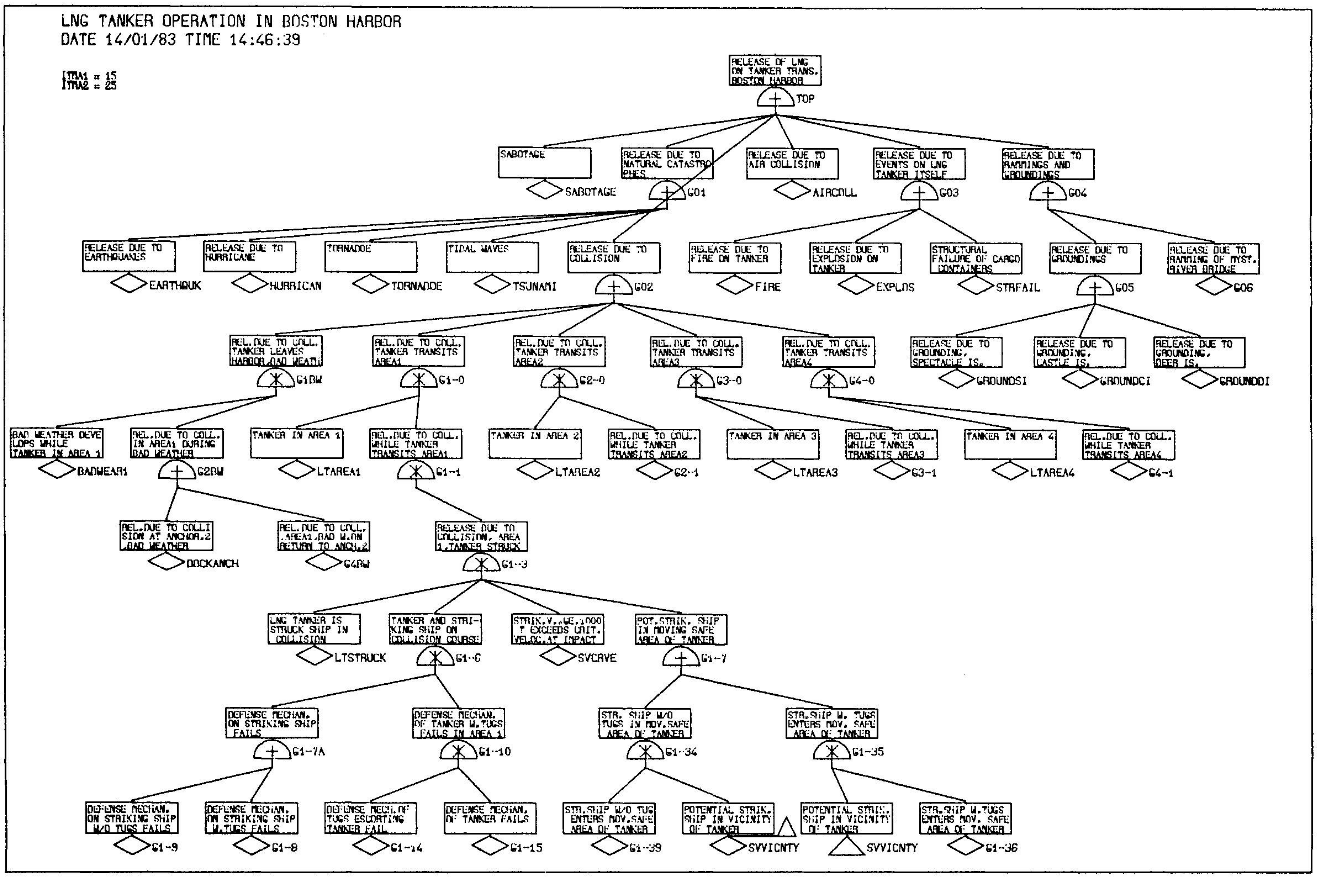


Fig.1: Portion of a type 1 model, LNG tanker operation in harbour, [9].

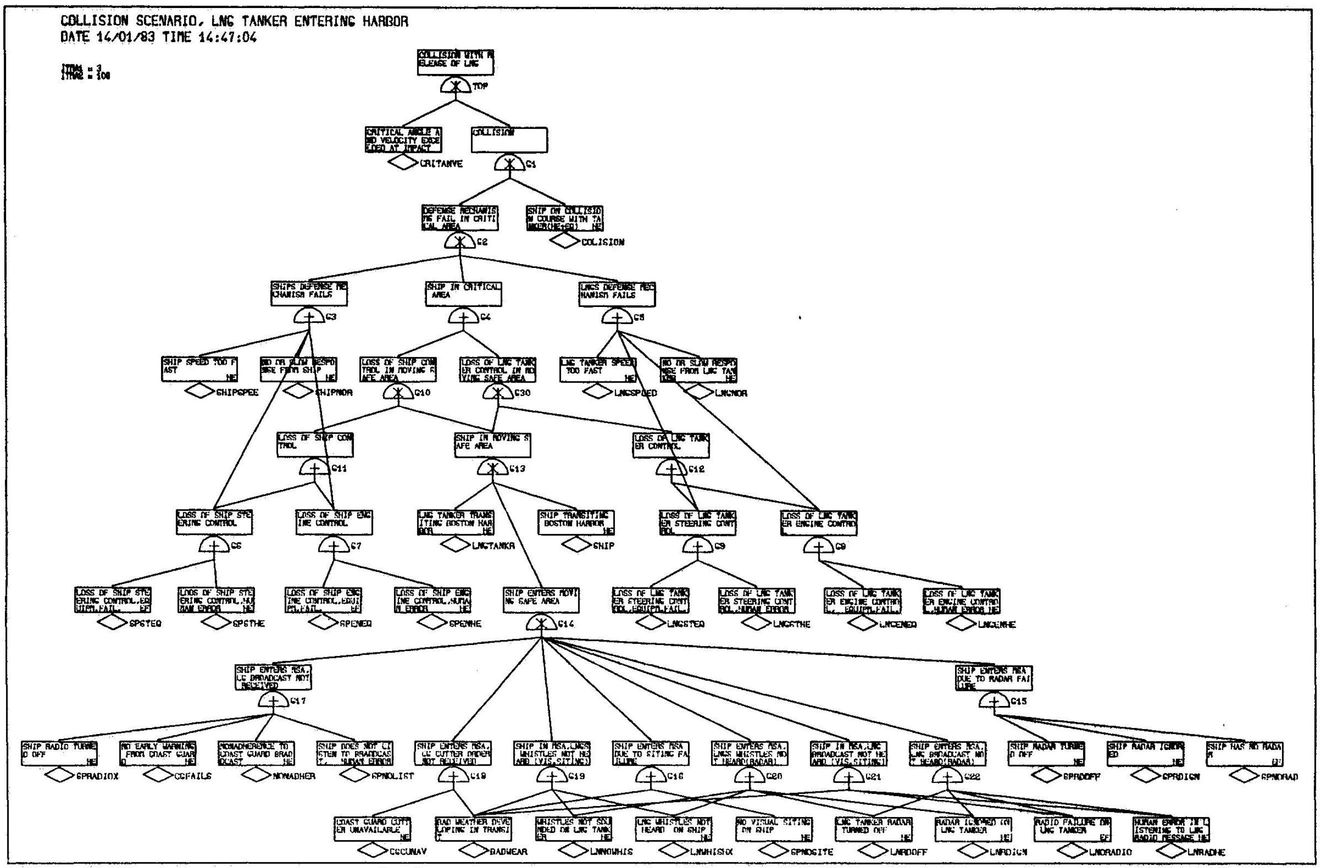


Fig.2: Collison scenario, [10].

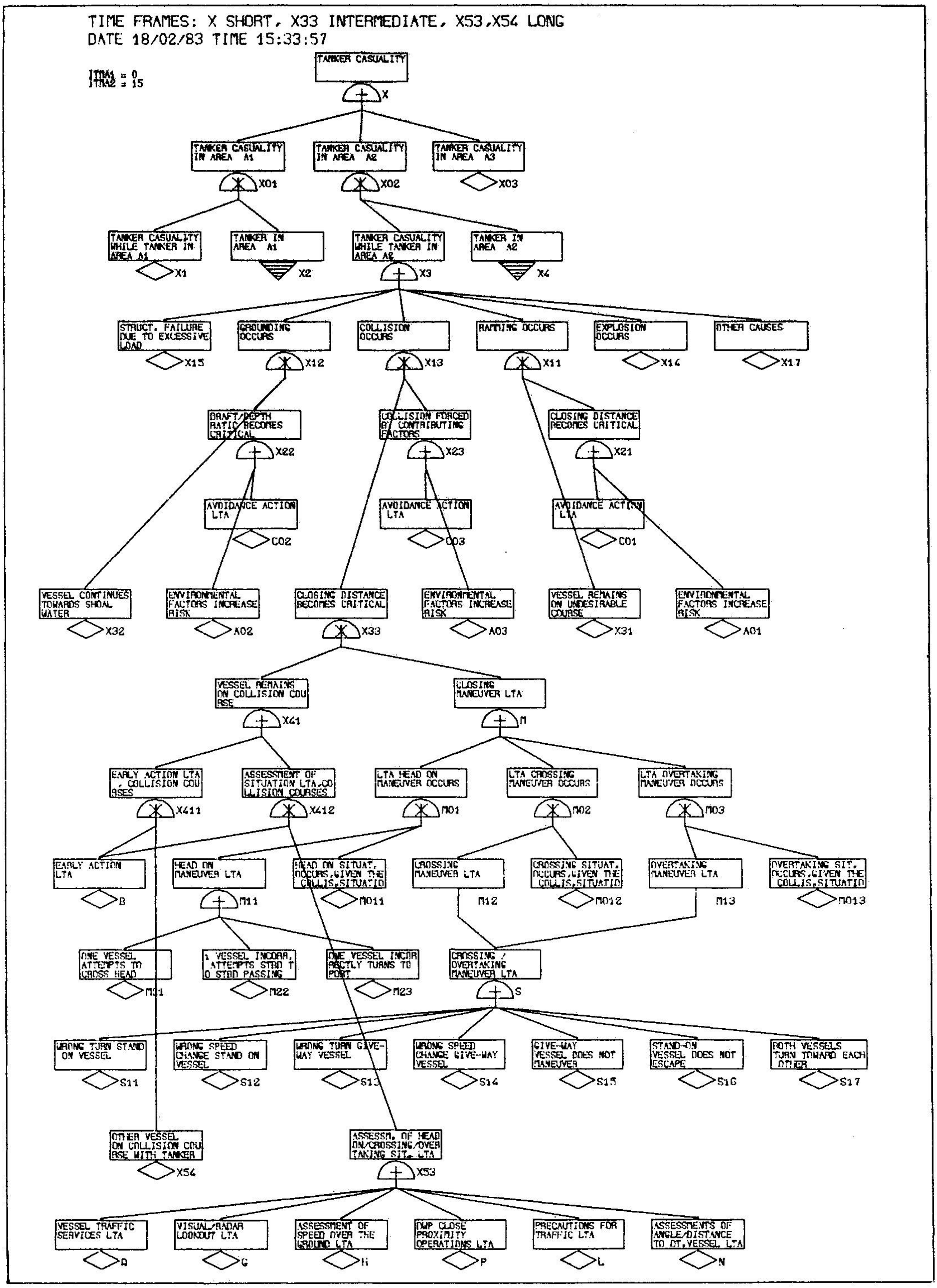


Fig.3: Portion of type 2 model, tanker operation

Starting from the approach made in [8] a type 2 model is developed to analyse tanker traffic in the Heligoland Bight. Operational components (e.g. due to navigation, environmental conditions, human factors) and mechanical components (such as structural failures, equipment failures) are included in the model. Local areas are chosen with respect to traffic flow characteristics, geographic restrictions of waterway, jurisdiction objective of the investigation, etc..

A subdivision of the fault tree structure corresponding to local areas can be seen in the upper part of Fig.3 (events X01, X02, X03 ...). Critical events X11, X12, ..., X17 are top events of separate subtrees. The short time frame is above X31. The long time frame ranges from the X31 level to the X53 level. The long time frame is below X 53. Nearly all events in Fig.3 are further analysed in detailed subtrees. Only X2 and X4 are basic events, the probabilities of which result from the mission profile of the tanker. Event X54 is estimated in relation to shipping density.

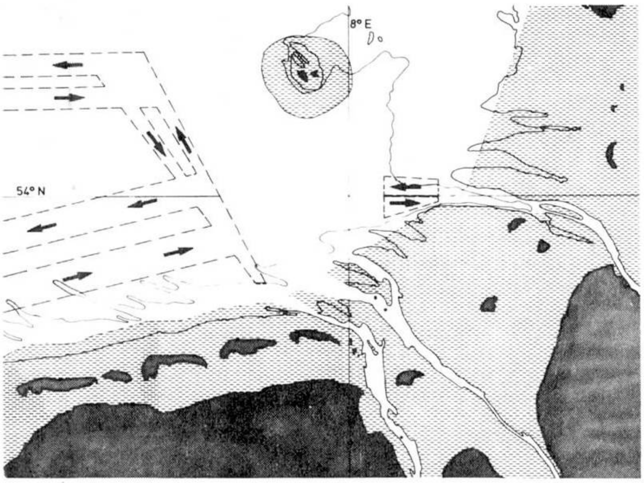


Fig.4 Heligoland Bight, general view

5. CONCLUSION

Some advantages of the fault tree approach are the more rational analysis of system behaviour, capability of sensitivity studies and of comparing alternate systems or subsystems. To make the results more informative, more reliable basic event data have to be collected. Particularly for operative components some uncertainty exists. Data may also be obtained from modern nautical simulators. Correlations of operative events might be introduced to quantitative analysis in the way it is done for mechanical components in [12], [13]. Possible safety measures could be optimized, if component cost functions can be established.

6. REFERENCES

1. Willie, R.R., Computer-Aided Fault Tree Analysis, (FTAP), ORC 78-14, Operations Research Center, University of California, Berkeley, 1978.
2. Lambert, H.E., Gilman, F.M., The IMPORTANCE Computer Code, Report UCRL-79269, Lawrence Livermore Laboratory, Univ. of California, Berkeley, 1977
3. Program System FORM4/FORMU/FORSYS; partly described in: Fießler, B., Das Programmsystem FORM zur Berechnung der Versagenswahrscheinlichkeit von Komponenten von Tragsystemen, Berichte zur Zuverlässigkeitstheorie der Bauwerke, Issue 43, Special Research Project 98, Technical University of Munich, 1979.
4. Rabien, U., Program FRTGEN, Fault Tree Editing, User Manual, Germanischer Lloyd, Hamburg, 1981.

5. Scharrer, FRTPLT, Graphical Output of Fault Trees, User Manual, Germanischer Lloyd, Hamburg, 1981.

6. Barlow, R.E., Proschan, F., Statistical Theory of Reliability and Life Testing, New York, Holt, Rinehart & Winston, 1975.

7. Ditlevsen, O., Uncertainty Modeling, McGraw-Hill Inc., 1981

8. W.E. Faragher, et al., Deepwater Ports Approach/Exit Hazard and Risk Assessment, Planning and Research Corp, McLean, Va., Rept. CG-D-6-79 (1979).

9. Barlow, R., Lambert, H., The Effect of U.S. Coast Guard Rules in Reducing the probability of LNG-Tanker-Ship Collision in Boston Harbor, Fourth International System Safety Conference, San Francisco, 1979.

10. Lambert, H.E., The Digraph Fault Tree Methodology and its Use in Transportation, TERA Corporation, Berkeley, California.

11. S.A. Lapp and G.J. Powers, "Computer-Aided Synthesis of Fault-Trees", IEEE Trans. on Reliability, R-26, April 1977, pp. 2-13.

12. Rackwitz, R.,; Peintinger, B.,: Reliability of General Structural Systems under Combined Loading, Berichte zur Zuverlässigkeitstheorie der Bauwerke, Technical University of Munich, Issue 58, 1981.

13. Hohenbichler, M.: Approximate Evaluation of the Multinormal Distribution Function, Berichte zur Zuverlässigkeitstheorie der Bauwerke, Technical University of Munich, Issue 58, 1981.

Leere Seite
Blank page
Page vide