Risk Modelling

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Contents

Purpose of the presentation

- Overview of a risk model for common understanding on a risk model
- Introduce precise and simplified risk sub-model
- Consider a problem of a risk model

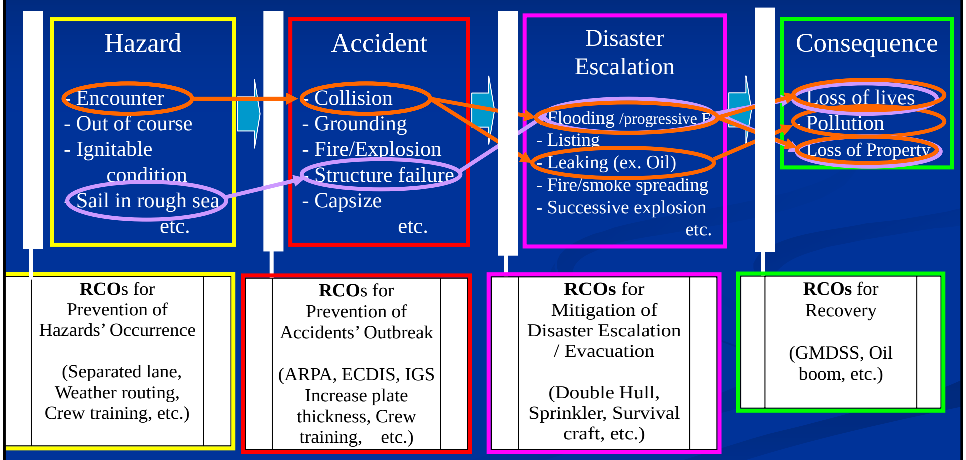
2. Overview of Risk Model

Importance of Risk Model

- Risk model is necessary for assessment of risk of a ship, who is newly designed based on new concept, and/or on whom newly developed equipments are installed, because she has no navigation and casualty data. --- This was pointed out in the discussion on SLA based GBS in CG of IMO.

2. Overview of Risk Model

Process of accident



Hazard
- Encounter
- Out of course
- Ignitable condition
- Sail in rough sea

etc.

Accident
- Collision
- Grounding
- Fire/Explosion
- Structure failure
- Capsize

etc.

Disaster Escalation
- Flooding /progressive F
- Listing
- Leaking (ex. Oil)
- Fire/smoke spreading
- Successive explosion

etc.

Consequence
- Loss of lives
- Pollution
- Loss of Property

RCOs for Prevention of Hazards’ Occurrence

(Separated lane, Weather routing, Crew training, etc.)

RCOs for Prevention of Accidents’ Outbreak

(ARPA, ECDIS, IGS Increase plate thickness, Crew training, etc.)

RCOs for Mitigation of Disaster Escalation / Evacuation

(Double Hull, Sprinkler, Survival craft, etc.)

RCOs for Recovery

(GMDSS, Oil boom, etc.)

RCO : Risk Control Option

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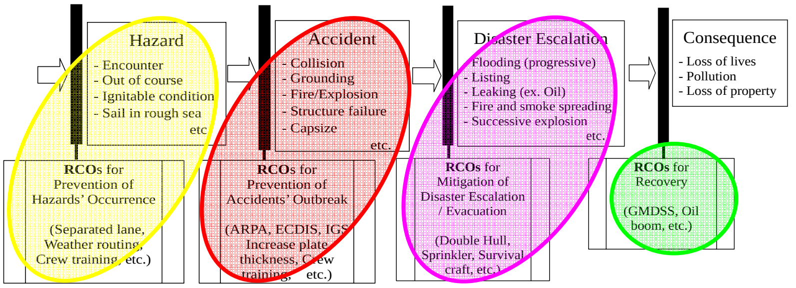
2. Overview of Risk Model

Definition of Risk Model



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etc

Accident
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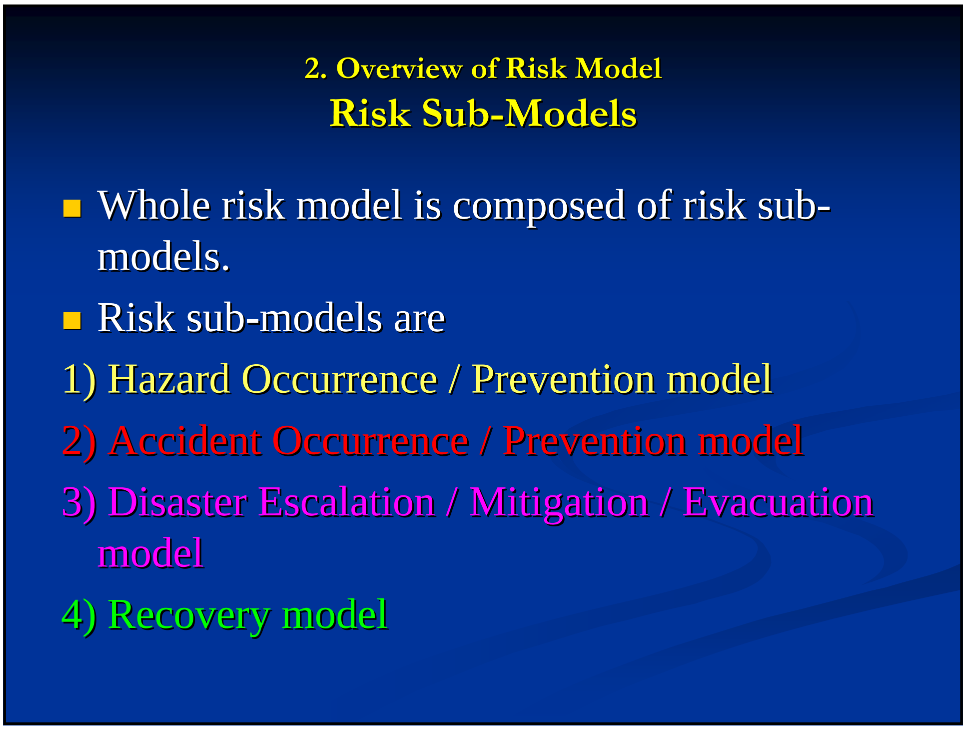
RCOs for Recovery

(GMDSS, Oil boom, etc.)

AS (Accident Scenario) = Combination (Hazard(i), Accident(j), Disaster Escalation(k),Consequence(l))

$$Risk(Ship) = \sum_{\text{for all AS}} Frequency(AS) \bullet Consequence(AS)$$

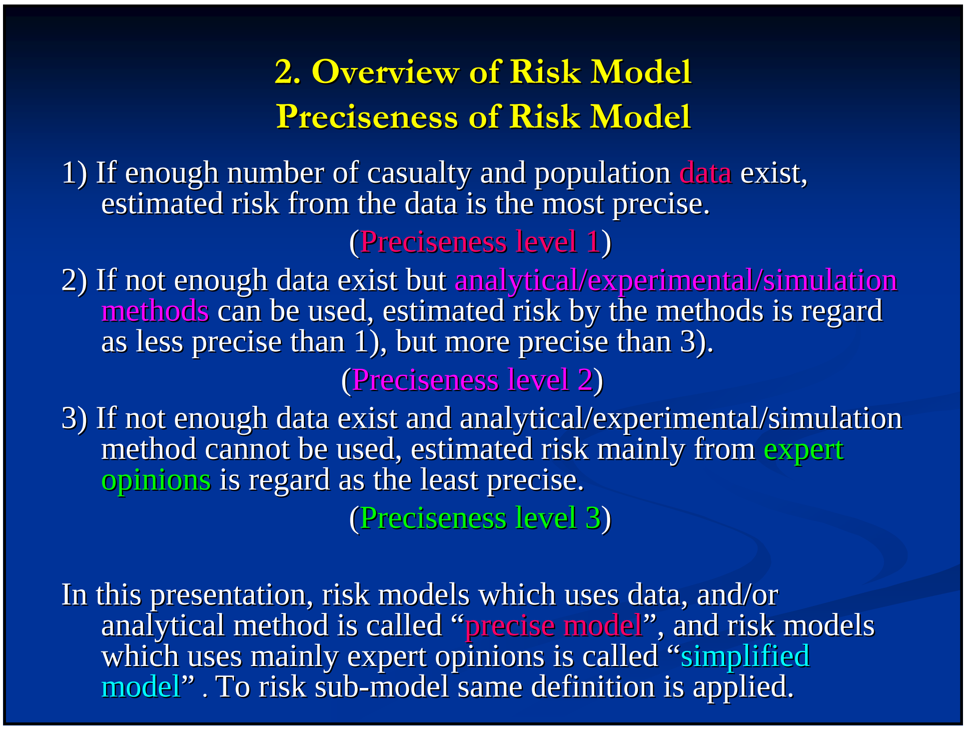
Risk model is a model that can estimate risk of a ship by examining accident scenarios considering RCOs.



2. Overview of Risk Model
Risk Sub-Models

- Whole risk model is composed of risk sub-models.
- Risk sub-models are

1) Hazard Occurrence / Prevention model
2) Accident Occurrence / Prevention model
3) Disaster Escalation / Mitigation / Evacuation model
4) Recovery model



2. Overview of Risk Model
Preciseness of Risk Model

1) If enough number of casualty and population data exist, estimated risk from the data is the most precise.

(Preciseness level 1)

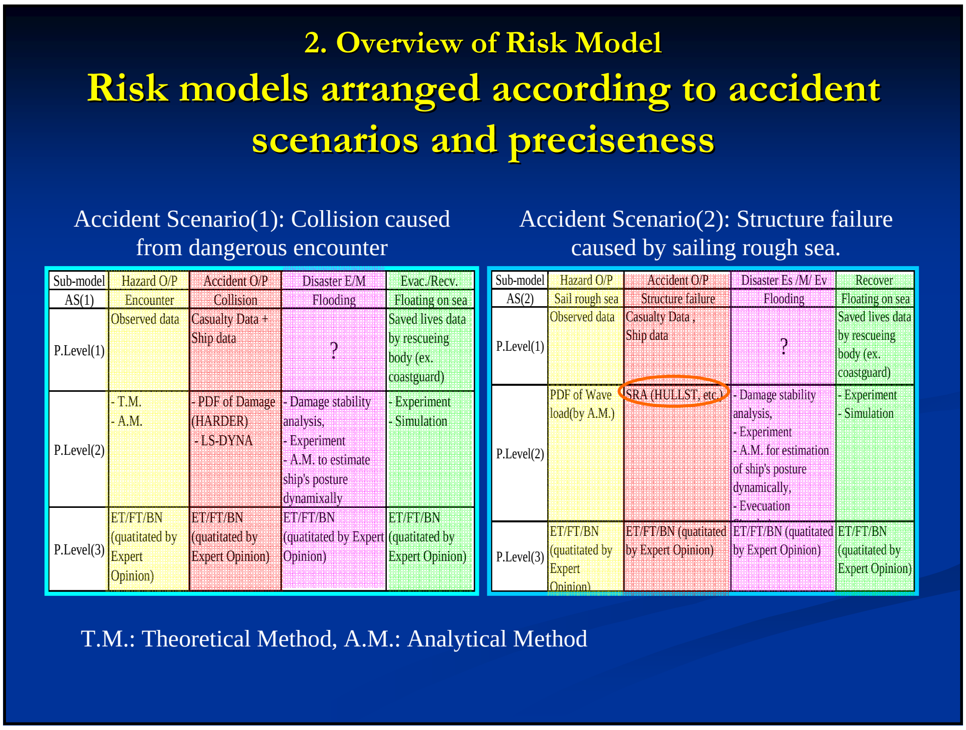
2) If not enough data exist but analytical/experimental/simulation methods can be used, estimated risk by the methods is regard as less precise than 1), but more precise than 3).

(Preciseness level 2)

3) If not enough data exist and analytical/experimental/simulation method cannot be used, estimated risk mainly from expert opinions is regard as the least precise.

(Preciseness level 3)

In this presentation, risk models which uses data, and/or analytical method is called "precise model", and risk models which uses mainly expert opinions is called "simplified model" . To risk sub-model same definition is applied.



2. Overview of Risk Model

Risk models arranged according to accident scenarios and preciseness

Accident Scenario(1): Collision caused from dangerous encounter

Sub-model	Hazard O/P	Accident O/P	Disaster E/M	Evac./Recv.
AS(1)	Encounter	Collision	Flooding	Floating on sea
P.Level(1)	Observed data	Casualty Data + Ship data	?	Saved lives data by rescueing body (ex. coastguard)
P.Level(2)	- T.M. - A.M.	- PDF of Damage (HARDER) - LS-DYNA	- Damage stability analysis, - Experiment - A.M. to estimate ship's posture dynamixally	- Experiment - Simulation
P.Level(3)	ET/FT/BN (quatitated by Expert Opinion)	ET/FT/BN (quatitated by Expert Opinion)	ET/FT/BN (quatitated by Expert Opinion)	ET/FT/BN (quatitated by Expert Opinion)

Accident Scenario(2): Structure failure caused by sailing rough sea.

Sub-model	Hazard O/P	Accident O/P	Disaster Es /M/ Ev	Recover
AS(2)	Sail rough sea	Structure failure	Flooding	Floating on sea
P.Level(1)	Observed data	Casualty Data , Ship data	?	Saved lives data by rescueing body (ex. coastguard)
P.Level(2)	PDF of Wave load(by A.M.)	SRA (HULLST, etc.)	- Damage stability analysis, - Experiment - A.M. for estimation of ship's posture dynamically, - Evecuation	- Experiment - Simulation
P.Level(3)	ET/FT/BN (quatitated by Expert Opinion)	ET/FT/BN (quatitated by Expert Opinion)	ET/FT/BN (quatitated by Expert Opinion)	ET/FT/BN (quatitated by Expert Opinion)

T.M.: Theoretical Method, A.M.: Analytical Method

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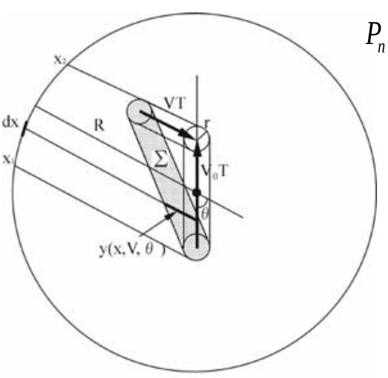
3. Example of Precise Risk Sub-Model

Hazard Occurrence/Prevention Model (Collision)

Model for dangerous encounters' number



$$P_n\left(\overset{\lambda_c}{\boxed{\int_0^{2\pi}\int_{V_1(x)}^{V_2(x)}\int_{\alpha_1(x)}^{\alpha_2(x)}\lambda(x)g(x,V)f(x,\alpha)\frac{y(x,V,\theta)}{V}\,dxdVd\theta}}\right)$$

- Circular Boundary

$$\lambda_c=\frac{4r\rho T}{\pi}(V_0+V)E\left(\frac{2\sqrt{V_0V}}{V_0+V}\right)$$

$$E\left(\frac{2\sqrt{V_0V}}{V_0+V}\right)=\int_0^{\frac{\pi}{2}}\sqrt{1-\frac{4V_0V}{(V_0+V)^2}\sin^2\theta}\,d\theta$$

a complete elliptic integral of the second kind

- Rectangular Boundary

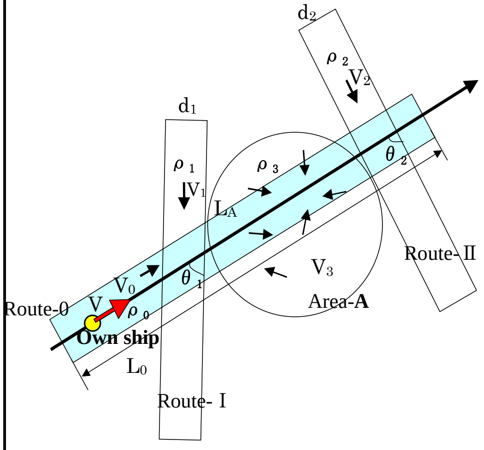
$$\lambda_c=2r\rho T\sqrt{V_0^2+V^2+2V_0V\cos\theta}$$

ρ : Dencity of other ships

$\Theta=0$: Opposite direction

3. Example of Precise Risk Sub-Model
Hazard Occurrence/Prevention Model (Collision)

Estimation of dangerous encounters' number in realistic waters



$$\lambda_0 = 2r\rho_0 T_0\sqrt{V^2 + V_0^2 + 2VV_0\cos\pi}$$
$$\lambda_1 = 2r\rho_1 T_1\sqrt{V^2 + V_1^2 + 2VV_1\cos\theta_1}$$
$$\lambda_2 = 2r\rho_2 T_2\sqrt{V^2 + V_2^2 + 2VV_0\cos\theta_2}$$
$$\lambda_3 = \frac{4r\rho_3 T}{\pi}(V + V_3)E\left(\frac{2\sqrt{VV_3}}{V + V_3}\right)$$
$$\lambda_{TOTAL} = \lambda_0 + \lambda_1 + \lambda_2 + \lambda_3$$

V: Velocity of own ship

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3. Example of Precise Risk Sub-Model
Hazard Occurrence/Prevention Model (Collision)

RCO-1: Separated Sea Lane
RCO-2: Control ship's velocity

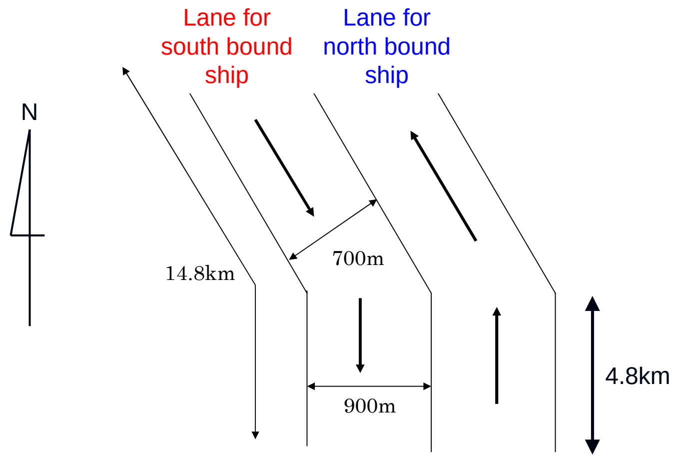
$$\begin{aligned}\lambda_c &= 2r\rho T\sqrt{V_0^2 + V^2 + 2V_0V\cos\theta} \\ &= 2r\rho T(V_0 + V) \qquad (\theta = 0) \\ &= 2r\rho T\boxed{|V_0 - V|} \qquad \boxed{(\theta = \pi)}\end{aligned}$$

Opposite direction
Co-direction

- λc is maximized at θ is 0, i.e. other ships are opposite directional and, λc is minimized if θ is π. Then to separate sea lane is a good RCO to diminish dangerous encounters so as to prevent collision.
- In separated sea lane, making the difference of velocity of ships small is effective to reduce dangerous encounters' number. → Velocity control is effective.

3. Example of Precise Risk Sub-Model
Hazard Occurrence/Prevention Model (Collision)

Effectiveness of separated sea lane
(Example of USTR : Uraga Suido Traffic Route in Tokyo bay)



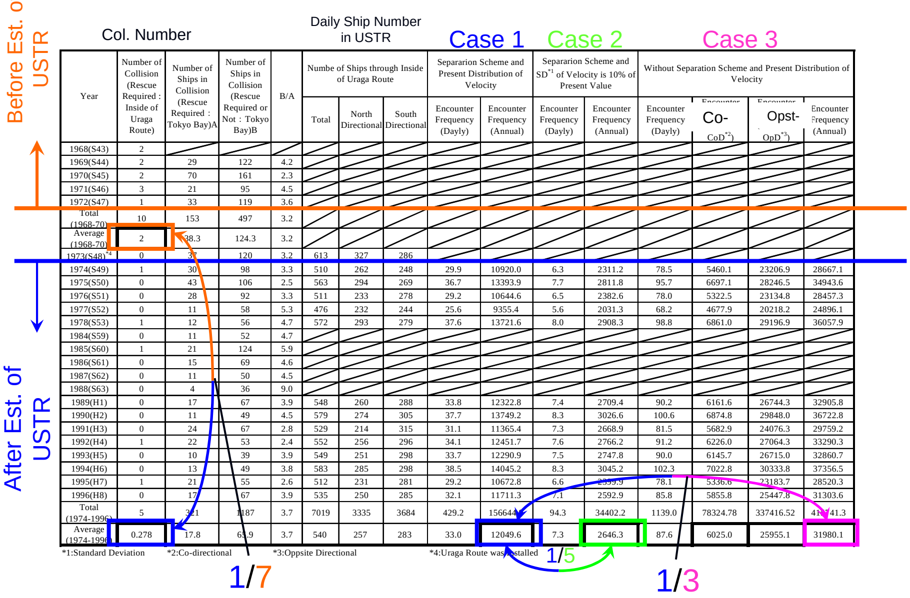
3. Example of Precise Risk Sub-Model
Hazard Occurrence/Prevention Model (Collision)

Effectiveness of separated sea lane
(Examined cases)

1. **Case 1** :Separated sea lane (Current condition)
2. **Case 2** :Separated sea lane + velocity control (Std.Deviation ->10% of the current value)
3. **Case 3** :Without separation scheme

3. Example of Precise Risk Sub-Model
Hazard Occurrence/Prevention Model (Collision)

Results of 3 cases



Year	Number of Collision (Rescue Required : Inside of Uraga Route)	Number of Ships in Collision (Rescue Required : Tokyo Bay)A	Number of Ships in Collision (Rescue Required or Not : Tokyo Bay)B	B/A	Numbe of Ships through Inside of Uraga Route: Total	North Directional	South Directional	Separarion Scheme and Present Distribution of Velocity: Encounter Frequency (Dayly)	Encounter Frequency (Annual)	Separarion Scheme and SD^{*1} of Velocity is 10% of Present Value: Encounter Frequency (Dayly)	Encounter Frequency (Annual)	Without Separation Scheme and Present Distribution of Velocity: Encounter Frequency (Dayly)	Encounter Co- CoD^{*2})	Encounter Opst- OpD^{*3})	Encounter Frequency (Annual)
1968(S43)	2														
1969(S44)	2	29	122	4.2											
1970(S45)	2	70	161	2.3											
1971(S46)	3	21	95	4.5											
1972(S47)	1	33	119	3.6											
Total (1968-70)	10	153	497	3.2											
Average (1968-70)	2	38.3	124.3	3.2											
1973(S48)^{*4}	0	37	120	3.2	613	327	286								
1974(S49)	1	30	98	3.3	510	262	248	29.9	10920.0	6.3	2311.2	78.5	5460.1	23206.9	28667.1
1975(S50)	0	43	106	2.5	563	294	269	36.7	13393.9	7.7	2811.8	95.7	6697.1	28246.5	34943.6
1976(S51)	0	28	92	3.3	511	233	278	29.2	10644.6	6.5	2382.6	78.0	5322.5	23134.8	28457.3
1977(S52)	0	11	58	5.3	476	232	244	25.6	9355.4	5.6	2031.3	68.2	4677.9	20218.2	24896.1
1978(S53)	1	12	56	4.7	572	293	279	37.6	13721.6	8.0	2908.3	98.8	6861.0	29196.9	36057.9
1984(S59)	0	11	52	4.7											
1985(S60)	1	21	124	5.9											
1986(S61)	0	15	69	4.6											
1987(S62)	0	11	50	4.5											
1988(S63)	0	4	36	9.0											
1989(H1)	0	17	67	3.9	548	260	288	33.8	12322.8	7.4	2709.4	90.2	6161.6	26744.3	32905.8
1990(H2)	0	11	49	4.5	579	274	305	37.7	13749.2	8.3	3026.6	100.6	6874.8	29848.0	36722.8
1991(H3)	0	24	67	2.8	529	214	315	31.1	11365.4	7.3	2668.9	81.5	5682.9	24076.3	29759.2
1992(H4)	1	22	53	2.4	552	256	296	34.1	12451.7	7.6	2766.2	91.2	6226.0	27064.3	33290.3
1993(H5)	0	10	39	3.9	549	251	298	33.7	12290.9	7.5	2747.8	90.0	6145.7	26715.0	32860.7
1994(H6)	0	13	49	3.8	583	285	298	38.5	14045.2	8.3	3045.2	102.3	7022.8	30333.8	37356.5
1995(H7)	1	21	55	2.6	512	231	281	29.2	10672.8	6.6	2399.9	78.1	5336.6	23183.7	28520.3
1996(H8)	0	17	67	3.9	535	250	285	32.1	11711.3	7.1	2592.9	85.8	5855.8	25447.8	31303.6
Total (1974-1996)	5	321	1187	3.7	7019	3335	3684	429.2	15664[illegible]	94.3	34402.2	1139.0	78324.78	337416.52	41[illegible]41.3
Average (1974-1996)	0.278	17.8	65.9	3.7	540	257	283	33.0	12049.6	7.3	2646.3	87.6	6025.0	25955.1	31980.1

*1:Standard Deviation *2:Co-directional *3:Oppsite Directional *4:Uraga Route was Installed

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3. Example of Precise Risk Sub-Model
Hazard Occurrence/Prevention Model (Collision)

Collision avoidance failure probability

- Taking account of difference in the difficulty between evasive actions against co- and opposite- directional traffic

Collision avoidance failure probability in USTR

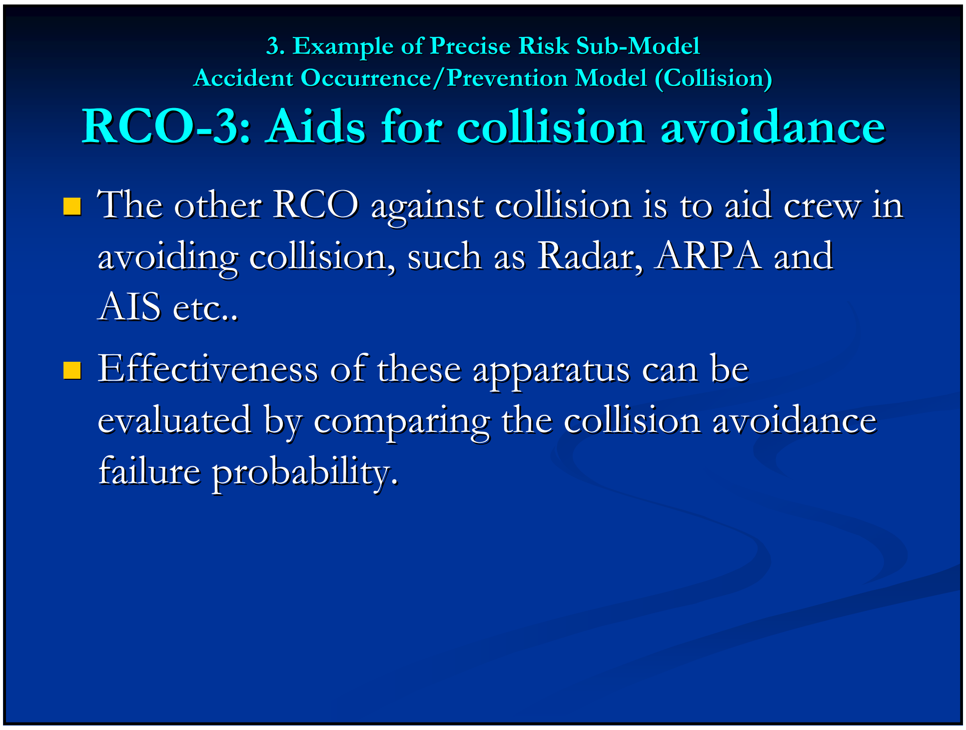
	Collision Avoidance Failure Probability	P2/P1	P4/P3
Co-directional (P1)	8.525×10^{-5}	2.66	
Opposite Directional (P2)	2.268×10^{-4}		
Separation Scheme (P3=P1)	8.525×10^{-5}		2.38
Without Separation Scheme(bi-directional) (P4)	2.031×10^{-4}		

Fujii Y., et.al., 1981,Marine Traffic Engineering, Kaibundo,p.83

Sea area	Failure probability of collision avoidance: Opposite directional(A)	Co-directional(B)	A/B	Notes
Uraga channel	3.0×10^{-4}	1×10^{-4}	3	5 years of late 1960s
Akashi channel	0.8×10^{-4}	1.1×10^{-4}	0.73	5 years of late 1960s
Naruto channel	1×10^{-4}	0.4×10^{-4}	2.5	5 years of late 1960s
Dover Strait	1.8×10^{-4}	1×10^{-4}	1.8	9 yeas before and after 1970
Mean	2.0×10^{-4}	1×10^{-4}	2	Precision : $10^{\pm0.5}$

The difference between the decrease ratio of collisions' number (1/7) and the decrease ratio of encounters' number(1/3) can be explained by introduction of the difference in difficulty between evasive actions against traffics.

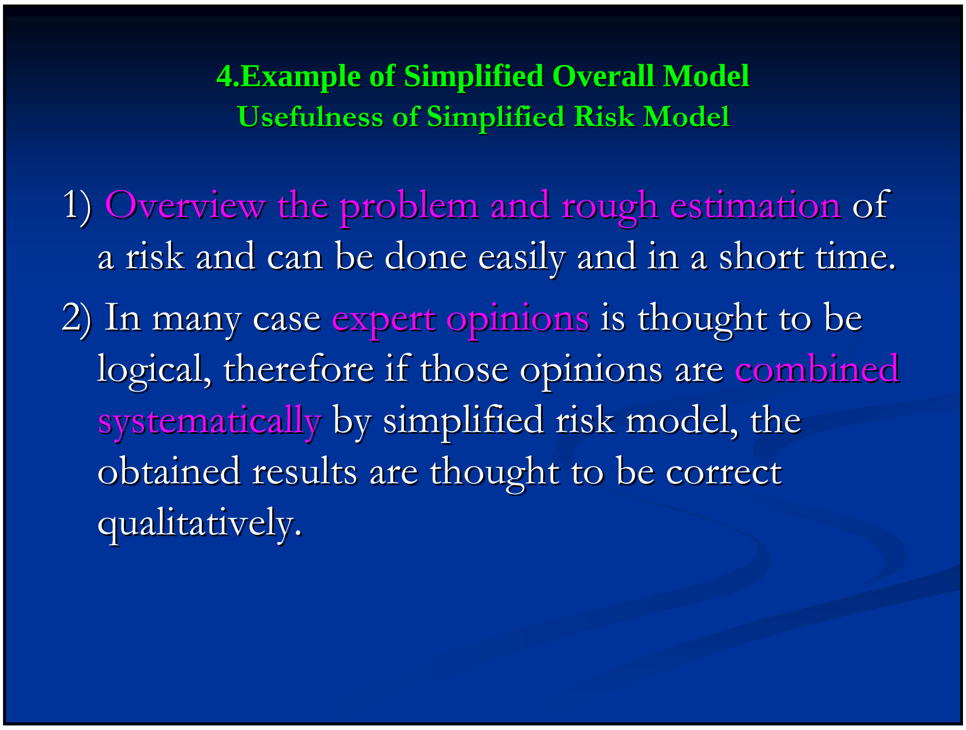
These things discussed above is written in detail in the paper "Effectiveness of separation scheme for prevention of collision by diminishing ships' encounter probability" in the proceedings of ICCGS2004.



3. Example of Precise Risk Sub-Model
Accident Occurrence/Prevention Model (Collision)

RCO-3: Aids for collision avoidance

- The other RCO against collision is to aid crew in avoiding collision, such as Radar, ARPA and AIS etc..
- Effectiveness of these apparatus can be evaluated by comparing the collision avoidance failure probability.



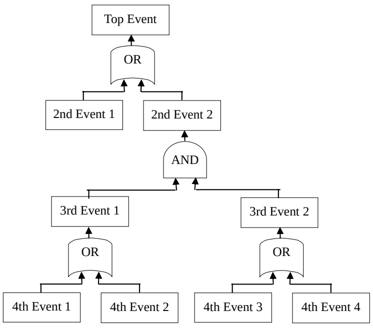
4.Example of Simplified Overall Model
Usefulness of Simplified Risk Model

1) Overview the problem and rough estimation of a risk and can be done easily and in a short time.
2) In many case expert opinions is thought to be logical, therefore if those opinions are combined systematically by simplified risk model, the obtained results are thought to be correct qualitatively.

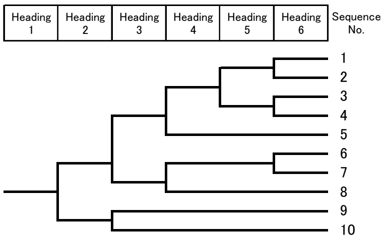
4.Example of Simplified Overall Model

Universal method for simplified risk models

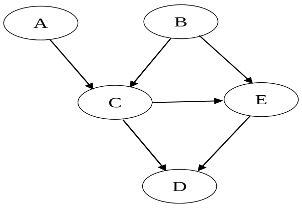
FAULT TREE



EVENT TREE



BAYESIAN NETWORK



4.Example of Simplified Overall Model

Equivalency of ET,FT,BN

- ET (Event Tree),FT (Fault Tree) and BN (Bayesian Network) are essentially equivalent.
- They can express all possible combinations of states of elemental events and they can produce corresponding occurrence probabilities.

$$P\left(\bigcap_{i=1}^{m} A_{ij(i)}\right)$$

$$A_{ij}\bigcap_{j\neq k} A_{ik}=\phi,\ A_i=\bigcap_{j=1}^{n(i)} A_{ij},\ P(A_i)=\sum_{j=1}^{n(i)} P(A_{ij})$$

- A combination of states of elemental events can be called a scenario.

4.Example of Simplified Overall Model

Merit and demerit of ET

- [Merit] All event sequences (accident scenarios) are described, so it is easy to find out which event sequence is most critical.
- [Demerit] Number of headings becomes more and more, event sequences is getting more and more numerous so that it may become hard to write down all event sequences of a tree.
- [Demerit] Setting conditional probabilities to the branch is not easy.

4.Example of Simplified Overall Model

Merit and demerit of FT

- [Merit] Logical structure of a problem can be easily grasped.
- [Merit] Discrimination of important elements is comparatively easy.
- [demerit] Accident scenarios are not easily distinguished.
- [demerit] Setting conditional probabilities to the branch is not easy.

4.Example of Simplified Overall Model

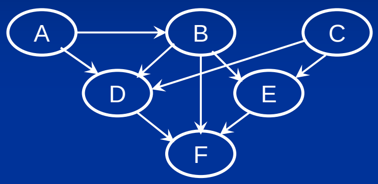
Merit and demerit of BN

- [Merit] To create network by adding elements is easy.
- [Merit] Setting conditional probabilities of nodes is easy.
- [Demerit] Accident scenarios are not easily distinguished.

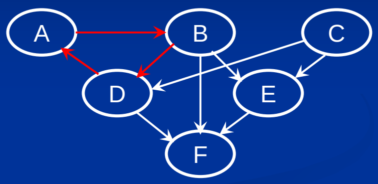
4.Example of Simplified Overall Model

Bayesian Network (BN)

Bayesian network



Not Bayesian network



Definition of Bayesian network (Jensen: “Bayesian Networks and Decision Graphs”)

- Bayesian network consists of the following:

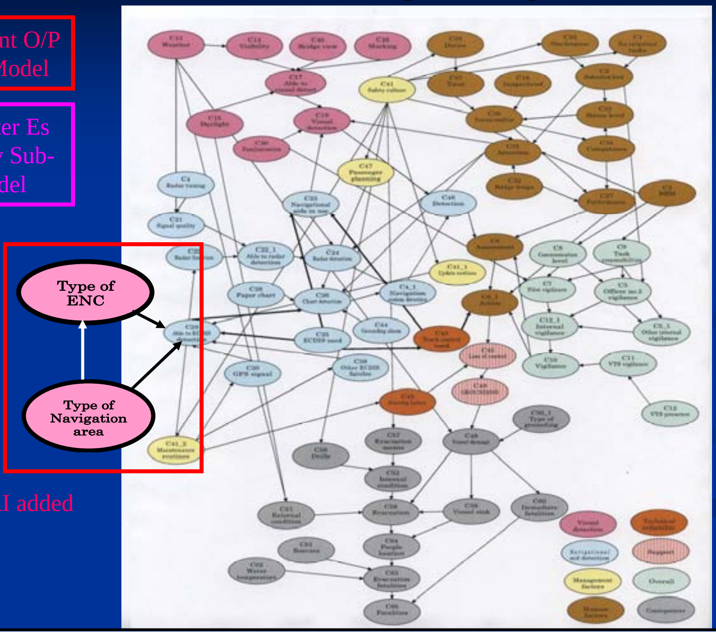
1) A set of variables and a set of directed edges between variables.
2) Each variable has a finite set of mutually exclusive states.
3) The variables together with the directed edges form a directed acyclic graph.
4) To each variable A with parents B1,…,Bn, there is attached the potential table P(A|B1,…,Bn)

4.Example of Simplified Overall Model

Bayesian network(BN) for grounding (NAV51/10)

Accident O/P Sub-Model

Disaster Es /M /Ev Sub-Model



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4.Example of Simplified Overall Model

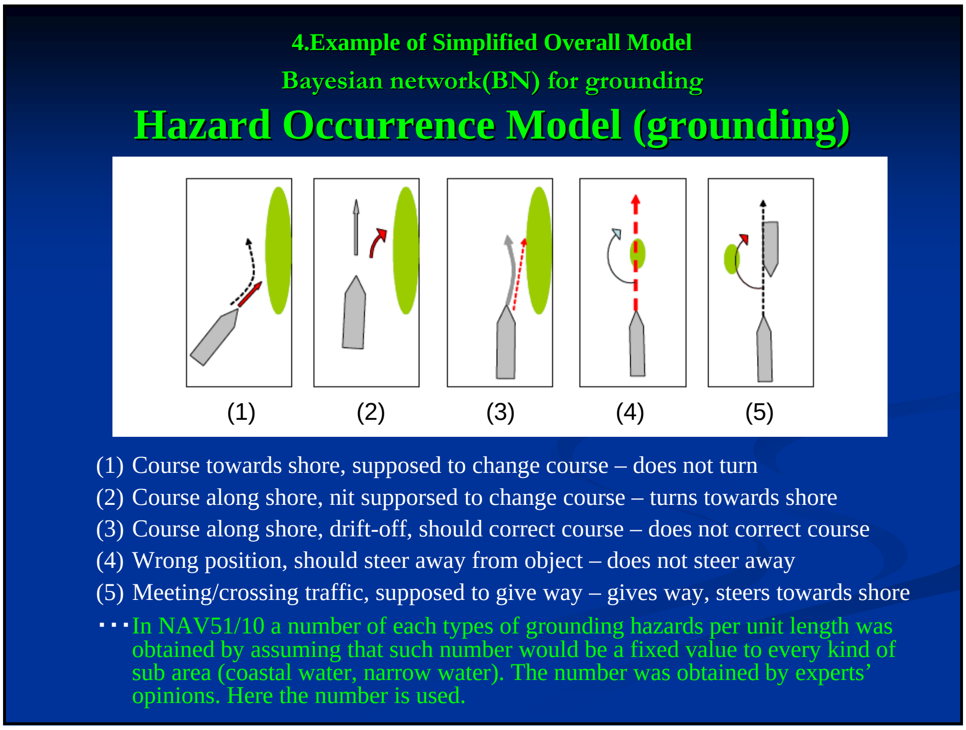
Bayesian network(BN) for grounding

Obtaining Annual grounding frequency (F-grd) & Number of fatalities (N-ftl) by the outputs of grounding BN

- This BN outputs a grounding probability of a ship(P-grd) and a probability that a person in the ship died(P-ftl) when a grounding hazard occurs.
- Sea area are divided into 3 sub areas below.
  1) Open Water :No obstacles within 5 miles.
  2) Coastal Water : No obstacles within 2 miles.
  3) Narrow Water : No obstacles within 0.5 miles.
- To a trade of a ship, calculate lengths of above 3 kind of sub areas, then estimate occurrence number of grounding hazards of every type of grounding hazard. Moreover obtain total number(N-grd-h) of grounding hazards by summarizing them.
- Estimate an annual grounding frequency (F-grd) by N-trd(annual trade number) * N-grd-h * P-grd.

Estimate an annual fatality number(N-ftl) by N-trd * N-psn(number of persons on board) * N-grd-h * P-ftl.

F-grd = N-trd * N-grd-h * P-grd
N-ftl = N-trd * N-psn * N-grd-h * P-ftl



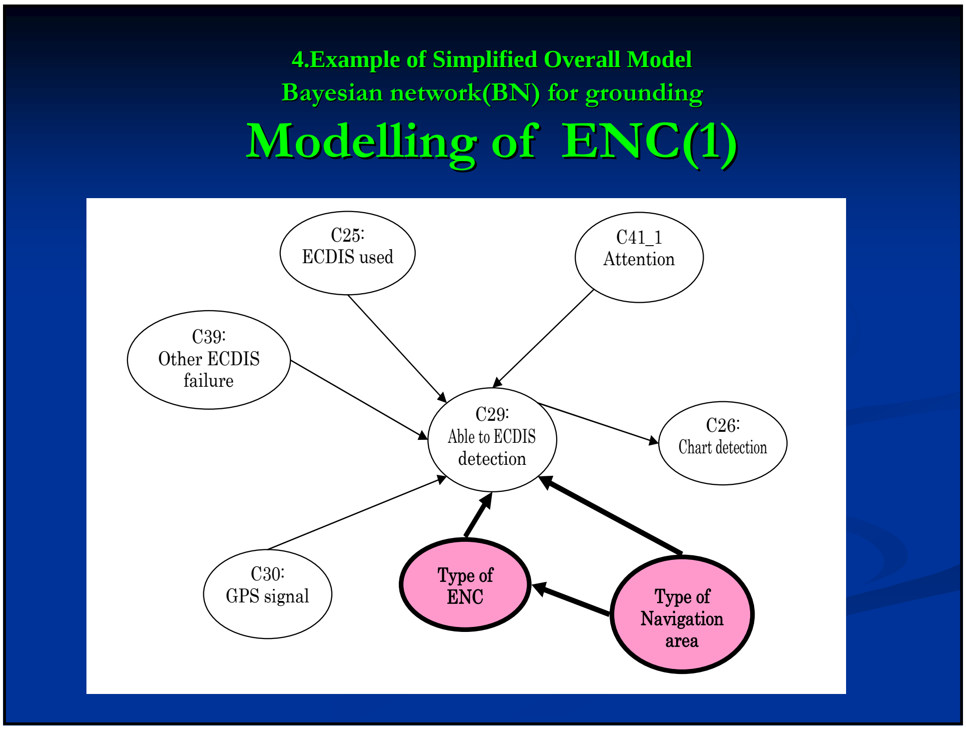
4.Example of Simplified Overall Model

Bayesian network(BN) for grounding

Hazard Occurrence Model (grounding)

(1) Course towards shore, supposed to change course – does not turn
(2) Course along shore, nit supporsed to change course – turns towards shore
(3) Course along shore, drift-off, should correct course – does not correct course
(4) Wrong position, should steer away from object – does not steer away
(5) Meeting/crossing traffic, supposed to give way – gives way, steers towards shore

・・・In NAV51/10 a number of each types of grounding hazards per unit length was obtained by assuming that such number would be a fixed value to every kind of sub area (coastal water, narrow water). The number was obtained by experts' opinions. Here the number is used.



4.Example of Simplified Overall Model

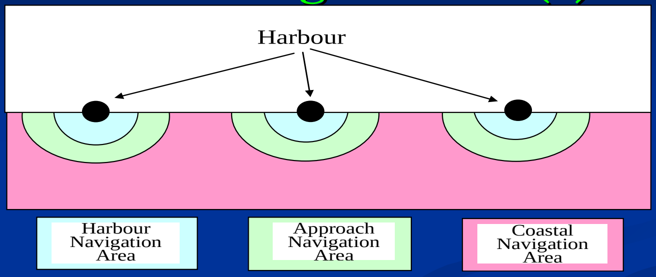
Bayesian network(BN) for grounding

Modelling of ENC(1)

4.Example of Simplified Overall Model

Bayesian network(BN) for grounding

Modelling of ENC(2)



Waters division into navigation area

1) Obtain existence ratios of coastal waters and narrow waters to a route of every type of a cargo ship.
2) Estimate existence ratio of every type of navigation area to every type of waters. (i.e. estimate all cells of CPT of node ”Type of Navigation Area”)
3) Estimate probability that every type of ENC is the smallest obtainable scaled to every type of navigation area. (i.e. estimate all cells of CPT of node “Type of ENC” to every type of waters of every route)
4) Modify the CPT of node “Able to ECDIS Detection” including above ENC related nodes.

4.Example of Simplified Overall Model

Bayesian network(BN) for grounding

CPTs of ENC related nodes

CPT of the node “Type of Navigation Area”

Type of waters / Type of Nav. Area	Coastal Waters	Narrow Waters
Harbour Nav. Area	a11	a12
Approach Nav. Area	a21	a22
Coastal Nav. Area	a31	a23
Total	1	1

CPT of node “Type of ENC”

Type of Nav. A. / Type of ENC	Harbour Nav. Area	Approach Nav. Area	Coastal Nav. Area
Harbour	b11	b12	b13
Approaches	b21	b22	b23
Coastal	b31	b32	b33
General	b41	b42	b43
Overview	b51	b52	b53
Total	1	1	1

CPT of the node “Able to ECDIS Detection”

ECDIS used	GPS signal	Other ECDIS failure	Update routine	Type of nav. area	Type of ENC	Able to ECDIS detection	
						Yes	No
YES	YES	No failure	Good	Harbour	Harbour	1	0
					Approches	0.1	0.9
					Coastal	0	1
					Gneral	0	1
					Overview	0	1
				Approach	Harbour	1	0
					Approches	1	0
					Coastal	0.05	0.95
					Gneral	0	1
					Overview	0	1
				Coast	Harbour	0	1
					Approches	0.1	0.9
					Coastal	1	0
					Gneral	0	1
					Overview	0	1
			Poor	Harbour	Harbour	0.5	0.5
					Approches	0.05	0.95
					Coastal	0	1
					Gneral	0	1
					Overview	0	1
				Approach	Harbour	0.5	0.5
					Approches	0.5	0.5
					Coastal	0.05	0.95
					Gneral	0	1
					Overview	0	1
				Coast	Harbour	0	1
					Approches	0.05	0.95
					Coastal	1	0
					Gneral	0	1
					Overview	0	1

4.Example of Simplified Overall Model

Bayesian network(BN) for grounding

Cost benefit assessment (NAV52/6/2)

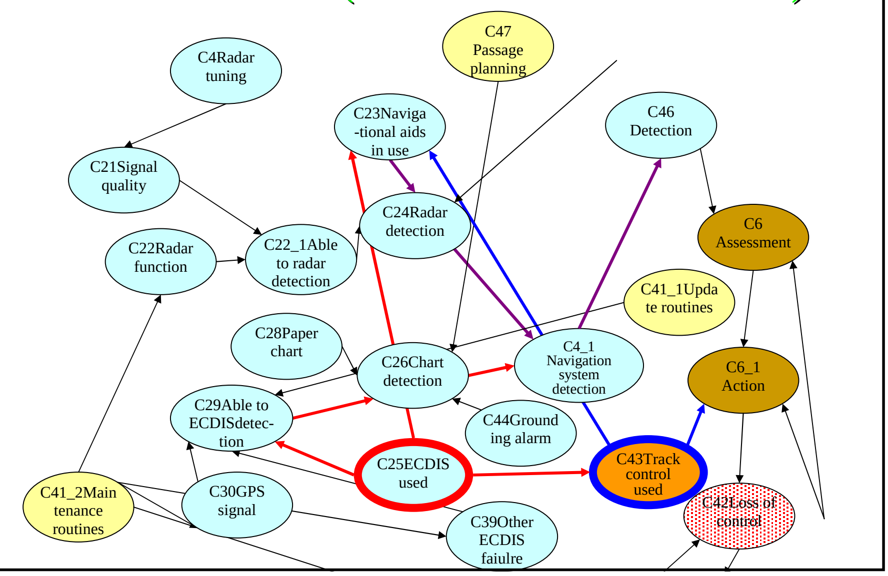
Route	Ship type	Average lifetime	No. of Fatalities per lifetime	No. of Fatalities per lifetime(No ECDIS)	No of lives saved per lifetime	% reduction in number of fatalities	Gross CAF Cost of implemen- tation of ECDIS = 60,000 (NPV by $)	
Route1 (Yokohama - Ras Tanura)	Tanker	25	1.88E-02	4.65E-02	2.77E-02	60%	2.17E+06	<3M$
Route2 (Oita - Port Hedland)	Ore carrier	25	1.96E-02	4.32E-02	2.36E-02	55%	2.55E+06	<3M$
Route3 (Kobe - Rotterdam)	Container	25	3.30E-02	6.91E-02	3.61E-02	52%	1.66E+06	<3M$
Route4-1 (Nagoya - New York)	Car Carrier	25	2.73E-03	7.99E-03	5.26E-03	66%	1.14E+07	>3M$
Route4-2 (Hirosima - Kii Suido - Nagoya-New	Car Carrier	25	8.67E-03	2.70E-02	1.83E-02	68%	3.28E+06	≒3M$

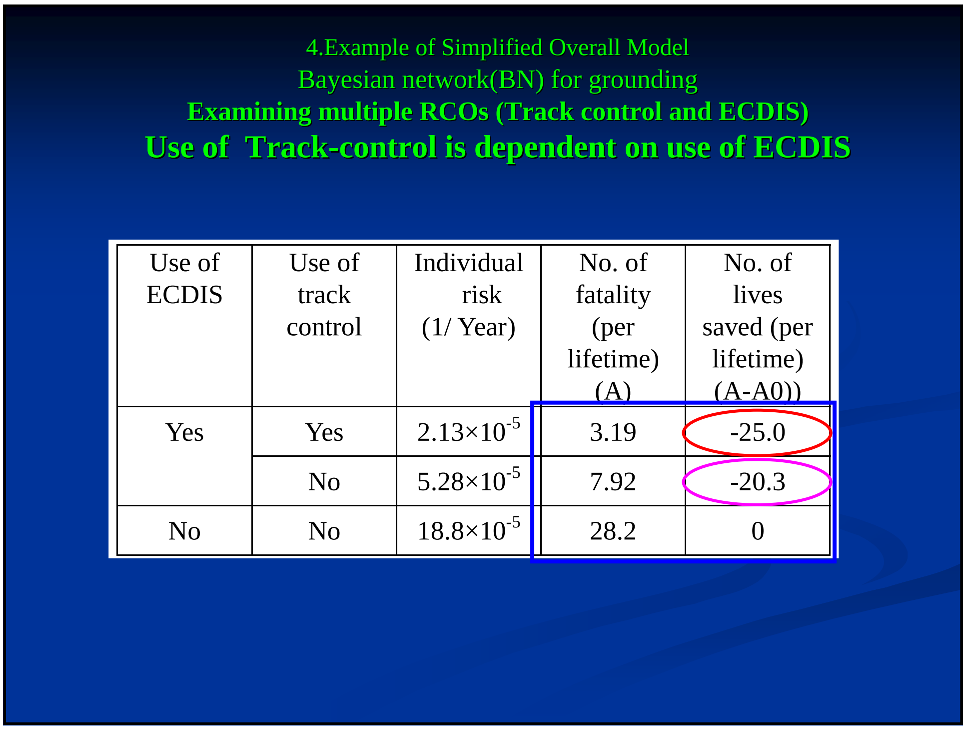
4.Example of Simplified Overall Model

Bayesian network(BN) for grounding

Evaluation of Multiple RCO's by BN

Selected RCOs (ECDIS and Track control)

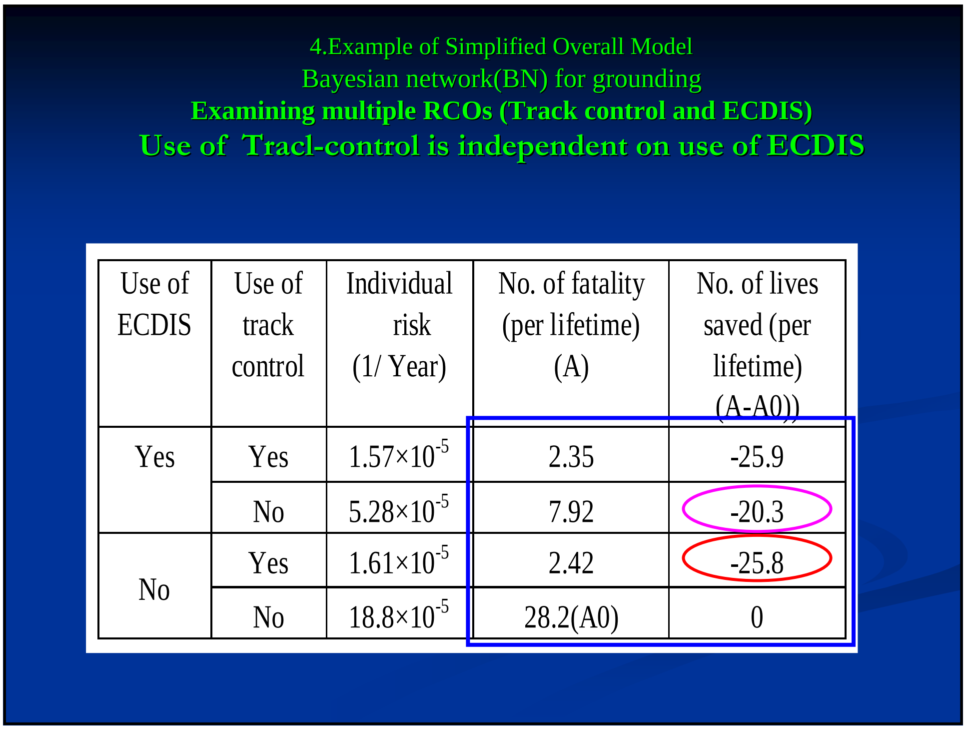




4.Example of Simplified Overall Model
Bayesian network(BN) for grounding
Examining multiple RCOs (Track control and ECDIS)

Use of Track-control is dependent on use of ECDIS

Use of ECDIS	Use of track control	Individual risk (1/ Year)	No. of fatality (per lifetime) (A)	No. of lives saved (per lifetime) (A-A0))
Yes	Yes	2.13×10^{-5}	3.19	-25.0
	No	5.28×10^{-5}	7.92	-20.3
No	No	18.8×10^{-5}	28.2	0



4.Example of Simplified Overall Model
Bayesian network(BN) for grounding
Examining multiple RCOs (Track control and ECDIS)

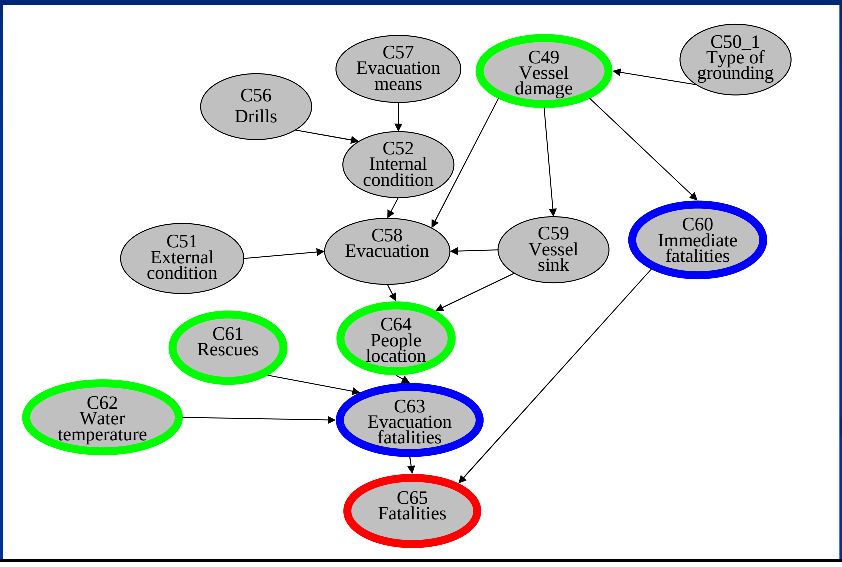
Use of Tracl-control is independent on use of ECDIS

Use of ECDIS	Use of track control	Individual risk (1/ Year)	No. of fatality (per lifetime) (A)	No. of lives saved (per lifetime) (A-A0))
Yes	Yes	1.57×10^{-5}	2.35	-25.9
	No	5.28×10^{-5}	7.92	-20.3
No	Yes	1.61×10^{-5}	2.42	-25.8
	No	18.8×10^{-5}	28.2(A0)	0

5. Consideration of Uncertainty

Evaluation of Uncertainty of simplified risk model by BN

Example：Estimation of fatality probability



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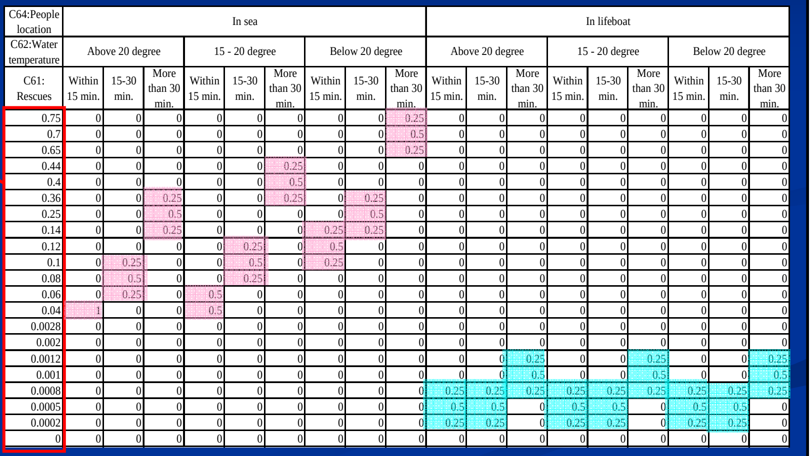
5. Consideration of Uncertainty

Evaluation of Uncertainty of simplified risk model by BN

CPT of Node C63(Evavuation Fatality)

Probabili-
ty range
of C63

(Fatality
probabili-
ty)

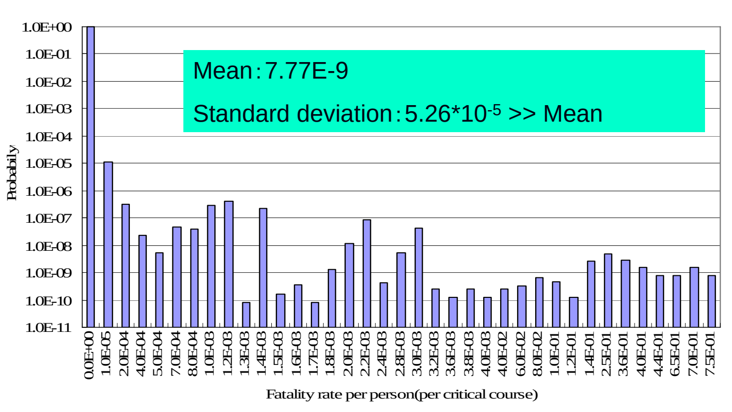


C64:People location	In sea									In lifeboat								
C62:Water temperature	Above 20 degree			15 - 20 degree			Below 20 degree			Above 20 degree			15 - 20 degree			Below 20 degree		
C61: Rescues	Within 15 min.	15-30 min.	More than 30 min.	Within 15 min.	15-30 min.	More than 30 min.	Within 15 min.	15-30 min.	More than 30 min.	Within 15 min.	15-30 min.	More than 30 min.	Within 15 min.	15-30 min.	More than 30 min.	Within 15 min.	15-30 min.	More than 30 min.
0.75	0	0	0	0	0	0	0	0	0.25	0	0	0	0	0	0	0	0	0
0.7	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0
0.65	0	0	0	0	0	0	0	0	0.25	0	0	0	0	0	0	0	0	0
0.44	0	0	0	0	0	0.25	0	0	0	0	0	0	0	0	0	0	0	0
0.4	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0
0.36	0	0	0.25	0	0	0.25	0	0.25	0	0	0	0	0	0	0	0	0	0
0.25	0	0	0.5	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0
0.14	0	0	0.25	0	0	0	0.25	0.25	0	0	0	0	0	0	0	0	0	0
0.12	0	0	0	0	0.25	0	0.5	0	0	0	0	0	0	0	0	0	0	0
0.1	0	0.25	0	0	0.5	0	0.25	0	0	0	0	0	0	0	0	0	0	0
0.08	0	0.5	0	0	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0
0.06	0	0.25	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.04	1	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0028	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0012	0	0	0	0	0	0	0	0	0	0	0	0.25	0	0	0.25	0	0	0.25
0.001	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0.5	0	0	0.5
0.0008	0	0	0	0	0	0	0	0	0	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
0.0005	0	0	0	0	0	0	0	0	0	0.5	0.5	0	0.5	0.5	0	0.5	0.5	0
0.0002	0	0	0	0	0	0	0	0	0	0.25	0.25	0	0.25	0.25	0	0.25	0.25	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

5. Consideration of Uncertainty

Evaluation of Uncertainty of simplified risk model by BN

Probability distribution of node C65(Fatality)



Mean : 7.77E-9

Standard deviation : $5.26*10^{-5}$ >> Mean

Width of uncertainty of the estimated value of fatality rate is rather large comparing with the absolute value of the estimator.

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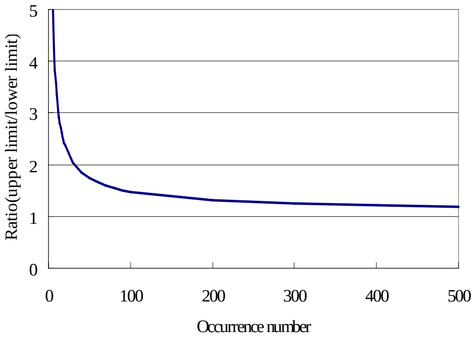
5. Consideration of Uncertainty

Evaluation of Uncertainty of precise risk sub-model

Parameter of Poisson distribution



Occurrence number vs Ratio (Upper limit/Lower limit)

$$\frac{\chi^2_{2(N+1)}(2.5\%)}{2} \le \lambda T \le \frac{\chi^2_{2(N+1)}(97.5\%)}{2}$$

λ : Average occurrence rate

N : Occurrence number for T

$$\text{Lower limit} = \frac{\chi^2_{2(N+1)}(2.5\%)}{2}$$

$$\text{Upper limit} = \frac{\chi^2_{2(N+1)}(97.5\%)}{2}$$

Uncertainty of estimated parameter of Poisson distribution becomes smaller as occurrence number becomes large. → Data is important.

5. Consideration of Uncertainty

Principle of preciseness level of risk model

- Preciseness of a risk model and uncertainty of it is a trade-off relation clearly.
- Since the required width of uncertainty is thought to be dependent on problems, it is necessary to determine the level of preciseness of a risk model to every problem to be assessed.
- Or first, make a level 3 preciseness risk model, ex. by BN for assessing roughly, then narrow the assessed accident scenarios (ASs) and/or parts of ASs and if necessary, more precise risk model or sub-model should be considered.

6.Conclusion

1. Risk models of a ship is discussed holistically and a few examples of a risk model and a risk sub-model are introduced and discussed.
2. Uncertainty, which is one of the big problems of a risk model, is considered. It is demonstrated that preciseness level of a risk model would greatly affect the uncertainty.
3. Principle of determination of preciseness of risk model is proposed.