granting and site block grants. This approach is an effort to simplify funding procedures for more than one federal assistance program. The funding process begins with the designation of one of the several federal agencies involved in the project to be implemented as the legal agency for the project. If it is approved, then the process will have required only one application for funds in conjunction with only one audit trail. This approach to multiproject, multiagency funding may ultimately prove the most valuable for IFTFC capital implementation.

Local Funding Sources

Possible local sources of funding include general obligation (GO) and revenue bonds. GO bonds require a referendum that pledges the faith and credit of the city with collateral security of all taxable property. Cities are, however, limited as to the amount of GO indebtedness they can have by state law. In addition, the IFTFC would compete with other city needs and so might be given low public priority.

Revenue bonds can also be used for financing when the issuing agency can provide assurance that income for repayment of the bonds will be in excess of the debt service requirements. Normally, interest rates for revenue bonds are higher than those for GO bonds because of their greater risk.

Other Sources

One final possibility for funding would include general and special revenue sharing for the local government. Revenue sharing, however, would most likely encounter difficulty in meeting the intent and requirements of the 1974 Community Development Act. Further, the IFTFC would be competing with ongoing uses of funds and thus would encounter enormous difficulties.

BENEFITS OF IFTFCs

The major benefits of planned IFTFCs are

1. Lower cost for equal service;
2. Better cost control in delivery of services;
3. Better services and capacity available to carriers;
4. Improved control, safety, and security;
5. Better use of land and equipment;
6. Relief of congestion in urban areas;
7. Lower sunk costs and savings in dollars to the federal, state, and local government;
8. Reduction in energy use;
9. Reduction of regional pollution; and
10. Improved regional employment, economy, and industrial development.

In conclusion, the benefit of conducting research by using the IFTFC concept involves a deeper and more orderly understanding of the processes and interactions that occur with respect to transportation modes and goods movement within a region. It is for this purpose that the methodology was formulated and, through its use, greater understanding of these interactions will result.

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Risk Analysis for Marine Transportation

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Personnel, valuable commodities, and hazardous materials being transported by sea or inland waterway have been lost or released to the environment after serious ship collisions, rammings, or groundings. The quantitative determination of the risks of such events is therefore of substantial importance to marine transportation. Previous studies of ship collision probabilities have been semiempirical in nature, involving various assumptions for navigational behavior or functional dependencies. This paper derives the necessary physical relations implied by stochastic behavior through the introduction of a ship collision probability flux. The model yields analytical expressions for the probabilities of ship collisions and includes rammings and groundings as special cases. In addition, explicit expressions are given for the probabilities of a ship's being the struck versus the striking vessel. Suggestions for various applications of the stochastic flux model are presented.

It has been customary to begin any discussion of ship collision probabilities by stating that, in principle, collisions should not occur at all since the movement of ship traffic supposedly takes place under rules of the road and operating plans that are designed to prevent collisions. Collisions are, therefore, indisputable evidence that the movements of at least a small number of ships for short periods of time are not orderly. Hence, it appears reasonable to assume that the movement of ships will sometimes, though infrequently, be stochastic. Indeed, this behavior has usually been either explicitly or implicitly assumed in studies of ship collison probabilities because the specific errors or malfunctions that sometimes result in collisions are so highly variable and nonsystematic that the overall ensemble of errors or malfunctions resembles a stochastic process. However, in previous modeling attempts, further specific functional relations or navigational behavior was also assumed to obtain collision probabilities.

This study shows that these additional and more elaborate assumptions are not only unnecessary but are also not permitted by the first assumption. This paper develops a generalized model, based on the single assumption of stochastic motion, from which expressions are derived for the probability of a ship collision, the expected number of ship collisions, the probability that a ship involved in a collision is the striking or struck ship, and the frequency of ramming or grounding.

STOCHASTIC FLUX MODEL

Under the assumption of stochastic motion, the movements of ships are not correlated; the ships under consideration will not interact before a collision occurs. Thus, the analytically insoluble problem of N interacting bodies is reducible to a problem that involves only the two colliding ships. It is convenient to analyze a two-body problem in the center of a mass coordinate system so that, in effect, it is reduced to that of a single body of reduced mass moving about the other body at the relative velocity between the two bodies (1).

Accordingly, the collision problem for ships S_i and S_j of lengths l_i and l_j, widths w_i and w_j, and velocities $\vec{v}_i$ and $\vec{v}_j$ respectively, in the global reference frame shown in Figure 1, is transformed into the equivalent one-body system shown in Figure 2. In the equivalent system, the collision energy is immediately given by $E = (1/2)\mu v_R^2$ where μ is the reduced mass and v_R is the relative velocity. The collision angle is defined as θ_R rather than θ, which determines only the orientation of the striking ship.

If the speed of each ship is constant in a region of characteristic dimension D (area D^2), the probability of a collision between ships S_i and S_j in each traverse of the region by S_i is then

$$C_{ij} = T_i P_j P_{ij} \tag{1}$$

Figure 1. Collision problem: global reference frame.

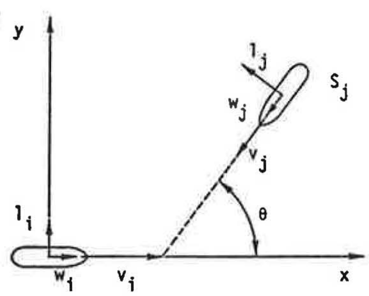
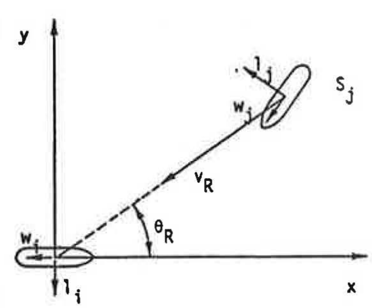


Figure 2. Collision problem: equivalent one-body system.



where

T_i = time S_i requires to traverse D,
P_j = probability of finding S_j in region D^2, and
P_{ij} = probability per unit time of a collision between S_i and S_j given that S_j is in D^2.

If the magnitude of $\vec{v}_k$ is denoted by v_k, then $T_i = D/v_i$ and $P_j = (1/\tau)(D/v_j)$ where, if velocity is specified in meters per second, τ is the number of seconds in a year. To obtain P_{ij}, consider the quantity

$$\Phi(\theta_R) = [\vec{\sigma}(\theta_R) \cdot \vec{v}_R(\theta_R)]/2\pi D^2 \tag{2}$$

where $\vec{v}_R$ is the relative velocity and $\vec{\sigma} = \vec{\sigma}_i + \vec{\sigma}_j$ is the effective collision "cross section"; $\vec{\sigma}_k = w_k\hat{n}_{wk} + l_k\hat{n}_{lk}$ where $\hat{n}_{wk}$ and $\hat{n}_{lk}$ are unit vectors normal to the width and length of the k^{th} ship in the direction that maximizes Φ. Since the quantity denoted by Φ has the dimensions of ships per unit of time, it is appropriately called the colliding ship flux. Clearly, the conditional probability of a collision per unit of time between S_i and S_j is then equal to the flux of colliding ships from all possible directions:

$$P_{ij} = \int d\theta_R \, \lambda(\theta_R)\Phi(\theta_R) \tag{3}$$

where the nonisotropic density function is expressed as follows:

$$\lambda(\theta_R) = v_R^2/(v_j^2 - v_i^2 + v_i v_R \cos\theta_R) \tag{4}$$

Thus, the probability of a collison with S_j per transit of region D^2 by S_i is

$$C_{ij} = (1/2\pi\tau)/(1/v_i v_j) \int d\theta_R \, \lambda(\theta_R)\, \vec{\sigma}(\theta_R) \quad \vec{v}_R(\theta_R) \tag{5}$$

To perform this integration, it is judicious to transform to the variable θ, where $\theta_R = \mathrm{ctn}^{-1}$ (ctn $\theta + \beta$ csc θ) in which $\beta = v_i/v_j$.

It should be apparent that the transformation is double valued if $\beta > 1$ but single valued if $\beta < 1$. Moreover, there exists a maximum angle $\theta_R^{max} = \csc^{-1} \beta$ if $\beta > 1$. Clearly, these mathematical properties yield to obvious physical interpretations.

The straightforward evaluation of the resulting integral yields, for $v_j \geq v_i > (D/\tau)$,

$$C_{ij} = \big((1/\pi\tau)(w_i/v_j)\{2\cos^{-1}[-(v_i/v_j)] - \pi\} + (w_j/v_i)\,\pi + 2(w_i/v_i)\sin\cos^{-1}[-(v_i/v_j)] + 2(l_i/v_i) + 2(l_j/v_j)\big) \tag{6}$$

By symmetry, the collision probability for $v_i \geq v_j \geq (D/\tau)$ is obtained by interchanging the i and j indexes on the right-hand side of the equation.

A ship can be expected to enter into a collision mode governed by the preceding stochastic flux equations if it or another ship in the region violates the rules of the road during a fraction α_i of its operational time. In the time interval T_i in which ship S_i is transiting region D^2, the probability of a collision involving S_i and S_j is then

$$C_{ij}^{(\alpha)} = (\alpha_i + \alpha_j - \alpha_i\alpha_j)\, C_{ij} \equiv \alpha_{ij} C_{ij} \tag{7}$$

The probability α_i reflects all factors $\alpha_i^{(k)}$ causing nonadherence to the rules of the road, i.e., human error, equipment failure, or willful negligence. In a first approximation, $\alpha_i^{(k)}$ can be regarded as statistically independent and independent of dynamic considerations so that

$$\alpha_i = \sum_k \alpha_i^{(k)} \tag{8}$$

Therefore, in the absence of statistically significant data on ship collisions, a nonempirical or first-principles estimate of the probability of collision is available through use of fundamental information on such factors as general human behavior and reliability of equipment (2). Whenever meaningful data on ship collisions do exist, of course, an empirical fit for α_i can be performed.

Thus, the probability and the expected number of collisions involving ship S_i during M transits of a region that experiences N ship transits per year are, respectively,

$$C_i^{(\alpha)} = 1 - \prod_{j=1}^{N-M} [1 - C_{ij}^{(\alpha)}]^M \tag{9}$$

and

$$K_i^{(\alpha)} = \sum_{i=1}^{M} \sum_{j=1}^{N-M} C_{ij}^{(\alpha)} \tag{10}$$

Note that the basic collision probability $[C_{ij}^{(\alpha)}]$ is independent of the size of the region. This is because the size of the region is merely the grid size selected for convenience in accordance with data specifications. However, N and M, and thus $C_i^{(\alpha)}$ and $K_i^{(\alpha)}$, vary with D.

SPECIAL CASES

An implicit result of this analysis is that the basic probability of collisions can be analytically partitioned into striking ship and struck ship incidences. If ship i is considered the struck ship when impact occurs along its length and the striking ship when impact occurs along its width (regardless of whether the other ship is also impacted along its width), it is readily apparent that the probability of i's being the struck ship during a transit is

$$C_{ij}^{(\alpha,1)} = C_{ij}^{(\alpha)} \; (l_j = w_i = 0) \tag{11}$$

and the probability of i's being the striking ship is

$$C_{ij}^{(\alpha,2)} = C_{ij}^{(\alpha)} - C_{ij}^{(\alpha,1)} = C_{ij}^{(\alpha)} \; (l_i = w_j = 0) \tag{12}$$

In cases where only side impacts can result in serious consequences to ships that are transporting hazardous cargoes, $C_{ij}^{(\alpha,1)}$ is the only important probability.

Since the dynamic variables v_i appear explicitly in this kinematic model, the analysis is adequately generalized to include, as another special case, the frequency of transiting ships ramming stationary objects such as ships at anchor, sand bars, oil platforms, and buoys. That is, if L stationary obstacles are situated in area D^2 and each occupies a rectangular area of dimension η_j and ξ_j, the number of rammings after N ship transits is

$$R^{(\alpha)} = \sum_{i=1}^{N} \sum_{j=i}^{L} C_{ij}^{(\alpha)} \; (w_j = \eta_j, l_j = \xi_j, v_j = \alpha_j = 0)$$

$$= (1/D) \sum_{i=1}^{N} \sum_{j=1}^{L} \alpha_i \, [w_i + (2/\pi)(\eta_j + \xi_j)] \tag{13}$$

APPLICATIONS

If the stochastic flux equations are used along with aggregated marine traffic and casualty statistics from seven major harbor areas of the United States during the 6-year period between 1969 to 1975, the validity of the model can be ascertained by comparing its predictions with the historical statistics. The table below gives the expected number of collisions predicted by the model and the number of collisions observed during the 6-year period at each of seven sites:

Harbor Region	Collisions: Predicted (to nearest integer)	Observed
Boston	0	0
Galveston	1	2
Long Beach	0	0
Los Angeles	1	1
Mississippi River Delta	1	1
New York	3	3
Tampa	0	0

Details of the analysis can be found elsewhere (3).

The close agreement between expected and observed events is one indication of the validity of the model. The value of the model, however, is not in these simple results, but in its ability to provide a detailed analysis of the risks and sensitivities of specific ships in proposed or existing operations. Under the sponsorship of various public and private organizations, the stochastic flux equations have been applied to particular operations in many other regions that have very diverse characteristics including long narrow channels and wide open bodies of water. The results of the analyses have been used to evaluate, as well as manage, the risks of marine transportation.

DISCUSSION OF RESULTS

Several significant results have been obtained from this model, which is based on a single assumption. By use of Equations 9, 10, 11, 12, 13, and, for total collisions,

$$K^{(\alpha)} = \sum_{i=1}^{N} \sum_{j=i}^{L} C_{ij}^{(\alpha)} \tag{14}$$

these results can all be expressed in terms of a basic collision probability function, as follows:

$$C_{ij}^{(\alpha)} = (\alpha_{ij}/2\pi\tau v_i v_j) \int d\theta_R \, \lambda(\theta_R) \bar{\sigma}(\theta_R) \times \dot{v}_R(\theta_R) \tag{15}$$

The critical functional dependencies derived through the kinematic analysis of stochastic motion are, of course, the necessary relations between the canonical variables v_i and the probability, angle, and energy of the collision. In particular, the following results are noted:

1. The total number of collisions is inversely proportional to the speeds of ships. Thus, in the same number of transits, fewer collisions are expected at higher speeds than at lower speeds.
2. The probability of a collision per unit cross section is significantly greater at small forward angles because v_R is large.
3. Collision energy at small forward angles is considerably greater because energy increases with v_R^2.
4. Optimal velocities exist at which collision probabilities are reduced without a substantial increase in collision energies. Probable losses are minimized at these velocities.
5. The probabilities of collision, of a ship's

being the striking versus the struck vessel in a collision, and the frequencies of rammings and groundings can be intrinsically and analytically related.

Although data have often been said to indicate that course angles are isotropically distributed, it does not follow that collision angles are also isotropically distributed. What has been described as a 90^o impact is not normal incidence; 90^o simply describes the orientation of the striking ship. Because of the variation of relative velocity and collision energy with collision angle, a 90^o impact clearly does not necessarily represent the worst case.

The usefulness of the model discussed here derives largely from the appearance of the canonical variables (v_i). These variables essentially make it possible to exchange spatial information for time-related information, which is more readily available and less variable. That is, it is not necessary to specify a ship's location or course in a region but only to specify the time it spends in the region. Thus, the size of the region D^2 can be viewed as a measure of the imprecision or uncertainty about a ship's position.

The fundamental collision probability integral developed for the analysis of stochastic motion is also suitable for other modes of motion since the density function $\lambda(\theta_R)$ can be arbitrarily perturbed or restricted to reflect nonisotropic distributions of ship orientations in the global reference frame. Thus, specific situations such as ship crossings, meetings, and overtakings can be individually analyzed. However, such efforts to quantitatively predict and restrict future accident scenarios require additional assumptions.

Because all the model results appear in analytical form, the implications of perturbations of the input parameters to reflect excursions from known or existing situations or to explore the sensitivities of the predictions can be easily determined. In particular, the model easily lends itself to the investigation of transportation scenarios projected for specific sites and operations.

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Locks and Dam 26: A Dilemma in National Transportation Policy

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The issue of Locks and Dam 26 and its relation to the issue of waterway user charges represents a critical decision point in emerging national transportation policy. The history, operation, and deterioration of Locks and Dam 26 on the Mississippi River and its place as the legislative fulcrum by which to impose user charges on the waterway system are reviewed. Various types of user charges are defined, and their impacts are quantitatively explored. The relation of user charges to emerging national transportation policy and the current user charge legislation under congressional consideration are discussed. It is concluded that any user charge scheme should be initiated on a partial and monitored scale with respect to capital and operating cost recovery so that the feedback to the national multimodal transportation system can be studied and unstable patterns of use and investment do not result. The implications of rail-water rivalry with respect to modal equity are also considered.

To the casual observer, the U.S. Army Corps of Engineers' Henry T. Rainey Dam near Alton, Illinois, seems a most unlikely subject for a national controversy. This facility, commonly known as Locks and Dam 26, appears a rather ponderous and substantial expanse of iron and concrete spanning the Mississippi River, its passivity underscored by the constant activity of river traffic around it. Yet the structure is not passive but responds dynamically to a myriad of mechanical, geological, and hydrological forces that threaten its physical condition and efficiency. In turn, it is generating economic, political, and social pressures that have brought before the nation the question as to whether the public or its users shall pay for replacement and operation of the facility.

Locks and Dam 26 was authorized by the Rivers and Harbors Act of 1935 and placed in operation on May 1, 1938. The structure has two locks on the north bank of the river, a main lock 30 by 182 m (100 by 600 ft) long and an auxiliary lock 33 m (110 ft) wide by 109 m (360 ft) long. The dam consists of a gated spillway with three roller gates 24 m (80 ft) wide by 8 m (25 ft) high, and 30 tainter (adjustable flow) gates 12 m (40 ft) wide by 9 m (30 ft) high. The dam impounds a pool at a maximum elevation 127 m (419 ft) above sea level, which extends 64 km (38.5 miles) up the Mississippi River to Locks and Dam 25 and 129 km (80.1 miles) up the Illinois River to the LaGrange Lock and Dam (1).

Locks and Dam 26 is the penultimate facility of 27 locks and dams on the upper Mississippi River that create navigable, slack water pools for a total of 1079 km (669 miles), from the Upper St. Anthony Falls near Minneapolis to Locks and Dam 27 near Granite City, Illinois. Under the Rivers and Harbors Act, the Corps of Engineers was authorized to maintain a 2.7-m (9-ft) navigation channel depth between Minneapolis and the confluence of the Mississippi and Missouri rivers approximately 13 km (8 miles) downstream of