EFFECTIVENESS EVALUATION OF EXPENSE FOR LOSS PREVENTION*

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SUMMARY

A study has been performed to establish a desirable procedure to evaluate effectiveness of the expense for loss prevention. The losses are divided into two categories, direct and indirect losses, and the sum of the indirect losses, each of which is scarcely predictable, is assumed to be inferable based on that of direct losses. The region to be under the influence of a disaster is divided into sub-regions, and an expected value of each direct loss is considered to be given by a product of the probability of disaster occurrence, the function relating a hazard degree to damage, and the cost of an object in the sub-region. The proposed procedure is attempted to apply for effectiveness evaluation of the expense for loss prevention against fires of large scale oil storage tanks, and the problems to be solved are pointed out.

INTRODUCTION

When a possibility to occur a disaster has been predicted, enormous efforts would be made to prevent the disaster or to reduce the loss to be caused. To make such efforts successful, various types of methods have been applied. However, there are few attempts to evaluate effectiveness of the method that they adopted or to examine the inter-relation of different types of methods for reducing losses to be caused by the same disaster. Thus, in the present situation, it seems not easy for engineers in process industries to evaluate effectiveness of a newly developed or improved method for loss prevention or to recommend a best combination of the methods.

In spite of the difficulty, a general and objective procedure to evaluate effectiveness of the expense for loss prevention is necessary because the expense should be supported by a logic similar to that for other economical activities[1-3]. We have to make efforts to establish such a procedure, although a long time will be necessary and an established one will not be realized in near future. The present study is of a preliminary stage of the efforts, but the results will be meaningful to establish an appropriate procedure for the effectiveness evaluation of the expense for loss prevention.

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* To be presented at the International Conference on Safety and Loss Prevention in the Chemical and Oil Processing Industries; 23rd to 27th October 1989; Singapore

POSSIBILITY OF EFFECTIVENESS EVALUATION BASED ON PROCEDURES CURRENTLY USED FOR HAZARD ASSESSMENTS

For the adoption of a particular method for loss prevention, a comprehensive reason to support the method seems to be needed, and a hazard assessment would have been carried out instead of an effectiveness evaluation. Indeed, if it is possible to quantitatively evaluate hazards of every matters, the difference of hazards for the cases with and without application of the method for loss prevention can be elucidated, and effectiveness evaluation of the expense for loss prevention seems possible in principle. Thus, in the following part of this section, discussion will be presented on the possibility and limit of application of several currently used procedures for hazard assessments to effectiveness evaluation of the expense for loss prevention.

There are a few types of experimental methods for hazard assessments, such as property measurements, tests for examining characteristics, model experiments of accidents[1,4]. Each of the material properties such as flash temperature, ignition temperature, and minimum ignition energy can give a measure for hazard classification. The values of these properties are useful to compare the effectiveness of a method with that of a similar one. It may be easy to understand that keeping the material temperature below - 20 C is more effective for preventing fires than keeping it below - 10 C. However, the values are useless for the comparison with a method of a different type. On the basis of only the material properties, it is impossible to compare the effectiveness of the action to keep the material temperature below - 10 C with that to wear electrification free clothes in the room. For effectiveness evaluation of the method for loss prevention, the reduction of the expected loss attributable to adoption of the method should be evaluated. Only the material properties cannot give any conclusion on effectiveness of the expense for loss prevention.

The hazard assessment of an equipment, apparatus, or system has been performed on the basis of the results of tests for examining its characteristics. In a case when a part of the equipment, apparatus, or system is improved for loss prevention, the reduction of hazard degree may be predictable somewhat qualitatively by elucidating the resulting change of characteristics. However, in the case when an equipment is replaced by other one, the variation of effectiveness would not be predictable unless a unified procedure for hazard assessments is established. Several steps seem necessary between the tests for examining the characteristics and prediction of the expected value of loss, but so far discussion on these steps has never been heard.

Model experiments of accidents can be performed when an approximate process of the accident is known. This procedure for hazard assessments would relate to the effectiveness evaluation by exploring the difference of occurrence probabilities of or damages caused by accidents at the cases with and without application of a method for loss prevention. For applying this procedure, even if the result is a relative one, a number of elaborate experiments are needed. The purpose of the model experiments is not to evaluate the effectiveness of the method for loss prevention but to ascertain the cause or process of a particular accident.

Phenomenological analyses such as simulations and analyses of accidents and

safety analyses such as FMEA, MORT, and FTA are theoretical procedures currently used for hazard assessments.

In the phenomenological analyses, the process of disaster occurrence should be assumed[4]. In order to relate each of these procedures to the effectiveness evaluation, the effect of the adopted plan for loss prevention on various phenomena during the process should be predicted. The prediction of the changes of various phenomena, as will be discussed in the later sections, is indispensable to evaluate the effectiveness and the most important process for it. The phenomenological analyses currently used for hazard assessments have been scarcely applied for the prediction of the changes of phenomena because of their purpose to elucidate the process of disaster occurrence. However, with each procedure of this type, comparison of hazards at various conditions can be easily carried out, i.e., the effectiveness evaluation is possible.

The safety analyses have been mainly performed for prevention of accident occurrence[5,6]. A procedure of this type would be convenient to the evaluation of the probability of accident occurrence and applicable to the effectiveness evaluation. However, there have been few examples of suitable applications of a procedure of this type.

As mentioned above, currently used procedures for hazard assessments are for detecting hazards so that there have been few attempts to apply a procedure for hazard assessments to the effectiveness evaluation. Probably, perceiving that the hazard assessments are still needed much improvement prevents the procedures for the effectiveness evaluation from developing. However, the hazard assessments and effectiveness evaluation are different in the purpose and should be developed at the same time.

THEORY FOR EFFECTIVENESS EVALUATION

For effectiveness evaluation of the expense for loss prevention, it is necessary to estimate the expected value representing the reduction of loss attributable to the adopted method(s)(or plan). The evaluation will be effective for the following processes:

i) To select an optimum method among candidates for reduction of loss.
ii) To compare the expected reduction of loss attributable to a method to be adopted with the expense for the method.
iii) To decide the method to be adopted and timing to apply it for reduction of loss caused by a particular equipment, apparatus, or system.

Therefore, the effectiveness evaluation should keep the following characteristics:

a) To quantitatively infer the effects of the method for reduction of loss.
b) To compare the effects of the method for reduction of loss with the expense to adopt it(minus the reduction of expense if any).
c) To evaluate the change of hazard with time and/or circumstances.

These characteristics imply that by applying the effectiveness evaluation one can relatively and, if possible, absolutely evaluate the effectiveness of every type of methods for loss prevention in an amount of money. The evaluation should be general and quantitative.

It can be assumed that effectiveness of the expense for loss prevention can be expressed by the extent(practically an expected value) of loss reduction attributable to the expense. Thus, the effectiveness cannot be evaluated unless the expected loss to be caused by the disaster is accurately estimated.

Assuming that L is the sum of losses expected to be caused by a certain disaster, L can be given by the sum of the expected values l_1, l_2, l_3 ·····l_n of various types of direct and indirect losses, i.e.,

$$L=\sum_{k=1}^{n} l_k \qquad (1)$$

The losses are not only those caused by fracture of equipments, apparatus, systems, and buildings, damages on raw materials and products, injuries, and fatalities but also those caused by wide range of effects such as the stop of operation of the plant broken at the disaster, reduction of products, control or stop of operation of the plants in own and relating companies, control or stop of traffic near the site of the disaster, increase of the insurance rate, and reduction of social confidence.

For an accurate evaluation of L, it is necessary to evaluate all conceivable losses. Since the indirect losses will be estimated on the basis of the direct losses, the latter ones should be estimated first. Thus, in the following, the direct losses will be attempted to estimate, and then based on the results, the effectiveness evaluation will be attempted to perform.

It seems not easy to classify the losses into direct and indirect ones. In the present study, the direct losses are defined as the losses caused by fracture of equipment, apparatus, systems, and buildings, damages on raw materials and products, injuries, and fatalities. Although the indirect losses are known to depend on the actions after the accident, they can be given as a function of the direct losses assuming appropriate actions.

An expected value of a loss l_k of a certain type can be assumed to depend on the value v_k of the object at a sub-region under the influence of the disaster(or accident), hazard degree h_k at the sub-region, and probability p of the disaster occurrence, i.e.,

$$l_k=p\cdot\alpha_k(h_k)\cdot v_k \qquad (2)$$

where, $\alpha_k(h_k)$ represents the ratio of the lost value to original one.

The meaning of ak would be seen by supposing the situation that only one object is valuable in a sub-region. Assuming that the object completely loses its value at h_k above h_c and it keep its whole value at h_k below h_c, α_k is given as

$$\left.\begin{aligned}\alpha_k(h_k)&=1 \qquad & h_k>h_c\\ &=0 \qquad & h_k\leqq h_c\end{aligned}\right\} \qquad (3)$$

Assuming that $l_1, l_2,$ ·····l_l are direct losses and $l_m,$·····l_n are indirect losses, then

$$L=p\cdot\sum_{k=1}^{n}\alpha_k(h_k)\cdot v_k=p\cdot\sum_{k=1}^{l}\alpha_k(h_k)\cdot v_k+p\cdot\sum_{k=m}^{n}\alpha_k(h_k)\cdot v_k=L_d+L_i \qquad (4)$$

where, L_d and L_i are respectively, the sums of direct and indirect losses, i.e.,

$$L_d = p \cdot \sum_{k=1}^{l} \alpha_k(h_k) \cdot v_k \tag{5}$$

$$L_i = p \cdot \sum_{k=m}^{n} \alpha_k(h_k)\, v_k \tag{6}$$

The probability p of disaster occurrence should be predicted by a system safety analysis or disaster stochastics, and the values of the objects and persons can be predicted on the basis of daily operation and living. Also,

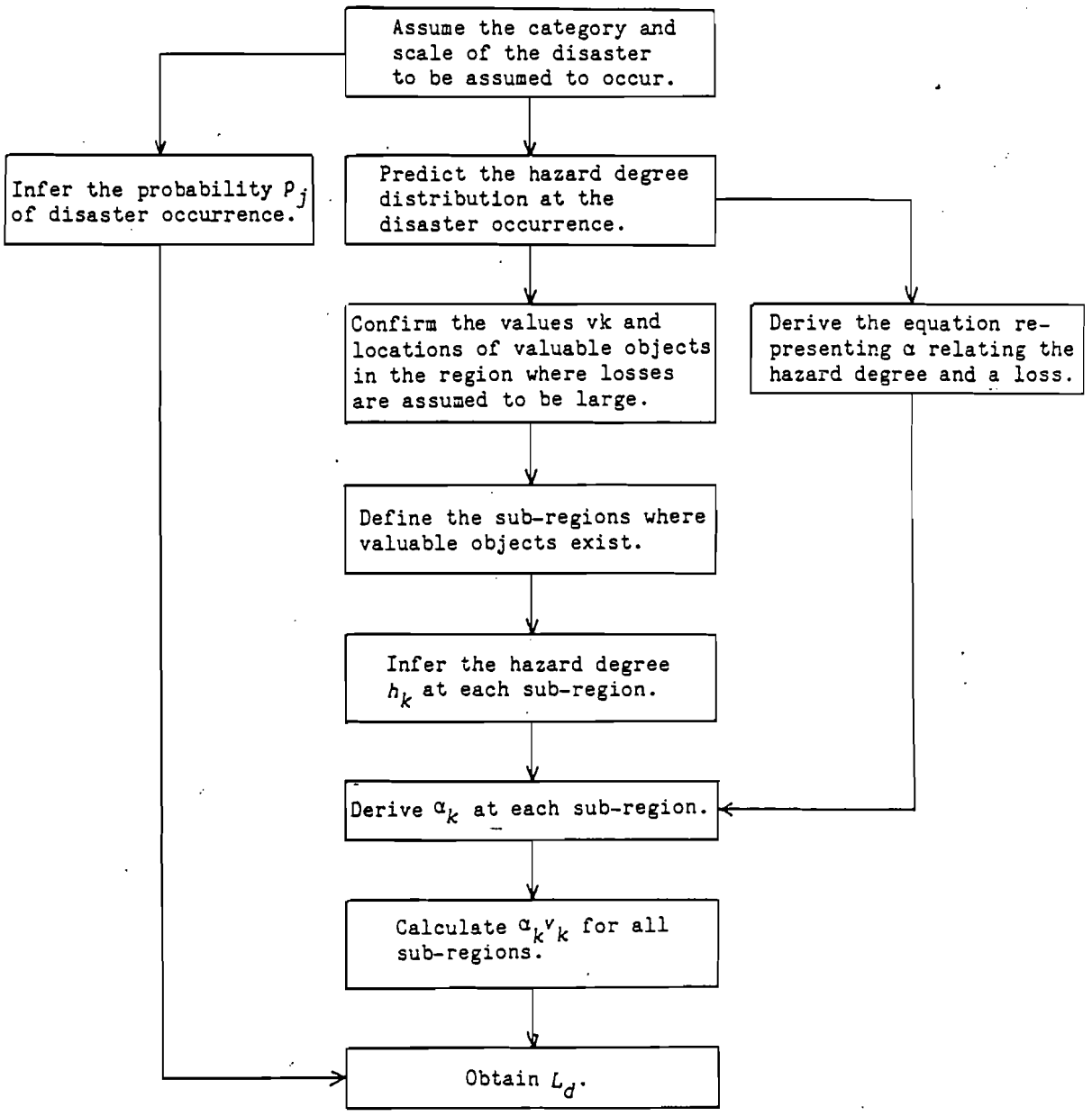

Figure 1. Procedure to evaluate an expected value of the sum L_d of direct losses.

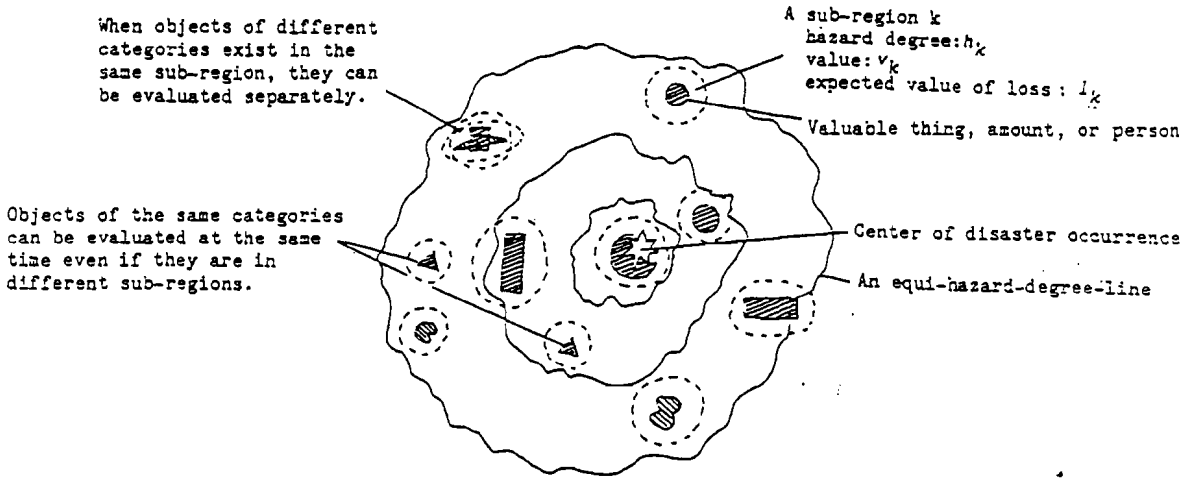

Figure 2. Distributions of hazard degree, valuable thing, amount and person, and determination of the sub-regions for effectiveness evaluation.

α_k (h_k) can be easily predicted from the predicted value of h_k if the endurance of the object(person, thing, or amount) to be discussed against hazard is known. Based on these facts, the procedure to predict L_d is presented in Figure 1, when a disaster occurs at the situation shown in Figure 2.

As shown in Figure 1 or Eq. 5, the values of p, α_k (h_k), h_k, and v_k or equations to predict these values are necessary to evaluate the sum of direct losses. If any one of them can not be obtained, the evaluation is impossible. The method effective for loss prevention means to be effective for reduction of one of these losses. A meaningful method for loss prevention is of benefit to the organization to adopt it[2,3]. Thus, the method, by adoption of which the benefit cannot be expected or is too small, will be ignored. If the method action does not satisfy the following equation,

$$\Delta C < \Delta L \tag{7}$$

where ΔC and ΔL represent the increase of expense and reduction of expected loss by adopting the method, respectively, the action does not make sense[1]. Further, when the ratio of the total reduction ΔL_d of direct losses to that ΔL_i of indirect losses is R, Eq. 7 can be rewritten as

$$\Delta C < \left(\frac{1+R}{R}\right)\Delta L_d \tag{8}$$

This indicates the limit to adopt the method for loss prevention. The following discussion is performed assuming that the relation expressed by Eq. 8 is satisfied.

The methods to reduce the probability p of accident occurrence can be easily pointed out by safety analyses. The discussion to reduce p has been presented in a number of previous reports[1-4]. In the present study, the emphasis is on the fact that the reduction of L_d is proportional to the reduction of p.

There are two different kinds of methods for reducing the hazard degree h_k, i.e., the methods for reducing the hazard degree of a whole region where damage will be suffered at the occurrence of a disaster and those of a limited region. It is easily seen that the former methods are effective to reduce L_d. The latter methods are sometimes more elaborate than the former ones, but by adopting them mainly for regions where expensive objects exist, a large reduction of L_d must be expected at the same amount of expense.

$\alpha_k(h_k)$ is a function of h_k. The function is not necessarily in the form as represented by Eq. 3, but in most cases, ak(hk) rapidly changes as h_k approaches a certain value (h_c in the case represented by Eq. 3). This fact implies that an method for reduction of h_k is not effective in a certain range but very effective in another range even if the reduction is slight.

The method to reduce v_k in the vicinity of the site of disaster occurrence is effective like that to reduce p. When a disaster is predicted to occur, the method for making v_k at that site zero, if it is possible, is perfect for loss prevention. Practically, the prediction of disaster occurrence is not easy, and in most cases, vk becomes a fairly large to keep daily operation and living even if the disaster is predicted likely to occur.

In the above discussion, a disaster to occur is assumed a specified one. However, the scale of the accident cannot be predicted in most cases, and in most cases, the method to be performed is effective for a particular type of disasters. Assuming that a certain type of disasters are predicted to occur but their scales are ambiguous, there remain ambiguities on the hazard degree at disaster occurrence. When the ambiguities can be represented by a probability distribution $p_j(h_{kj})$(p in Eq. (2) is equal to $\int p_j dh_{kj}$), Eq. 5 is replaced by the following equation.

$$L_d = \sum_{k=1}^{l} v_k \int_{h_{kj}} p_j \alpha_k \, dh_{kj} \tag{9}$$

For different types of disasters, the expressions of h_{kj} and equations representing the dependence of α_k on h_{kj} would be different. However, for

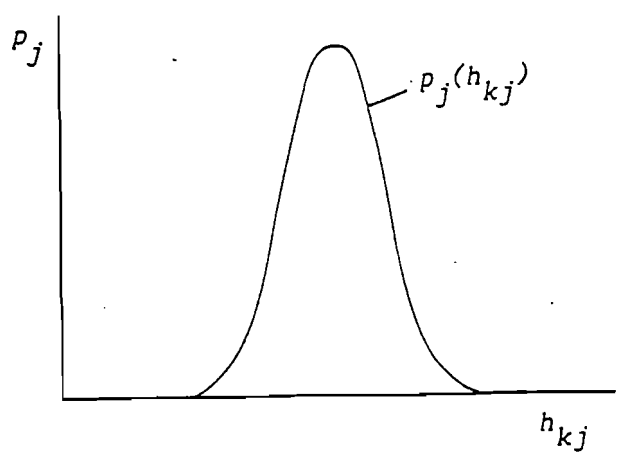

Figure 3. An example of the variation of probability p_j with hazard degree h_{kj}.

each type of disasters, the direct losses should be inferred in similar procedures. The expected value of the sum of losses caused by a disaster is the sum of all expected values of losses and can be evaluated by estimating individual expected values of losses caused by different types of accidents and adding them.

Assuming that the valuables, instead of discretely located objects, are distributed in a domain S, Eq. 9 is replaced by

$$L_d = \int_s v'_k dS \int_{h_{kj}} p_j \alpha_k \, dh_{kj} \qquad (9)'$$

where v'_k is a function representing the value distributed in S.

The effectiveness evaluation of the expense for loss prevention can be performed by predicting the difference ΔL_d of L_d with and without the proposed method.

For the prediction of the dependence of p_j on h_{kj}, a stochastic safety analysis, phenomenological analysis, or disaster statistics is needed. Available data are few at present but expected to be accumulated in near future because of their importance.

If the phenomena concerning disasters to occur are assumed, h_{kj} can be predicted, and the method for numerical expression of hazards will be used[2,3]. The hazard degree H in previous studies can be expressed by p_j and h_{kj} as follows:

$$H = \int_{h_{kj}} p_j h_{kj} dh_{kj} \qquad (10)$$

$\alpha(h_k)$ depends on the characteristics of objects under evaluation of their losses caused by disasters, and the loss evaluation is possible if the dependence of each loss on causative phenomena (fire radiation, blast wave pressure, vessel pressure, smoke toxicity, projectile behavior and so on) is

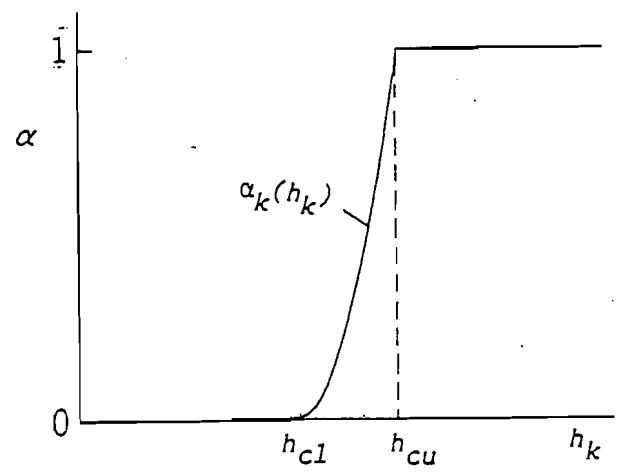

Figure 4. A typical variation of α with h_k.
h_{cl} : the lowest value of hk in the range where a changes.
h_{cu} : the highest value of hk in the range where a changes.

known. The dependence is generally expressed as shown in Figure 4(The most simple example of it was shown in Eq. 3). Such a dependence can be easily inferred on the basis of a number of presently available data.

Since v_k is the value of each object, it can be easily evaluated. Importance is to re-evaluate whenever any one of equipments, apparatus, and operators is changed.

APPLICATION OF THE PROCEDURE TO THE EFFECTIVENESS EVALUATION OF THE EXPENSE FOR LOSS PREVENTION AGAINST OIL RESERVOIR TANK FIRES

In order to apply the procedure proposed in the previous section to effectiveness evaluation of the expense for loss prevention in a practical case, one should overcome a number of difficulties and would need a plenty of time and elaborate efforts. Probably such a situation is a reason why there are so few examples of the effectiveness evaluation. This section presents the results of the attempt to apply the proposed procedure to a few examples concerning loss prevention methods against oil reservoir tank fires.

The distance between oil reservoir tanks has been frequently discussed in the process for evaluating or confirming the safety of the dangerous goods reservation. The increase of the distance has been considered to be effective to prevent the neighboring tanks from ignition. In this case, the imagined disaster is a tank fire, and the losses to be evaluated can be assumed to be the loss l_1 due to the burning or contamination of oil in the tank at fire occurrence, that l_2, due to the destruction of the tank, that l_3 due to the burning and contamination of oil in neighboring tank(s), and that l_4 due to the destruction of neighboring tank(s).

l_1 and l_2 cannot be reduced by increasing the distance, so that the losses to be estimated for evaluating effectiveness of the expense to increase the distance are l_3 and l_4. For the evaluation of l3 and l4 needed are the probability p_j of occurrence of an oil tank fire, hazard degree(s) h_{kj} $(k=3,4)$ at the location(s) of neighboring tank(s), the value v_3 of oil in neighboring tank(s), and that v_4 of the neighboring tank(s), when the fire intensity, tank scale, and oil properties are fixed. α_k needed for the evaluation is inferred on the basis of h_{kj}. In this case, h_{kj} can be assumed to correspond to the accumulation of the intensity $\dot{q}_k''$ of radiation at the location(s) of the neighboring tank(s), i.e.,

$$h_{kj} = \int \dot{q}_k'' dt \tag{11}$$

If the value of hkj is above that sufficient to ignite oil in the neighboring tank being evaluated, $\alpha_k = 1$, and otherwise, $\alpha_k = 0$.

The frequency of tank fires of a certain scale and specified kind of oil is very small. Consequently, available data are too few to infer reliable values of p_j. Therefore, I would recommend to use the values of pj inferred on the basis of the whole tank fires. Thus, although there are problems on the inference of p_j and efforts must be needed to infer α_k, the effectiveness evaluation will be possible.

A system for extinguishing fixed at a tank has been adopted to reduce the losses to be caused by a tank fire. Its purpose is the same as that of the tank distance discussed above, but the functions of these two are quite

different. This system is considered to be effective for suppression of a tank fire growth, especially at its initial stage. On the similar discussion as the tank distance, the losses to be estimated are not l_3 and l_4, but l_1 and l_2.

Since the system is effective for suppression of fire growth, the distribution of p_j on Figure 3 should shift to smaller values of h_{kj} (k=1,2). In this case, α_1 must be given as an equation representing the damage due to contamination of oil as well as that due to burning. Both p_j and α_1 are not easy to estimate, so that an appropriate evaluation of effectiveness of the system for loss prevention seems extremely difficult. However, it can be pointed out that adoption of the system shifts the distribution of p_j and reduces largely the damage.

When a system for extinguishing is not fixed, it is effective to suppress both fire growth at a tank and fire transfer to neighboring tanks. For effectiveness evaluation of this system, l_1, l_2, l_3, and l_4 should be predicted. α_k (k=1,2,3,4) and p_j, which depend on the ability and characteristics of the system, are also not easy to estimate.

The number and abilities of firemen are known very important for loss prevention against oil reservoir tank fires, but so far very few attempts has been done to find optimum number of firemen and/or optimum level of their education. For such an attempt, which will give us the most effective expense for loss prevention, effectiveness evaluation must be needed.

To find out an appropriate combination of the methods for reducing the losses caused by oil reservoir tank fires, effectiveness evaluation for all the candidates as discussed above. Since v_k, h_{kj}, p_j, and α_k depend on the situation of the objects at a disaster under consideration, the combination should depend on the factors to influence the situation, i.e., not unique. Some factory is at a site very close to a city. For effectiveness evaluation of the expense for loss prevention at such a factory, the distribution of a large values of v_k should be assumed in the region outside of the factory. This situation is quite different from that of a factory in countryside. Similar discussion can be done on maintenance, economic policy, and so on.

I believe the importance of effectiveness evaluation of the expense for loss prevention and recommend to attempt the procedure discussed throughout the present study. Also, I encourage to develop a novel concept for the effectiveness evaluation and to accumulate available data.

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