CRITERIA FOR PLANT SEPARATION DISTANCES AND LOCATION

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An interactive computer program has been developed which can be used for the assessment of hazards of newly planned and existing chemical plant installations. It is possible to generate a numerical value for the potential hazard of plant which allows comparison with other plants and to construct hazard contours around each plant item based on inventory, type of hazard, consequences and probability of event data. The program also optimises the lay-out of plant for maximising safety and cost reduction in the form of use of minimal land area.

INTRODUCTION

A number of studies (1,2) have recently been undertaken to evaluate the risks faced by local populations and other industries from the siting of new chemical plant installations or modifications to those already in existence. These studies, most notably that covering the Canvey Island/Thurrock area have identified possible incidents, estimated the probability of such incidents and their potential consequences. Such studies have identified the need for protective hardware and the development of procedural software. The hardware has included systems, which reduce the probability of a major incident and/or reduce the extent and magnitude of a potential incident. The software developments include the use of risk contours and zoning, and the analysis of specific situations and the formulation of lay-out criteria.

The probability and extent of a potential hazard can often be reduced by consideration of the topography and meteorology as well as the use of approved codes in allowing self-rescue and ease of access for the emergency services.

Any strategy on siting and lay-out policy must consider all possible incidents leading to loss of integrity and the usual consequent release of toxic and/or flammable material. The frequency of particular events occurring can be obtained from plant records. It is necessary to strike an economic balance when evaluating the need for safety systems in terms of separation distances or protective equipment between taking the worst possible event which occurs very rarely and the smaller incident which occurs more frequently.

The strategy described below attempts to formulate a relationship between the extent of hazardous plant effects and the available methods for their minimisation be that by spacing alone or by the use of special equipment or by a combination of both.

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THE PROBLEM

Figure 1 represents a simplified breakdown of the design process. It identifies the need for data, such as that outlined in Figure 2. There are few attempts to develop this data into criteria for plant lay-out and location which would enable designs of the highest practicable safety standards to be achieved. This is mainly due to the fact that such a design tool would represent a highly complex chain of interdependent operations in which a break in continuity due to lack of specific data or inaccurate theory would render the total tool inoperable.

The problem of designing chemical plant from safety considerations may be divided into three main operations.

(i) identification of hazards within the plant
(ii) assessment of plant
(iii) optimisation of lay-out and location

The first operation requires a detailed survey of the plant. This can include an examination of operational procedures and processing parameters for the individual plant items and the whole installation. In order to aid the assessment and optimisation operations, it is possible to cover the installation by a theoretical grid. Such a grid then defines the number and size of blocks which can aid location and lay-out i.e. the position of plant items can be given by co-ordinates. A target block is defined as a block that is adversely affected by a hazard from another block termed a source block. Identification of a particular hazard requires that the hazard extent is known and that there is some preset value above which the effect is deemed unacceptable e.g. a level of destruction or loss. This may be achieved by calculating the intensity of potential hazards as a function of the distance from the source. In the assessment operation, the generation of any hazard rank or value must take three factors into consideration:-

(a) the extent of a hazard at some radius from the source item.

(b) the composite probability of a chosen hazard taking place. This, of course, may be dependent upon a number of independent, composite and mutually exclusive events.

(c) some chosen parameter that is a measure of the severity of the incident e.g. loss of human life, plant down-time, cost of replacement.

The optimisation consists of the relocation of hazardous items (or whole installations) so as to minimise their potential effects on other active and passive pieces of equipment i.e. this can involve the minimisation of the area of the land used, while maintaining a safe distance between items and the process flow route.

THE HAZARD VALUE

This may be generated by the consideration of the intensity of a potential hazard, such as internal explosions, pool fires, vapour fires, confined and unconfined vapour cloud explosions and the dispersion of toxic particulates and gases, the probability of occurrence and the severity of the incident. The generation of the hazard value can be illustrated by taking a simple example.

Figure 3 depicts a plant, which has been divided into nine equal units. It will be assumed that there is a plant item at coordinate x,y within unit 5. It will also be assumed that the item is responsible for an internal explosion that results in both the generation of missiles to a radius of 'r' metres and an unacceptable over-pressure

Paper 21

Q/C **(C PIETERSEN)** There is a large overestimation of damage distances in LPG example. In Mexico, heavily damaged area ± 600 m diameter, quantity of LPG involved was greater than 10,000 m^3. Damage distances shown (± 3000 m) are unrealistic

R/A The distance of ± 3 km quoted was for a single release of 8000 tonnes, and was for third degree bu ns, which can be expected at a lower heat flax than 'heavy damage.' A single release, for a Mexico —type installationn is clearly very unlikely.

Paper 23

Q/C **(R P PAPE)** Could the author tell us about variability in performance, both between individuals and for one individual on different occasions?

R/A We do know what the uncertainty bands are - purpose to get a more novel understanding of what goes on Yes we could tell you what probability of a person being vaiable in performance. We are interested in population characterisation to within an order of magnitude.

Q/C **(J LINDLEY)** It is generally assumed that learning curves become asymplotic, but did Mr Williams find any evidence that performances can reach a maximum and fall away as errors creep in owing to incorrect practices coming in, perhaps giving evidence for a need for retraining.

R/A The asymptotic nature of the curves are an artifact of the way the curves are plotted. Reliability technology is concerned with orders of magnitude - logarithmic plots. Most experiments don't last long enough to get sufficient data.

There is not enough informationn to say whether changes in practice affect the numbers.

Q/C **(B W ROBINSON)** Maintenance of trip systems is repetitive task. Experience and skill level was certainly high enough. When responsible for this type of work, recognised that craftsman responsible for testing for weeks on end became more error prone and to avoid this were rotated between different jobs.

R/A Individual effects are small in reliability terms compared with population trends. He refered to numbers given in paper relating to men who had been on same job for a long time. All the numbers available seem to show that people do not become more prone to errors with time.

SESSION 3 (afternoon)

PAPER 24

Q/C **(R E HEATH)** Exploring a similar technique in Mond, confidence limits on risk assessment have been found to be in the region of ±1½ orders of magnitude. Translated to distance uncertainty for a particular plant, this means that a given risk level could lie that gives a measure of the hazard producing ability of the plant as a whole. The absolute value of this number has no meaning. However, when it is compared to other plants it allows comparison to be made and particular hazardous plant items to be identified and hence provides a scale by which to measure acceptability of hazard.

The basic questions with regard to any type of assessment are:-

(i) At what point is an unacceptable solution reached?
(ii) If the solution is unacceptable, why is this so?
(iii) What methods can be used to change an unacceptable solution into an acceptable one?

The first two questions require the evolution of a test for acceptability and the third question requires methods to modify the lay-out of the proposed plant.

The above hazard value was broken-down into four parts

(i) the total value for the whole installation, H1.
(ii) the total value for each block covering all hazards, H2.
(iii) the total value for each unit and each type of potential hazard, H3.
(iv) a value for each item within each unit for each potential hazard type, H

The test for acceptability will consist of the systematic consideration of each of these values. This will enable identification of particular hazards within a plant and their location e.g.

(a) the value H1 determines whether further analysis is required. If H1 < acceptable value, the plant as a whole is acceptable and further analysis is not required. If H1 > acceptable value, the plant as a whole is not acceptable and further analysis is required.

(b) the value H2 identifies which unit(s) are acceptable. If H2 < acceptable value, the particular unit is acceptable and the next one may be considered. If H2 > acceptable value, then further analysis of the current block under consideration is required in order to determine the hazard or hazards, that contribute to the overall block value.

(c) the value H3 identifies which hazard within the current unit is unacceptable. If H3 < acceptable value, the particular hazard within the unit under consideration is acceptable and the next one may be considered. If H3 > acceptable value for a particular hazard, further analysis is required in order to determine which plant item within the current block is responsible for causing an unacceptable hazard

(d) the value H identifies which item within the selected block is responsible for the hazard.

In order to modify the extent of a hazard, it is necessary to consider not only the source of the hazard but also the target plant item. The extent of a hazard can be modified by two agents

(i) fixed and mobile protective equipment
(ii) plant items may be physically moved so as to reduce the potential effect of a particular hazard.

If the plant has been built, then it may be concluded that the only modification possible is the inclusion of protective equipment. However, if the plant is at the design stage then it may be assumed that items can be relocated on safety grounds.

Thus the final stage of the analysis for new plants may be carried out and the spacial coordinates of the plant items optimised so as to minimise the plant area, subject to a number of constraints, such as process requirements and road-ways.

OPTIMISATION OF LAY-OUT

It is convenient to consider a theoretical plant with a specified range of chemical plant items (I). Let the plant items i.e. distillation columns, storage tanks have the following parameters

P_{11}, P_{12}, P_{13} ... etc.

where P_{11} = the intensity of item 1 to hazard type 1

P_{12} = the intensity of item 1 to hazard type 2 as evaluated by the previous analysis

and S_{11}, S_{12}, S_{13} ... etc

where S_{11} = the sensitivity of item 1 to hazard type 1

S_{12} = the sensitivity of item 1 to hazard type 2

The units of S and P will depend upon the type of hazard being considered. The effect (E) of hazard type K from source i to item j is given by

$$E_{ijK} = f_K (P_{iK}, r_{ij})$$

where r_{ij} = the separation distance between i and j.

Now a hazard is acceptable if

$$E_{ijk} < S_{jK}$$

i.e. $S_{jK} > f_K(P_{jK}, r_{ij})$

from which it follows

$$r_{ij} > F_K(S_{jK}, P_{ij})$$

where F_K = an inverse function of f_K

Consider the following example. Let P_{iK} be the heat source of W in kW, so that $P_{iK} = W$. Thus the effect of the source is the intensity of heat in kW m^{-2}.

Hence $E_{ijK} = W/(2\pi r_{ij}^{2})$

thus the form of f is

$$f(P_{iK}, r_{ij}) = P_{iK}/(2\pi r_{ij}^{2})$$

where K = radiant heat intensity

If the maximum heat intensity that can be withstood by I_j is S_{jK} then:-

$$S_{jK} \propto P_{iK}/(2\pi r_{ij}^{2})$$

rearranging, we have

$$r_{ij} \propto [P_{iK}/(2\pi S_{jK})]^{\frac{1}{2}}$$

so

$$F(S_{jK},P_{iK}) = [P_{iK}/(2\pi S_{jK})]^{\frac{1}{2}}$$

Note that f_K and F_K differ for each type of hazard, K. The analysis can be carried out for each type of hazard

$$\text{i.e.}\quad r_{ij} > F_1(S_{j1},P_{i1})$$

$$r_{ij} > F_2(S_{j2},P_{i2}) \qquad \text{etc}$$

leading to

$$r_{ij} > \max_K[F_K(P_{iK},S_{jK})] \qquad K = 1,2\ldots\ldots N \text{ (N hazards)}$$

If $\hat{r}_{ij}$ is defined as the minimal acceptable separation for items I_i and I_j, then

$$r_{ij} \geq \hat{r}_{ij}$$

where $\hat{r}_{ij} = \max_K[F_K(P_{iK},S_{jK})] \qquad K = 1,2\ldots\ldots N$

The value of r_{ij} can be computed. The plant lay-out problem reduces to:-

minimise $C_F(x,y)$ where C_F is some cost function

subject to $\quad [(x_i-x_j)^2 + (y_i-y_j)^2]^{\frac{1}{2}} \geq r_{ij}$ ...(A)

over the range $\quad i = 1,2,3,4 \ldots\ldots N$
$\quad j = 1,2,3,4 \ldots\ldots N-1$

where r_{ij} is the larger of $\hat{r}_{ij}$ and $\hat{r}_{ji}$

Such a procedure results in halving the number of constraints.

$C_F(x,y)$ has been defined as some "cost function" or a measure of 'goodness' for the overall process. Equation (A) is a fairly standard non-linear programming problem. The equation can be simplified to:-

minimise $C_F(x,y)$

subject to

$$(x_i-x_j)^2 + (y_i-y_j)^2 \geq \tilde{r}_{ij}^{\,2} \qquad \text{...(B)}$$

From which the constraints are seen to be quadratic so that with a suitable C_F, equation B *could be a general quadratic programming problem. However, in this* case, it is not treatable by standard quadratic programming methods which assume quadratic C_F and linear constraints. Unfortunately equation B is also non-convex and the establishment of a global optimum is not easy. This complex optimisation problem can be simplified by the imposition of some assumptions. It can be assumed that the previous analysis has generated data for each plant item and hazard which enables the potential hazard intensity from a particular source to be computed as a function of distance. Such data may be used to impose a critical zone around each item where the outer edge of the zone represents the "acceptable" exposure limit for a particular hazard.

The siting problem can now be defined as:-

minimise $f(x)$

where $f(x)$, the object equation is related to the plant plot area.

This is subject to a series of constraints which include the hazard contours and specific design constraints.

THE OBJECT EQUATION

This is the function which allows the minimisation of the area occupied by the chemical plant. This area is a function of the relative distances between each of the plant items.

Consider a theoretical installation with five items of plant (see Figure 4). Let the coordinates of the plant items be x_n, y_n and the hazard radius R_n for the plant item number n. Assuming that the installation plot is a right angled quadrilateral the minimum area that can enclose all items plus their hazard radii is given by X_1Y_1. After a first approximation the new situation might be that shown in Figure 5. The figure shows that the items have been moved closer together without violation of the hazard boundaries. The area of the new position is given by X_2Y_2 and is a function of the new plant item's grid reference. Where $X_2Y_2 < X_1Y_1$. The next approximation will lead to $X_3Y_3 < X_2Y_2$ and so on until a constraint is broken or the set value is reached.

It is not necessary to restrict the optimisation to the plant areas bounded by straight lines. Further, as long as the calculated function reflects the progressive optimisation of the coordinates of the plant items, the actual value of the function need not have any practical relevance. In order to clarify this point consider the plant in Figure 6. As before there are five plant items which each possess a radial zone R_n metres. A circle can be constructed so that it enables all the plant items to be contained inside it. This can be achieved by using the centre of gravity of the five plant items as the centre of the circle

i.e. $x_g, y_g = \Sigma x_i / 5, \ \Sigma y_i / 5$

and choosing the radius of the circle such that:-

$$\text{rad} = [(x_g - x_n)^2 + (y_g - y_n)^2]^{1/2} + r_n$$

where n = the plant item that gives the largest value of rad. In this case
n = item 1.

As the optimisation proceeds the items converge and this is reflected in the reduction of the radius of the circle. It can be seen that the equation can be simplified further. The parameter that is being minimised is the value of "rad" and this is then used to evaluate the area of the circle. Thus rad. can be used as the value of the objective function.

Three problems may arise using this approach

(i) the optimisation will tend to result in the items fitting into a circular installation. However, this can be avoided by the correct choice of constraints.

(ii) the area enclosed by the circle is less than the area calculated using a similar analysis based on a square. However, long before this is of significance the constraints will be breached.

(iii) the analysis may result in only finding a local optimum. This is in fact a major advantage.

The chemical plant will initially consist of plant items that are positioned according to process requirements. The hazard prevention global optimum might result in the placement of the plant items in illogical process positions. The required optimisation can be seen as a number of operations aimed to optimise small groups of related items.

The constraints placed on the optimisation can relate to design requirements and to the hazard zones. In order to carry out the optimisation a hill-climbing technique, which does not require the differentiation of the objective function was adopted. The procedure used was based on the method proposed by Rosenbrock (3). The sequential search technique is effective for cases where the variables are constrained.

THE COMPUTER PROGRAM

The program was developed to design scientifically the lay-out of a chemical plant from safety considerations (4). The program removes the variation in judgement from hazard analysis and hence ensures a standard approach to the logic of plant lay-out. The lay-out problem is analysed in two complimentary ways. Firstly, a numerical value for the plant is generated. This number is based on the percentage damage and the composite probability of a particular hazard taking place; this enables particularly hazardous plant items to be identified. Secondly, the program considers given hazards for each plant item and generates hazard intensity zones around the plant item based on the inventory and hence the severity of the hazard. It informs the user of the projected hazard within the plant, in the form of contours around the item or actually decides where the items should be placed for greater safety and moves the plant items accordingly. This is achieved by consideration of the hazard, whether or not there is safety equipment and the initial position of the item as designed by the chemical engineer on a process flow basis. Further, the whole system is interactive such that modifications and re-designs are possible. Thus by using a "yard-stick" and contours, a complete design is possible.

The program has been written in the knowledge that the lack of statistical, experimental and historical data has rendered some of the subroutines inaccurate. However, the subroutines are written in a way that will facilitate amendments.

The overall program may be divided into two major parts

(i) the assessment program
(ii) the plant modification program

The assessment program corresponds to Figure 7 and is responsible for the execution of the mathematics leading to the identification and statistical assessment of hazards within an installation.

The main program is responsible for running a series of major sub-routines. These sub-routines determine the type of analysis required i.e. the analysis of an existing plant, additions/modifications to an already existing plant or a green-field site situation. A boundary is then set. This can be the fence around the installation or can include sensitive neighbouring facilities to the installation e.g. housing. The area surrounded by the boundary is then divided into blocks by use of a grid and the co-ordinate of all the plant items stored. Data for each plant item in each block is then requested from lower levels of sub-routines with regard to properties of substances, operating procedures and processing requirements. The output of this routine is then fed to the Hazards routines. Each of these subroutines considers a particular hazard and the damage producing capability of each item. The results are then produced as radial contour values around each plant item. The routine also calculates a value that is used later to assess the installation's or individual plant item's performance for a particular hazard. The final output from this subroutine consists of a file containing the items' code numbers, lists of contours and hazard values.

The plant modification program corresponds to Figure 8 and is responsible for the execution of the mathematics leading to the optimisation of the plant lay-out. The main program is responsible for calling up a number of sub-routines. These subroutines use the hazard values generated in the assessment program to test systematically the plant lay-out and so identify the type and location of any unacceptable hazards. A graphics routine draws the worst hazard contour around individual plant items. It also calls routines which test the effect of safety equipment designed to reduce the affect of particular hazards. After a reduction has been made the new hazard contours are stored for use in the optimisation routine i.e. the lay-out optimisation is based on the modification of the worst hazard contour.

CONCLUSIONS

(1) The foundation of a design strategy based on potential hazards has been devised for separation distances. This distance may be modified by the inclusion of preventative and protective devices.

(2) A computer program which executes the logic described in (1) above, has been devised. The algorithmic technique for the hazard assessment process is common for a green field site and additions/modifications to an existing installation. The program has been structured in a modular manner, which facilitates modification when new information becomes available.

(3) The hazard assessment takes the form of the generation of both a statistical hazard value and a hazard contour based upon the probability and magnitude of a potential incident. Such contours offer easy visualisation of potential damage to other units and the hazard value, a simple method for comparing the safety of different plants.

(4) The program systematically examines the events leading to potential fires and explosions by following the sequence of events after a loss of confinement.

(5) As well as the assessment of hazards from a chemical plant, a program has been developed for the optimisation of the layout by maintaining safety criteria whilst minimising land usage in order to minimise costs.

(6) The optimisation program is based on developments of the Rosenbrock approach. This was considered the most appropriate technique for this application.

(7) The limitations of the strategy and related programs are due to the lack of data such as probability of failure. The strategy has identified weaknesses in knowledge with regard to routes to a particular failure mode and the type of ensuing hazard.

ACKNOWLEDGEMENTS

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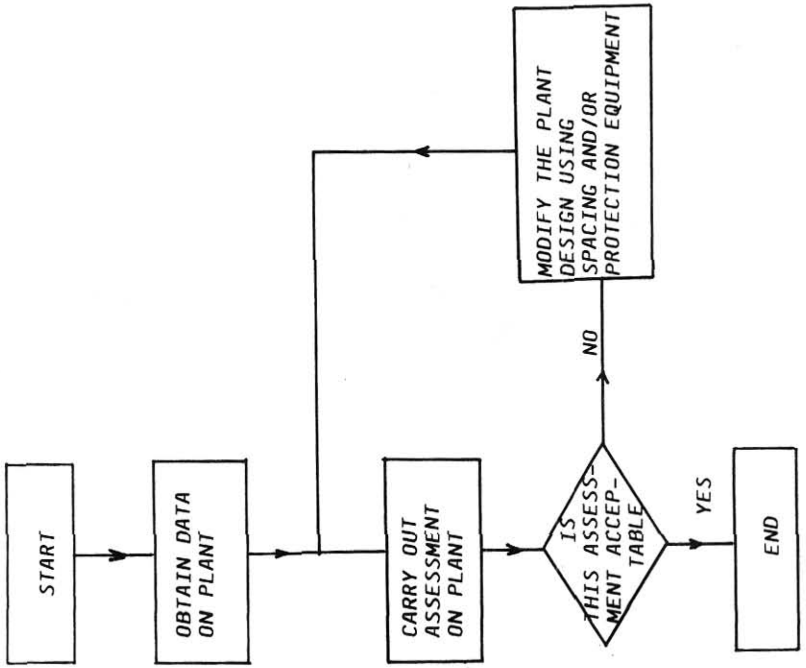
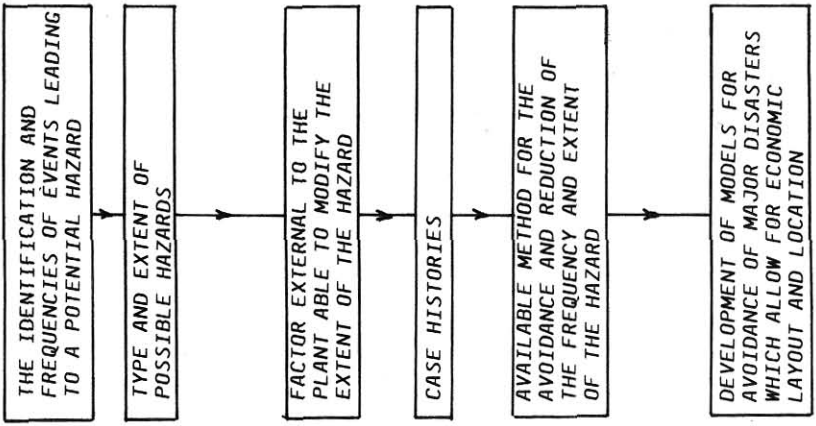
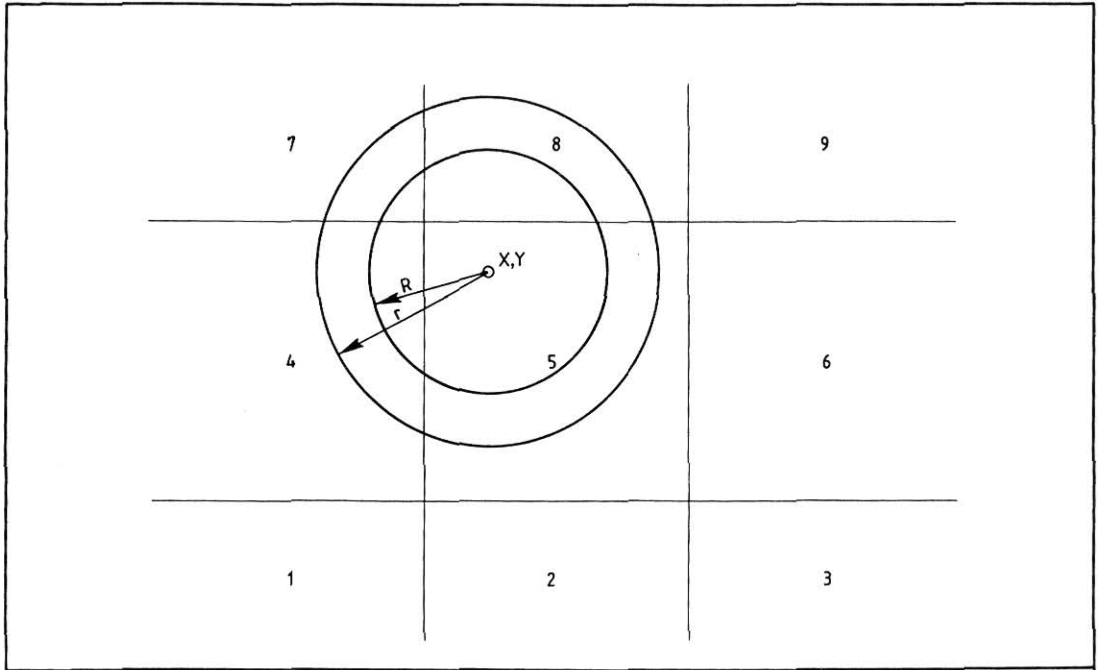


BREAKDOWN OF DESIGN PROCESS
Figure 1



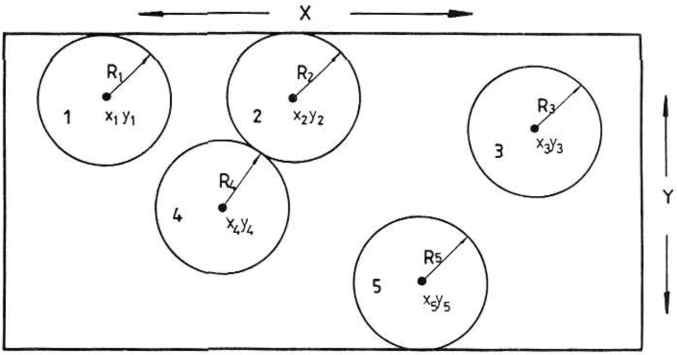
DATA REQUIREMENTS
Figure 2

FIGURE 3



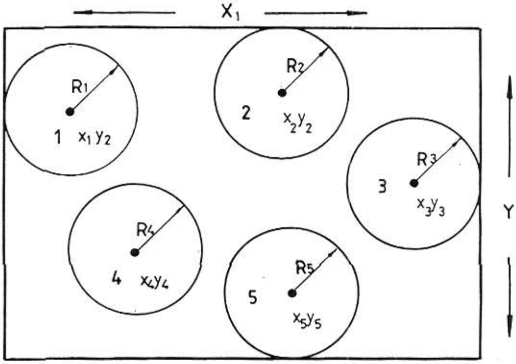
TYPICAL PLANT SHOWING THE HAZARD EXTENT FROM A PLANT ITEM (x,y)

FIGURE 4



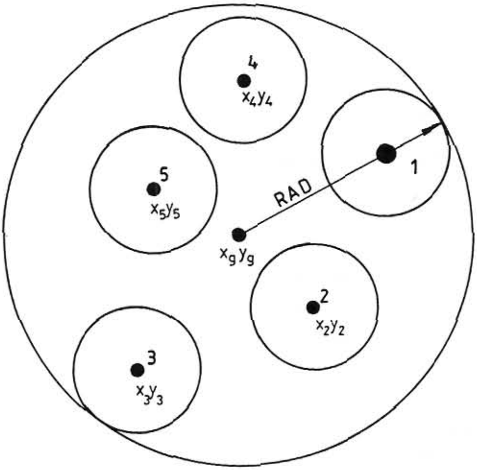
Typical plant area prior to optimisation

FIGURE 5

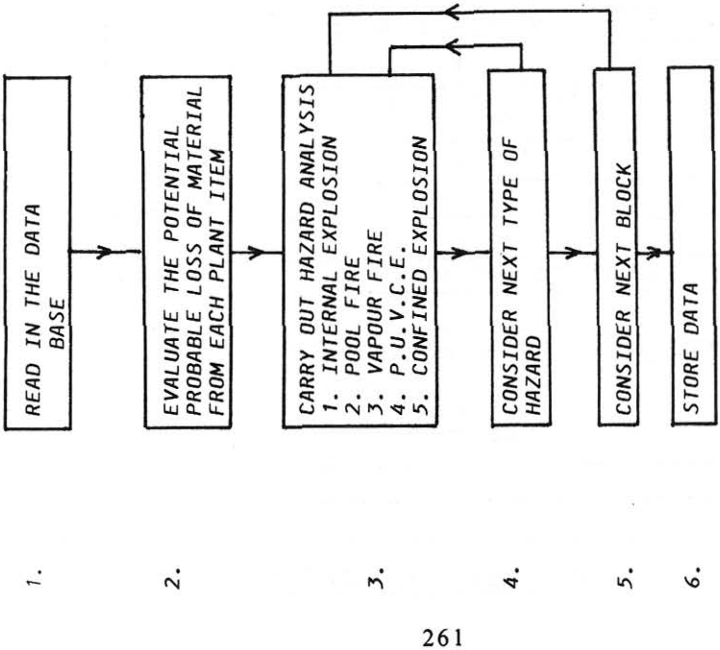


Typical plant area after first Iteration

FIGURE 6

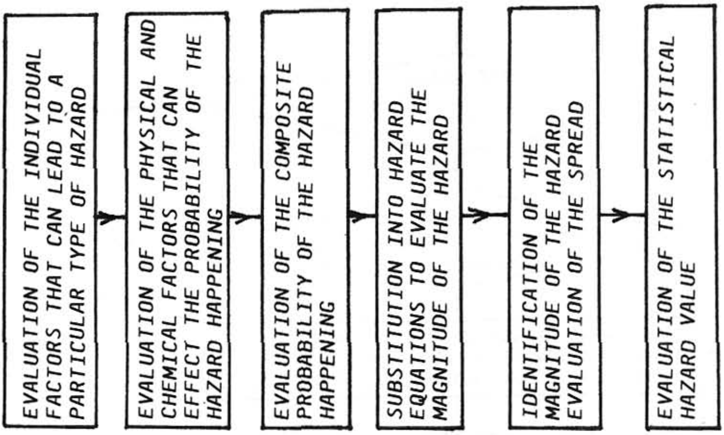


Typical plant area based on the centre of gravity of the plant items



HAZARD ASSESSMENT/IDENTIFICATION ALGORITHM
(LEVEL 1)

Figure 7a



HAZARD ASSESSMENT/IDENTIFICATION ALGORITHM
(LEVEL 2)

Figure 7b

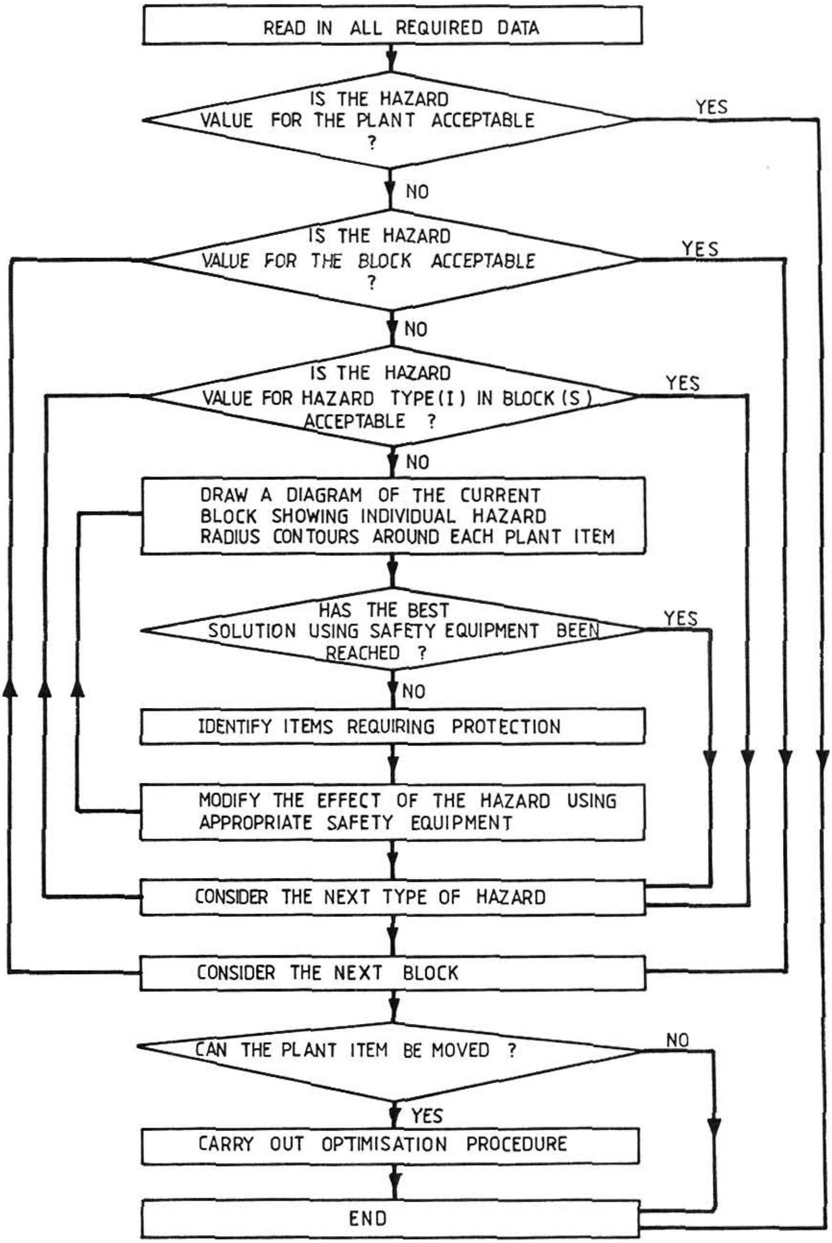


FIGURE 8 DESIGN TEST / MODIFICATION ALGORITHM