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Risk Assessment Model Regarding Allowable Extent of Construction Activities during Normal Operation in the Process Industry

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One of the challenges in the process industry is to carry out reconstruction and maintenance work on continuously operating plants. Improvements and necessary inspections in order to increase or preserve capacity and long-term safety need to be implemented with as little interference as possible with production. A solution often used is to carry out part of the work during normal operation or partial shutdowns. However, this compromises short-term safety, as more people are exposed to inherent plant hazards, and as the activities themselves may increase the risk for process related accidents. There is a lack of support for decisions concerning this type of compounded risk with high financial impact, and final judgement too often comes down to the individual.

This paper aims at presenting a tool that gives support, in a consistent manner, for decisions regarding the size of construction and maintenance work in specific plants in different operating modes. The principal idea is to assume a defined risk level for the actual plant in normal operation (with ordinary staffing) and investigate the safety margin, compared to a societal risk criteria, when the staffing level is increased for a short period in order to carry out a specific amount and complexity of work. The tool must be calibrated to the specific plant circumstances.

1. Background

During 2012 the Swedish Association for Process Safety ("Intressentföreningen för Processäkerhet", IPS) launched a project with the aim of finding or developing a methodology for giving consistent advice on the number of extra personnel that could be allowed to work in a plant during normal operation or partial shut-down. A literature study, mainly among industry standards, did not reveal any clear support for this type of decisions (Berntsson et al., 2013).

2. Description of the methodology

The methodology starts from an estimate of the risk level for a specified plant, when business runs as usual with ordinary staffing levels, followed by figuring out how big a margin exists that can be used to increase staffing for a short while. For this purpose an F/N diagram is used, which presents the risk level during normal operation for the whole site, together with defined tolerance criteria. The risk level of the plant in question can be represented by one point in the graph - a design accident scenario for the plant or area in question. If a quantitative risk analysis (QRA) is not available for the site, it is also possible to use a single design scenario, provided that the background risk from the rest of the site is considered in some other way.

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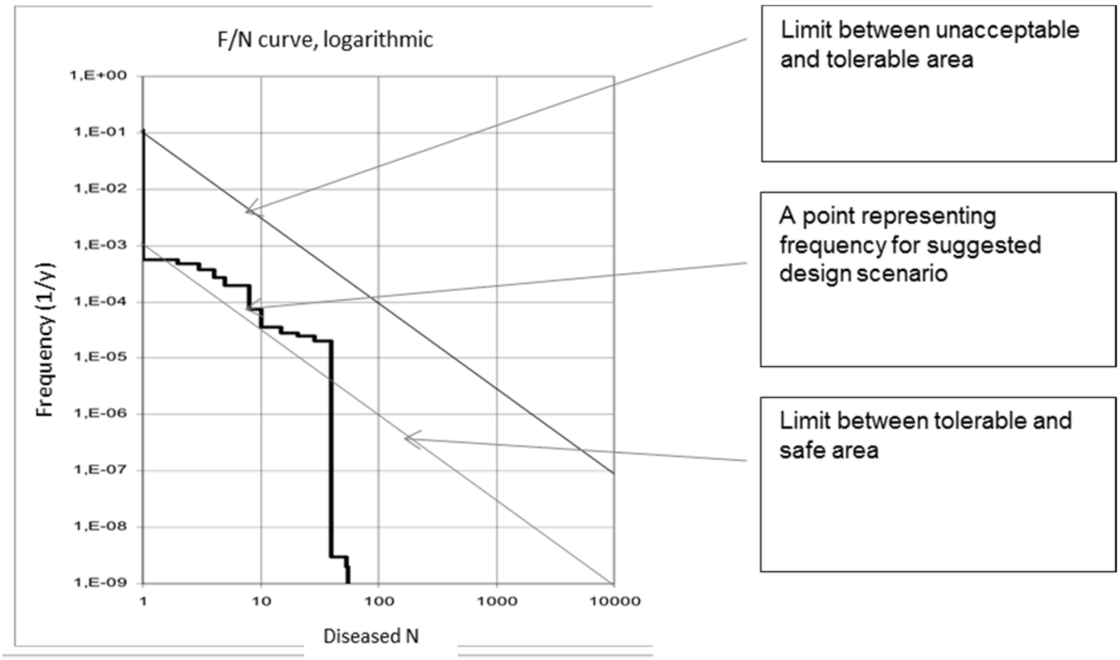

Figure 1: F/N diagram with acceptance criteria (example)

By weighing the impact of a temporary increase in staffing over a defined time period, compared to a full year, the margins can be calculated. Further factors are described below, which should also be considered when the margins are estimated.

2.1 The impact from operating mode

The operating mode of the plant in question as well as neighbouring plants is important. A more complex situation, like start-up or shut-down, is estimated to increase the likelihood of an accident, such as the design scenario. In that case the point in the F/N diagram moves upwards (increasing along y-axis), which will decrease the margin. How much the likelihood increases is a matter of judgement for the site in question, and depends both on the nature of the operations and the type of operating scenarios.

2.2 The impact from the complexity of work

The additional staffing at the plant is not only causing a higher population density that could be affected by an accident. The work carried out by the additional staff also increases complexity and the likelihood that an accident will occur. The more complex or dangerous work being carried out the lesser margin will be available, as the point in the F/N diagram moves upward.

A greater amount of work increases complexity, but different types of work may also have different impacts on complexity and risk. Hot-work would for example decrease the margin more than cold work, because of a higher risk for fire or explosion. In the same way crane lifts may increase the likelihood of accidental damage to equipment. Another type of work that also may increase complexity is confined space entries. This type of work does not have any impact on the likelihood of an accident as such, but may increase the consequences as it may impede evacuation. The same goes for work at high elevation or in narrow passages, where evacuation may be restricted.

2.3 The impact from emergency evacuation limitations

In addition to evacuation limitations for specific work activities there may also be general limitations, such as the number of places in shelters or at assembly points.

3. Adaption to a specific site risk level

In order to explain the methodology it will be applied to a reference plant using the results from a QRA as well as a defined design scenario as described above.

3.1 Design accident scenario

A reference plant was chosen, where both toxic and flammable materials were handled. The accident scenario that was believed having the greatest impact while work would be carried out was a break of a 2" pipe causing a toxic gas release. Figure 2 shows the individual risk contours for this scenario (Jacobsson, 2006).

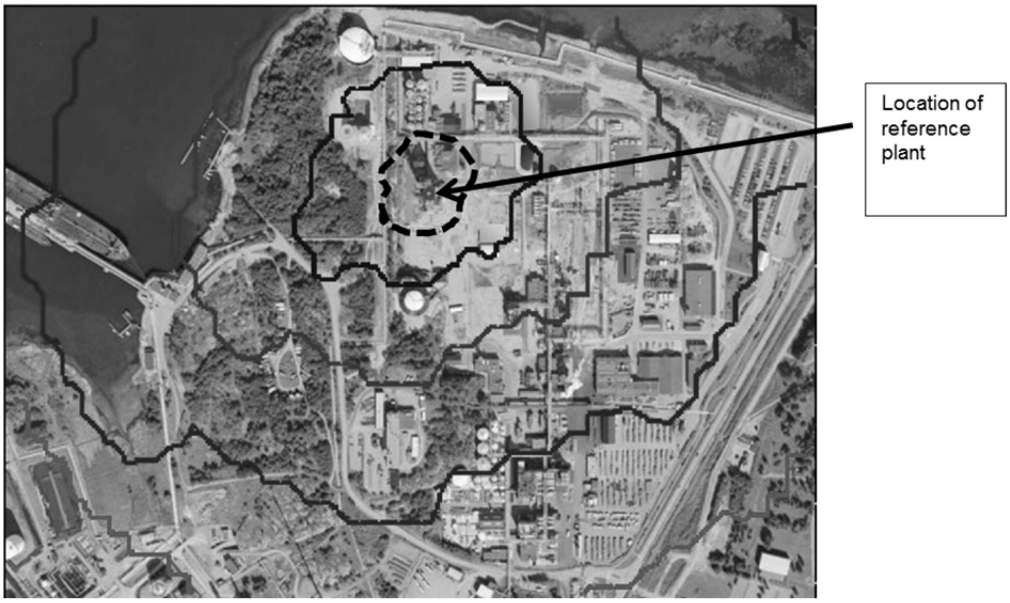

Figure 2: Individual risk contours for the design accident scenario, release of toxic gas. The dashed line represents 1.E-4 contour.

3.2 Acceptance criteria

In order to apply the methodology societal risk acceptance criteria have to be established. In this case acceptance criteria as shown in figure 1 were used (Berntsson et al., 2013). These are only indicative examples.

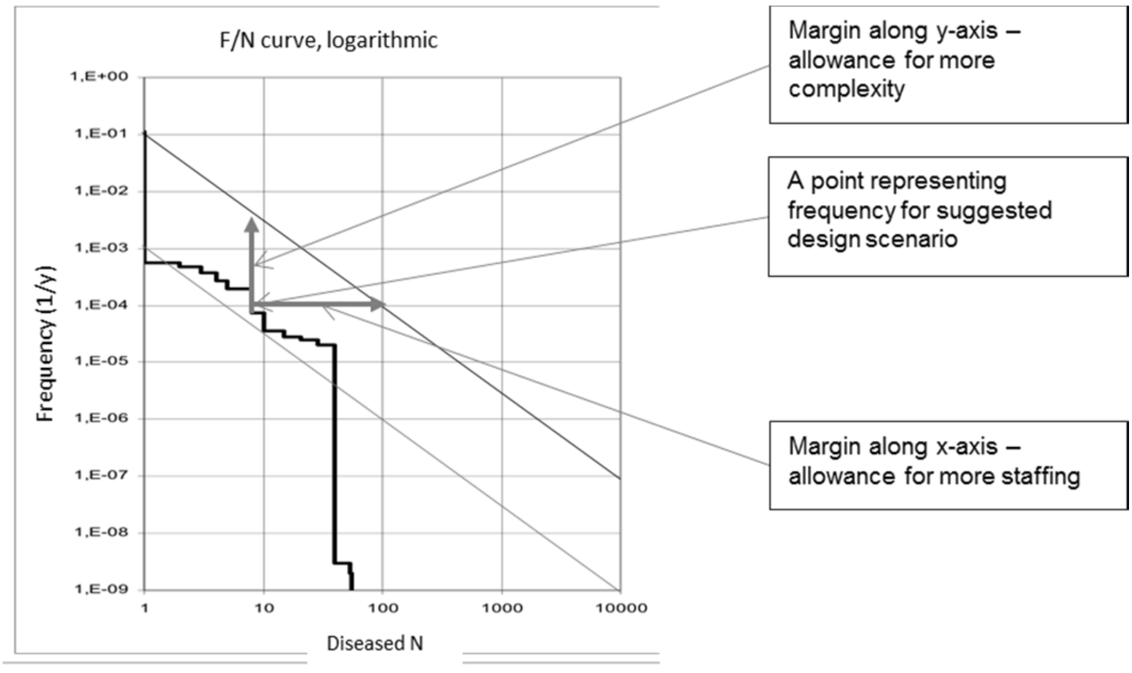

Figure 3: Margins for complexity and staffing

3.3 Approach

In order to utilize the information from the F/N curve the margin is checked for the actual plant from a societal risk point of view. By examining the individual risk contour for the design accident scenario, and checking which frequency range covers most of the area where work will be executed (see figure 2), a point on the F/N curve for the whole site can be chosen. In this case the frequency 1.E-4 seems to cover the work area quite well (figure 2). This is the way that the background risk from normal activities at the site is taken into account (figure 3). It is assumed that the lives of all persons not sheltedred will be lost if the scenario happens.
In simplified terms the margin along the x-axis would give the number of personnel that can be added in the work area, if there is no increase in complexity at all, i.e. no increase in likelihood of the design accident scenario (figure 3). The margin along the y-axis would give the possible increase in complexity that can be accepted, provided that no extra personnel are added (figure 3). The margins are recalculated to an equivalent short term staffing in terms of risk. In this case the additional staffing is considered for one month per year. The effect of increased complexity on available margin is explained below.

4. Tool design and adaption

The tool is a matrix, where the operating modes defines the rows and the complexity of the work situation define the columns, see table 1.

The different scenarios that were chosen for the reference plant were:

- Normal operation
- Start-up or shut-down periods
- Partially emptied plant, some systems in service with flammable materials
- Partially emptied plant, some systems in service with toxic materials

The work area in question is the plant area inside the dashed contour in figure 2. The normal daytime scenario and night time scenario for non-sheltered persons need to be taken into account. In table 1 the calculated numbers of excess individuals that will fit within the margins from the F/N curve are given, for a pre-determined time period (in this case 1 month). In this specific case only 40% of the available margin was allocated to the plant in question, as several plants at the site would need to use extra personnel at the same time.

Table 1: Calculated values of allowable excess personnel (during one month) for different operating modes and complexity of work at the reference plant

Complexity\ Operating mode	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	22	24	26
Start-up (x10)	155	98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shut-down (x5)	155	155	128	98	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Partial operation, toxic gas (x3)	155	155	155	148	128	110	88	48	0	0	0	0	0	0	0	0	0	0
Partial operation, flammables (x2)	155	155	155	155	155	150	134	124	110	98	48	0	0	0	0	0	0	0
Normal operation	155	155	155	155	155	155	155	155	155	155	146	135	124	110	98	76	48	0

4.1 Operating modes

At normal operation, without any increased complexity, the allowance for excess personnel can be extracted directly from the F/N-diagram in x-dimension (see figure 3), only corrected for the time period and normal staff levels. However, in practice, cases with low complexity allowance will be limited by the ability to evacuate and give shelter to everyone, see 4.2 below.
Start-up and shut-down periods are in this case estimated to increase the likelihood of the design scenario by a factor x10 and x5 respectively. Thus the available margin will decrease to one tenth or one fifth of the outcome at normal operating mode. In case the plant is partially emptied (typically some inventories still left) a factor x3 was chosen for toxic gas and a factor x2 for flammable materials.

4.2 Emergency evacuation limitations
At the site there were a number of assembly points, with limited capacity, where people should gather in case of an emergency. The normal staff will occupy part of the available capacity, leaving a specified number of spaces for additional staffing. In this case there were 415 spaces in total divided between 10 different assembly points. Normal daytime staff, including excess staff at other plants, was 260 persons, leaving maximum 155 spaces for additional staffing, provided that all ten assembly points are possible to reach from the work area, and give sufficient shelter from both toxic gas releases and vapour cloud explosions.

4.3 Complexity factor
The complexity factor is the estimated risk increase factor for a specific project in an operating plant. It is affected by both the type of work to be performed, *work factor*, and the *quantity of work* done on a daily basis.

4.4 Work factor
This factor estimates the relative risk increase for different types of construction work compared to cold work. The following types of work activities were selected as relevant: cold work, hot work, crane lifts, confined space entry. Each type of work was given a work factor, similar to the factors chosen for operating modes.

Cold work:	factor x1. Baseline.
Hot work:	factor x2. Hot work during operation increases the likelihood of ignition, which can lead to leakages of media.
Crane lifts:	factor x3. Presence of large, heavy vehicles and possibly lifting of heavy items above other process equipment motivate a three times higher risk than cold work.
Confined space entry:	factor x1.5. Slight increased risk compared to cold work - makes sheltering more difficult.

A judgement should also be made as to whether everyone would be able to evacuate within a reasonable time frame, for example 5 minutes, and reach the assembly point safely. If there are limitations that complicate evacuation for individual work activities, such as work at high elevation or restricted evacuation routes, an additional factor may be applied for those. The contribution to the complexity should be evaluated case by case, but a work factor similar to that for confined space entry (x1.5) seems reasonable.

4.5 Quantity of work and scaling factor
As the resource planning usually is done by discipline rather than by type of work it is necessary to estimate the typical content of each type of work within each discipline. Structural steel work was for example estimated to consist of 20% hot work, 20% crane lifts and 60% cold work. Combining these factors with the maximum number of persons working each day within each discipline gives the amount of work of the same type of work, for example hot work.
An overall scaling factor is also needed, which defines the relation between the number of persons performing each type of work and a specified increase in likelihood for the design scenario. In this case it was judged that 5 persons performing cold work each day would lead to a doubling of the risk level. The same scaling factor was used for all four types of work. This means that the number persons working simultaneously should be divided by a factor five (or multiplied by 0.2) in order to arrive at the complexity increase due to the quantity of work.
The risk increase factor for each type of work = Number of persons performing * work factor * scaling factor.
The overall complexity factor is equal to the sum of the risk increase factors for each type of work plus 1, see the example below.

5. A worked example at the reference plant

As preparation for a total shut-down some maintenance and project work was performed during normal operation at the reference plant. At the most there were 126 additional persons at the site, of which 77 were working at the reference plant. This was considered acceptable, but the opinion was that the safety margins were quite small. In order to test the adequacy of the assumptions made above, and to demonstrate the details of the methodology, the proposed tool is applied in this case.

5.1 Calculation of the complexity factor
The first step is to calculate the number of persons present at the plant each day, per each type of work, see 4.5 above. The result is given in the second column of table 2, and adds up to 62 persons. 15 persons out of 77 were performing tasks that did not add to the complexity, such as attendants at confined space entry. The risk increase factors and the complexity factor in column 5 are calculated according the formulas given in 4.5.

Table 2: Calculation of complexity factor

Type of work	No of persons working	Work factor	Scaling factor	Risk increase factor
Hot work	19,5	2	0,2	7,8
Cold work	32,1	1	0,2	6,4
Crane lifts	5,4	3	0,2	3,2
Confined entries	5	1,5	0,2	1,5
Complexity				19 + 1 = 20

This methodology thus estimates a risk increase of approximately twenty times during the preparation work while operating the plant in normal mode.

5.2 Allowed increased staffing

Table 1 gives the result 98 for complexity factor 20 and normal operation. This would be the maximum level of extra staffing allowed, compared to the actual level of 77 persons. The safety margin was limited, equal to only 3 more people working with hot work or 5 more people working with cold work, as the complexity factor would also increase with more manning. Note however that the plant in question was only allowed to occupy 40% of the total allowance for the site (a factor built into table 1).

6. Conclusions

In this paper a methodology is described which can be used to support consistent decisions concerning allowed additional staffing in a partially or fully operational plant. This is a first attempt at an approach, which need to be further validated and developed based on real experience. It is important that each business makes their own judgments concerning complexity factors, but the structure from this paper should be possible to use, regardless of type of facility.

In cases where the methodology is based on a single design case rather than a full QRA, it is important that the background risk level is taken into account. The choice of risk criteria, which each site owner need to make, plays also a major role.

It is worth noting that the methodology, despite some objective calculations, still depends on quite a few subjective assumptions. Therefore individual results should always be evaluated. The methodology primarily gives an estimate of the relative risk rather than the absolute risk level.

Acknowledgments

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